منظمة الاقطار العربية المصدرة للبترول
أوابك

النفط والتعاون العربي

المجلد الثالث و الأربعون 2017 - العدد 161

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- إعادة تكرير زيوت التزييت المستعملة وانعكاساتها الاقتصادية والبيئية

جمال حربي

البيبليوغرافيا

مجلة فصلية محكمة تصدر عن الأمانة العامة لمنظمة الاقطار العربية المصدرة للبترول (أوابك)

النفط
والتعاون العربي

مجلة فصلية محكمة تصدر عن الأمانة العامة لمنظمة الأقطار العربية المصدرة للبترول

الاشتراك السنوي :	**4** أعداد (ويشمل أجور البريد)

البلــدان العــربيــة

للأفراد :	**8** د. ك أو **25** دولاراً أمريكياً
للمؤسسات :	**12** د.ك أو **45** دولاراً أمريكياً

البلدان الأخرى

للأفراد :	**30** دولاراً أمريكياً
للمؤسسات :	**50** دولاراً أمريكياً

الاشتراكات باسم : منظمة الأقطار العربية المصدرة للبترول

النفط
والتعاون العربي

قواعد النشر في المجلة

تعريف بالمجلة واهدافها

النفط والتعاون العربي مجلة فصلية محكمة تعني بشؤون النفط والغاز والطاقة حيث تستقطب نخبة من المتخصصين العرب والأجانب لنشر أبحاثهم وتعزيز التعاون العلمي في المجالات التي تغطيها المجلة، كما تقوم على تشجيع الباحثين على إنجاز بحوثهم المبتكرة والأسهام في نشر المعرفة والثقافة البترولية وتلك المتعلقة بالطاقة وتعميمها والعمل على متابعة التطورات العلمية في مجال الصناعة البترولية.

الأبحاث

كافة الابحاث التي تتعلق بالنفط والغاز والطاقة والتي تهدف إلى الحصول على إضافات جديدة في حقل الفكر الإقتصادي العربي.

مراجعة الأبحاث والكتب

تقوم المجلة بنشر المقالات التي تقدم مراجعة تحليلية لكتب أو دراسات تم نشرها حول صناعة النفط والغاز والطاقة عموماً، بحيث تكون هذه المقالات مرجعاً للباحثين حول أحدث وأهم الإصدارات المتعلقة بالصناعة البترولية.

التقارير

تتناول التقارير وقائع مؤتمر أو ندوة حضرها الكاتب، شريطة أن تكون مواضيعها ذات صلة بالنفط والغاز والطاقة، كما يشترط استئذان الجهة التي أوفدته للمؤتمر أو المؤسسات المشرفة عليه لكي تسمح له بنشرها في مجلتنا. وان لا تزيد عدد صفحات التقرير عن 10 صفحات مع كافة الاشكال والخرائط والجداول ان وجدت.

شروط البحث

- نشر الأبحاث العلمية الأصيلة التي تلتزم بمنهجية البحث العلمي وخطواته المتعارف عليها دوليا ومكتوبة باللغة العربية.
- ان لا يتجاوز البحث العلمي المنشور على 40 صفحة، (متن البحث، الجداول والاشكال) بدون قائمة المراجع، ويرسل إلكترونيا كاملاً إلى المجلة على شكل word document.
- ترسل الاشكال، الخرائط والصور في ملف اضافي على شكل JPEG.
- استخدام خط Times New Roman في الكتابة وبحجم 12، وان تكون المسافة بين الاسطر 1.5. وان تكون تنسيق الهوامش الكلمات بطريقة Justified.
- ان يتم الاشارة الى مصادر المعلومات بطريقة علمية واضحة.

- عند اقتباس اي معلومات من اي مصدر (اذا كانت المعلومات رقميه او رؤية معينة او تحليل ما) يجب ان لا يتم الاقتباس الحرفي وانما يتم اخذ اساس الفكرة واعادة صياغتها بأسلوب الباحث نفسه، والاشارة الى مصدر الإقتباس. أما في حالات الإقتباس الحرفي فتضع المادة المقتبسة بين علامتي الإقتباس ("...").
- يفضل ان تذكر المدن ومراكز الابحاث والشركات والجامعات الاجنبية الواردة في سياق البحث باللغة الانجليزية ولا تكتب باللغة العربية.
- أرفاق نسخة من السيرة العلمية إذا كان الباحث يتعاون مع المجلة للمرة الأولى.
- تعبر جميع الافكار المنشورة في المجلة عن آراء كاتبيها ولا تعبر بالضرورة عن وجهة نظر جهة الإصدار ويخضع ترتيب الأبحاث المنشورة وفقاً للاعتبارات الفنية.
- البحوث المرفوضة يبلغ اصحابها من دون ابداء الأسباب.
- يمنح لكل كاتب بحث خمسة أعداد من العدد الذي نشر فيه بحثه.

ترسل المقالات والمراجعات باسم رئيس التحرير، مجلة النفط والتعاون العربي، أوابك،
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المحتويات

الأبحاث

البيبليوغرافيا

مجلة عربية تهتم بنشر المعرفة والثقافة البترولية وتلك المتعلقة بالطاقة وتعميمها والعمل على متابعة التطورات العلمية في مجال الصناعة البترولية

ملخص

إعادة تكرير زيوت التزييت المستعملة وانعكاساتها الاقتصادية والبيئية

سعد الله الفتحي

لقد كان اختيار منظمة الأقطار العربية المصدرة للبترول (أوابك) لموضوع بحث هذا العام حول إعادة تكرير زيوت التزييت المستعملة وانعكاساتها الاقتصادية والبيئية اختيارا موفقا.

إن زيوت التزييت المستعملة تؤثر بصورة سلبية على البيئة بفعل الملوثات التي تتراكم نتيجة للتدهور خلال دورة حياتها واستخدامها تحت ظروف الحرارة والاحتكاك.

لكنها في نفس الوقت ما تزال مصدراً هيدروكربونياً يجب المحافظة عليه بأكبر قدر من الناحية العملية لتقليل الاحتياج إلى النفط الخام ومشتقاته.

وبينما لا يزال جمع الزيوت المستعملة واستخدامها في الوقود أو في صناعة إعادة التكرير في الدول العربية يتم على نطاق ضيق ومحدد بدول قليلة، وأن الاهتمام بهذا الموضوع آخذ في الاتساع كما أن الزخم سيتزايد عندما تتبنى الحكومات سياسة دعم الصناعة عن طريق القوانين واللوائح والتعويضات المالية.

وتنقسم الورقة إلى 5 فصول، حيث يتناول الفصل الأول تاريخ صناعة التزييت وإعادة التكرير لمعرفة كيف تطورت من استهلاك زيوت الأساس البكر وملاحظة أوجه الشبه بينهما في مراحل المعالجة.

أما الفصل الثاني فيناقش التأثيرات البيئية والمحافظة على تنظيم مصادر الزيوت المستعملة فيما يخص التخلص منها أو حرقها لاستخلاص الطاقة أو معالجتها لإنتاج زيوت الأساس.

يغطي الفصل الثالث عمليات تكرير الزيوت المستعملة والأصلية، حيث ستناقش خطوات إنتاج الزيوت الأصلية غير المستعملة بشكل مختصر كمدخل إلى التعريف بالعمليات الأساسية لمعالجة الزيوت المستعملة.

ويغطي الفصل الرابع حرق الزيوت المستعملة من أجل الوقود واستخلاص الطاقة والتي تعد أحد أكبر المنافسين لصناعة إعادة تكرير الزيوت المستعملة، حيث تمت مناقشة الكميات بحسب التقسيم الإقليمي لاكتشاف التوجهات والفرص من أجل زيادة انتشار صناعة إعادة تكرير الزيوت المستعملة.

بينما يناقش الفصل الخامس اقتصاديات إعادة تكرير زيوت التزييت وأهم العوامل المؤثرة وتشمل العرض والطلب على زيوت التزييت، تأثير أسعار النفط واختيار نوع المعالجة، وغيرها، كما يقدم نموذجا اقتصاديا يمكن استخدامه من قبل الآخرين في دراسات قادمة.

أما الفصل السادس فيتناول صناعة زيوت التزييت في الدول العربية ويشمل إنتاج واستخدام هذه الزيوت، بالإضافة إلى مصانع وخطط إعادة التكرير في الدول العربية. وقد كان من الصعب على معد الدراسة الحصول على معلومات دقيقة بهذا الخصوص.

وتختتم الورقة بالاستنتاجات والتوصيات في الفصل السابع مع تركيز خاص على ما يتوجب عمله في الدول العربية.

إعادة تكرير زيوت التزييت المستعملة وانعكاساتها الاقتصادية والبيئية

جمال حربي

تناقش الورقة تكنولوجيا إعادة التكرير المستخدمة لإعادة استخدام زيوت التزييت المستعملة وتحويلها إلى منتج قابل للتسويق، حيث تم استعراض التكنولوجيا والتشريعات الحالية ذات الصلة. كما تتعمق الدراسة في شرح الجدوى الاقتصادية لإعادة التكرير والتي من بينها أن إعادة التكرير توفر فرصة اقتصادية لتحويل النفايات الخطرة (ذات القيمة المنخفضة) إلى منتجات بترولية عالية القيمة. كما تم بيان الفوائد البيئية المنبثقة عن تطبيق عملية إعادة تدوير زيوت التزييت المستعملة من خلال إعادة التكرير، وهي طريقة لتخفيف الآثار على البيئة. إنها لحقيقة مؤكدة أن إعادة المعالجة لتحويل تلك الزيوت إلى زيوت التزييت الأساسية تنتج ملوثات جوية أقل كما أنها تستهلك طاقة أقل من تكرير الزيوت البكر لتحويلها إلى زيوت تزييت أو حرقها لاستخلاص الطاقة.

علاوة على ذلك، تم استعراض التشريعات والأطر القانونية القابلة للتطبيق على إدارة صناعة زيوت التزييت، كما تم تحديد العوائق والمفاهيم الخاطئة التي تواجه صناعة إعادة التكرير، والتي تشمل بصورة مبدئية الحصول على الزيوت المستعملة ومدى تقبل المستهلك لها.

بوجه عام، فإن النتائج تدل على أن إعادة التكرير تمثل فرصة اقتصادية لإعادة تدوير مواد منخفضة القيمة وتحويلها إلى منتجات بترولية عالية القيمة وبانعكاسات أقل تأثيرا على البيئة.

إن إعادة تكرير زيوت التزييت المستعملة هو أفضل خيار لإعادة تدوير زيوت التزييت المستعملة.

البيبليوغرافيا

إعداد
عمر كرامة عطيفة
إدارة الإعلام والمكتبة

يشمل هذا القسم بيليوغرافيا بالمواضيع التي تطرقت إليها أحدث الكتب والوثائق ومقالات الدوريات العربية الواردة إلى مكتبة أوابك، مدرجة تحت رؤوس الموضوعات التالية:

- **الاقتصاد والتنمية**
- **البتروكيماويات**
- **البترول (النفط والغاز)**
- **التجارة والعلاقات الاقتصادية الدولية**
- **قضايا حماية البيئة**
- **الطاقة**
- **المالية والمالية العامة**
- **نقل التكنولوجيا**
- **موضوعات أخرى**

أولا- الاقتصاد والتنمية

آفاق الاقتصادات العربية، عام 2016-2017.-- الاقتصادي الكويتي.-- ع. 541 (2017/2).-- ص. 47-52.

الاقتصاد السعودي ينمو 1.4% و 1.2 % وصادرات اللؤلؤ والأحجار الكريمة تنمو بنسبة 55% في 2016.-- تقرير الاقتصاد والأعمال.-- ع. 13 (9/ 2017/4).-- ص. 18-19.

اقتصاديا: ماذا يعني فوز ماكرون برئاسة فرنسا؟.-- تقرير الاقتصاد والأعمال.-- ع. 18 (2017/5/14).-- ص. 22-29.

البسام، محمد. **التنمية المستدامة في مناخ عربي متغير**.-- التقدم العلمي.-- ع. 96 (2017/1).-- ص. 90-93.

تحديات الأمن الغذائي بدول الخليج وجهود تحقيقه.-- تقرير الخليج الاستراتيجي.-- ع. 18 (2017/5/13).-- ص. 33-41.

التعاون الجمركي السعودي-الإماراتي.-- تقرير الاقتصاد والأعمال.-- ع. 10 (2017/3/18).-- ص. 5-15.

تنويع القاعدة الإنتاجية في الإمارات- الجزء الثاني.-- تقرير الاقتصاد والأعمال.-- ع. 13) 9/ 2017/4(.-- ص. 6-17.

جامعة الدول العربية، وآخرون. **التقرير الاقتصادي العربي الموحد، 2016**.-- ابوظبي: صندوق النقد العربي، 2016.-- 549 ص.

الحميدي، عبدالرحمن بن عبدالله. **تعزيز جهود التنويع الاقتصادي أصبح أمرا بالغ الأهمية لجميع الدول العربية، بغض النظر عن اختلاف أوضاعها الاقتصادية والمالية**.-- نشرة ضمان الاستثمار.-- مج. 35، ع.1 (1-2017/3).-- ص. 12-13.

خارج التوقعات: الربع الاقتصادي الأول بعد قرار بريطانيا بالانفصال عن الاتحاد الأوروبي.-- تقرير الاقتصاد والأعمال.-- ع. 10 (2017/3/18).-- ص. 23-29.

الربيعي، فلاح خلف علي. **تحديات المواءمة بين مخرجات التعليم وسوق العمل في ليبيا**.-- المستقبل العربي.-- مج. 39، ع.457 (2017/3).-- ص. 66-94.

عبدالمجيد، وحيد. **معضلات إعادة البناء ... وتحديات المستقبل**.-- المستقبل العربي.-- مج. 39، ع. 458 (2017/4).-- ص. 8-20.

قراءة في تطورات العلاقات الاقتصادية بين مجلس التعاون الخليجي والاتحاد الأوروبي.-- تقرير الخليج الاستراتيجي.-- ع. 19) 2017/5/20(.-- ص. 31-37.

الملف الاقتصادي أمام الحكومة الائتلافية الجديدة بالمغرب.-- تقرير الاقتصاد والأعمال.-- ع. 12 (2017/4/1).-- ص. 22-26.

منتدى دافوس .. قيادة عالمية دقيقة ومسؤولة.-- الاقتصادي الكويتي.-- ع. 541 (2017/2).-- ص. 57-59.

منظمة العمل العربية. **التقرير العربي الخامس حول التشغيل والبطالة في الدول العربية: دعم القدرة التنافسية**

لتعزيز القابلية للتشغيل.. نحو معالجة اقتصادية مستدامة.-- القاهرة: جامعة الدول العربية، 2016.-- 362 ص.

نحو محو الأمية الاقتصادية: التمويل الأخضر.-- التجارة.-- مج. 46، ع. 3 (3/ 2017) .-- ص. 26-27.

نظرة عامة حول المنشآت الصغيرة والمتوسطة في دبي.-- النشرة الاقتصادية.-- مج. 10، ع. 153(3/2017).-- ص.

الوجهات الجاذبة للصناعة في العالم مستقبلا.-- النشرة الاقتصادية.-- مج. 10، ع. 153 (3/2017).-- ص. 1-3.

وطفة، على أسعد . **الدور التنموي للتربية في دول الخليج: مقاربات نقدية في العلاقة بين التربية والتنمية**.-- مجلة شؤون اجتماعية.-- مج. 33، ع. 132 (شتاء/2016).-- ص. 71-112.

ثانيا- البتروكيماويات

أرباح الكيماويات البترولية 125 مليون دينار 2016-2017.-- تقرير الاقتصاد والأعمال.-- ع. 13 (9/ 4/2017).-- ص. 52-53.

تراجع أرباح شركات البتروكيماويات السعودية في 2016.-- تقرير الاقتصاد والأعمال.-- (15/ 4/2017).-- ص. 24-25.

ثالثا- البترول

تطورات تجارة النفط والخام في دول الأوابك.-- أوابك.-- مج. 43، ع. 3 (3/2017).-- ص. 4-5.

جلاسر، تشارلز و كلاينك، وروزماري. **هل تتخلى واشنطن عن نفط الخليج؟ رؤية أمريكية**.-- تقرير الخليج الاستراتيجي.-- ع. 10 (16/3/2017).-- ص. 37-41.

قطاع النفط في كندا ودور متنامي للرمال النفطية: رؤية تحليلية.-- تقرير الاقتصاد والأعمال.-- ع. 18 (14/5/2017).-- ص. 36-44.

منظمة الأقطار العربية المصدرة للبترول. **تطور نمط تجارة النفط الخام والمنتجات النفطية في العالم**.-- الكويت: منظمة الاقطار العربية المصدرة للبترول، 2017.--116 ص.

هل ستعوض إيرادات الخصخصة إيرادات النفط السعودي؟.-- تقرير الاقتصاد والأعمال.-- (15/ 4/2017).-- ص. 6-15.

البترول - استكشافات

تنمية نفط عمان توقع عقدين مع سيح السرية وجلفا للهندسة والمقاولات لتنفيذ أعمال في فهود والخوير وجبال وقرن علم.-- تقرير الاقتصاد والأعمال.-- ع. 18 (14/5/2017).-- ص. 45-46.

جمعية البتروفيزيائيين ومحللي الآبار.-- الكويتي.-- ع. 1395 (3/2017).-- ص. 34-37.

البترول - أسعار

اكتشاف المزيد من مصادر الطاقة الجديدة والمتجددة يعتبر مطلوبا ومكملا للطاقة التقليدية.-- أوابك.-- مج. 43، ع. 3 (3/2017).-- ص. 6.

تسعير المشتقات النفطية في دول الخليج بين تراجع أسعار النفط وسياسات ترشيد الانفاق والاستهلاك.-- تقرير الاقتصاد والأعمال.-- ع. 16 (2017/4/29).-- ص. 38-46.

البترول - إنتاج

قراءة في استراتيجية أوبك لإدارة أسواق النفط في ضوء قرار تخفيض الإنتاج.-- تقرير الاقتصاد والأعمال.-- ع. 12 (2017/4/1).-- ص. 33-41.

البترول - تسويق

مخزونات النفط في الأسواق وأسعار النفط دائرة من التأثير والتأثر.-- تقرير الاقتصاد والأعمال.-- ع. 10 (2017/3/18).-- ص. 35-44.

منظمة الأقطار العربية المصدرة للبترول. **التقرير الربع السنوي حول الأوضاع البترولية العالمية: الربع الرابع، 2016**.-- الكويت: منظمة الاقطار العربية المصدرة للبترول، 2016.--77 ص.

المؤتمر الدولي العشرون عن البترول والثروة المعدنية والتنمية: الدعوة لتأسيس مجلس بحوث البترول العربي بالتنسيق مع منظمة الأوابك.-- أوابك.-- مج. 43، ع. 3 (2017/3).-- ص. 7.

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صناعة تكرير النفط في الكويت بين تحديات تواجهها وخطط لتطويرها ... رؤية تحليلية.-- تقرير الاقتصاد والأعمال.-- ع. 13(2017/4/9).-- ص. 44-51.

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طرح أرامكو وتغير جوهري في رؤية السعودية لمستقبل قطاع الطاقة في المملكة: رؤية تحليلية.-- تقرير الاقتصاد والأعمال.-- (2017/4/15).-- ص. 39-47.

البترول - صناعة

دور متنامي للمرأة العربية في الصناعة البترولية.-- أوابك.-- مج. 43، ع. 3 (2017/3).-- ص. 14-17.

مشكلة تواجه المنشآت النفطية: التآكل الداخلي وجهود مكافحته.-- الكويتي.-- ع. 1395 (2017/3).-- ص. 14-17.

الملتقى الرابع والعشرون لأساسيات صناعة النفط والغاز.-- أوابك.-- مج. 43، ع. 4 (2017/4).-- ص. 4-5.

الملتقى الرابع والعشرون لأساسيات صناعة النفط والغاز: استعراض التطورات العربية والدولية في الصناعة البترولية.-- أوابك.-- مج. 43، ع. 4 (2017/4).-- ص. 6-24.

منظمة الأقطار العربية المصدرة للبترول. **صناعة النفط والغاز الطبيعي غير التقليدية خارج أمريكا الشمالية وآفاقها المستقبلية**.-- الكويت: منظمة الاقطار العربية المصدرة للبترول، 2017.--110 ص.

رابعا- التجارة والعلاقات الاقتصادية الدولية

أبرز مؤشرات الأنشطة التجارية في الكويت في الكويت خلال عام 2016.-- الاقتصادي الكويتي.-- ع. 541 (2017/2).-- ص. 21-32.

تنشيط التجارة البيئية العربية وتحفيز التنمية.-- التجارة.-- مج. 46، ع. 3 (2017/3).-- ص. 24-25.

خامسا- الطاقة

قاسم، أمجد. **الجاتروفا: أشجار الذهب الأخضر لإنتاج الوقود الحيوي**.-- التقدم العلمي.-- ع. 96 (2017/1).-- ص. 86-89.

الطاقة - اقتصاديات

عمار، شبيرة بوعلام و أبوطير، نبيل. **الطاقة المتجددة وتحديات استغلالها في بلدان المغرب العربي**.-- المستقبل العربي.-- مج. 39، ع. 458 (2017/4).-- ص. 88-101.

قطاع الطاقة في إيران بعد مرور أكثر من عام على رفع العقوبات الاقتصادية رؤية تقييمية.-- تقرير الاقتصاد والأعمال.-- ع. 19 (2017/5/17).-- ص. 40-49.

الطاقة - المصادر

تقنية النانو لحفظ الطاقة بالمباني.-- الكويتي.--ع. 1395 (2017/3).-- ص. 30-33.

توجه خليجي متزايد نحو مصادر الطاقة المتجددة.-- الاقتصادي الكويتي.-- ع. 541 (2017/2).-- ص. 44-46.

سادسا- الغاز

الدورة الرابعة لمجموعة خبراء الغاز بالأمم المتحدة-الجنة الاقتصادية لأوروبا.-- أوابك.-- مج. 43، ع. 3 (2017/3).-- ص. 9.

قطر تطوير مشروع جديد في أكبر حقول العالم للغاز.-- تقرير الاقتصاد والأعمال.-- ع. 13 (9/ 2017/4).-- ص. 52-53.

سابعا- المالية والمالية العامة

الإصلاح الضريبي وعلاج عجز الموازنات الحكومية العربية.-- نشرة ضمان الاستثمار.-- مج. 35، ع. 1 (1-2017/3).-- ص. 16-18.

حدود المخاطر: إلى أين تتجه ازمة الدين العام في الأردن؟.-- تقرير الاقتصاد والأعمال.--ع. 16(29/ 2017/4).-- ص. 25-30.

سبل مواجهة العجز المالي لدول الخليج: رؤية تحليلية.-- تقرير الاقتصاد والأعمال.-- ع. 16 (29/ 2017/4).-- ص. 6-15.

عجز الموازنات الحكومية العربية وحدود استخدام الأدوات المالية.-- نشرة ضمان الاستثمار.-- مج. 35، ع.1 (1-2017/3).-- ص. 14-15.

عوامل متباينة ترسم توقعات أسعار الذهب.-- النشرة الاقتصادية.-- مج. 10، ع. 153 (2017/3).-- ص.4.

قراءة تحليلية في التقرير الربعي للميزانية السعودية لعام 2017: الجزء الأول.-- تقرير الاقتصاد والأعمال.-- ع. 19 (17/ 2017/5.-- ص. 6-14.

قراءة في واقع الاستثمار الخليجي بالخارج.-- تقرير الخليج الاستراتيجي.-- ع. 16 (29/ 2017/4).-- ص. 31-42

قراءة في وضع الاستثمار الأجنبي في دول الخليج على هامش الملتقى السنوي السابع للاستثمار في دبي.-- تقرير الخليج الاستراتيجي.-- ع. 14 (2017/4/15).-- ص. 28-34.

القمة العالمية الخامسة للحكومات.-- نشرة ضمان الاستثمار.-- مج. 35، ع.1 (1-3-2017).-- ص. 5-9.

قوريش، نصيرة. **أهمية الاستثمار الزراعي المسؤول لتحقيق الأمن الغذائي العربي**.-- المستقبل العربي.-- مج. 39، ع. 458 (2017/4).-- ص. 68-87

المملكة العربية السعودية: ميزانية عام 2017، زيادة في الانفاق وتراجع في العجز.-- الاقتصادي الكويتي.-- ع. 541 (2017/2).-- ص. 41-43.

منتدى المالية العامة يبحث تحديات تنويع الإرادات الحكومية في الدول العربية.-- نشرة ضمان الاستثمار.-- مج. 35، ع.1 (1-3-2017).-- ص. 10-11

وقفة مع الحساب الختامي للميزانية العامة لدولة الكويت، 2015-2016.-- الاقتصادي الكويتي.-- ع. 541 (2017/2).-- ص. 68-74.

ثامنا- تلوث البيئة وحمايتها

الأسكندراني، محمد شريف. **المتراكبات النانوية وتطبيقاتها في المركبات الفضائية**.-- التقدم العلمي.-- ع. 96 (2017/1).-- ص. 18-23.

التحكم بالطقس هل بات ممكنا؟.-- الاقتصادي الكويتي.-- ع. 541 (2017/2).-- ص. 75- 77.

تحمض المحيطات-1.-- نشرة البيئة البحرية.-- ع. 111 (1-3-2017).-- ص. 20-27.

جامعة الدول العربية، والمنظمة الإسلامية للتربية والعلوم والثقافة و برنامج الأمم المتحدة للبيئة. **دراسة التشريعات البيئية في الدول العربية ومدى التزامها بمتطلبات الاتفاقيات الدولية البيئية والمفاهيم الحديثة**.-- القاهرة: جامعة الدول العربية، 2009.--524 ص.

الحسين، شكراني. **على هامش مؤتمر الأطراف بشأن التغير المناخي: من تناقض المصالح إلى تعدد المقاربات، مراكش 7-18 نوفمبر 2016**.-- المستقبل العربي.-- مج. 39، ع. 457 (3/ 2017).-- ص. 167-173.

تاسعا- موضوعات أخرى

إنذار مبكر لدول الخليج: آليات مواجهة الجرائم الالكترونية.-- تقرير الخليج الاستراتيجي.-- ع. 19 (20/ 2017/5).-- ص. 19-30.

الداود، محمود علي. **عبدالله مبارك الصباح: التحول في الكويت**.-- المستقبل العربي.-- مج. 39، ع. 458 (2017/4).-- ص. 145-150.

قراءة في الأوراق العلمية العالمية للباحثين من الوطن العربي: إحصاءات 2004-2014.-- المستقبل العربي.-- مج. 39، ع. 457 (3/ 2017).-- ص. 21-38.

مقراتي، أنور. **ضوابط التأويل في البحث الاجتماعي**.-- مجلة شؤون اجتماعية.-- مج. 33، ع. 132 (شتاء/2016).-- ص. 151-166.

نظام التراسل الإلكتروني مع القطاع الحكومي.-- الكويتي.-- ع. 1395 (2017/3).-- ص. 18-21.

يخلف، فايزة. **الطفل والأنترنت: التضايف بين حدود التنشئة واستشكالات الإدمان**.-- مجلة شؤون اجتماعية.-- مج. 33، ع. 132 (شتاء/2016).-- ص. 177-185.

Chapter One

Re-Refining of Used Lubricating Oils and its Economic and Environmental Implications

* Saadallah Al Fathi

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Introduction

The Organization of Arab Petroleum Exporting Countries (OAPEC) is indeed fortunate in selecting the theme of this year's research titled "Re-Refining of Used Lubricating Oils and its Economic & Environmental Implications".

Used lubricating oils affect the environment adversely for the pollutants that they accumulate as a result of deterioration throughout the service life under the conditions of heat and friction.

At the same time, used oils are still a hydrocarbon resource that should be conserved as much as practicable to lessen the needs for crude oil and its products.

While the collection of used oil and its utilization for fuel or in re-refining industry in the Arab countries is small and limited to few countries, increasing interest is seen forthcoming and will pick up momentum once the governments make it a policy to support the industry by laws and regulations and financial compensation.

The breakdown of the requested research as outlined in (OAPEC) announcement has been covered here with the variation that was found necessary to cover the intended purpose especially with respect to burning used oil for energy recovery and the relationship with virgin lubes supply and demand. It was found that the used oils question is not isolated and must be viewed in relation to the overall industry of lubricants and to fuel users as well.

Chapter 1 deals with the history of lubrication and re-refining to see how the re-refining industry evolved from the consumption of virgin base oils and to take note of the similarity in processing steps of both.

In chapter 2 the environmental impact and resource conservation of used oils disposition is discussed with respect to dumping, burning for energy recovery or processing for base oil production.

Chapter 3 deals with virgin and used oil processing where virgin production steps are discussed briefly as an entrance to the main processing of used oils. Various processes are discussed in details to demonstrate their relevance to the modern requirements of lubricants. Processes to treat used oil for fuel purposes are also discussed.

Chapter 4 deals with burning used oil for fuel and energy recovery, a great competitor to used oil re-refining. The quantities are discussed on regional basis to discover the trends and the potential for further re-refining of used oil.

Chapter 5 deals with the economics of re-refining in discussing what affects this important aspect including supply and demand for lubricants, the impact of oil prices and the process selection and so on. An important economic model is also presented which can be used by others in further studies.

Chapter 6 deals with the lubricating oil industry in the Arab countries including the production and consumption of lubricants. The re-refining plants and plans in the Arab countries are also discussed. It was difficult to obtain accurate data here as is the case in other world regions.

Examples of countries experience are imbedded in the relevant chapters where the experience of Italy is included in chapter 5 and the experience of Saudi Arabia and the UAE is included in chapter 6.

Conclusions and recommendations are cited in chapter 7 with special emphasis on what is to be done in Arab countries.

Upfront, the executive summary is a condensation of the most important aspects of the report which also shows the direction followed in the research.

Needless to say that the lack of expensive consultant's reports made reliance on the Internet and public sources paramount. This is sometimes followed by discussion with private sources in the industry.

I hope this research serves the purpose of OAPEC and that the Organization would go ahead to promote the collection, controlled utilization and processing of used oils for the benefit of the economy, environment and the wellbeing of the Arab people in their different countries.

البحث الأول

Executive Summary

* Lubricats are known ever since man invented machines. They were either made from animal fat or vegetable oil. Petroleum lubricants were a byproduct of refining oil by 1880. In 1923 engine oils were classified according to viscocity. Lubrication manufacturers used clay and acid treatment to remove undesirables.

* Additives to inhibit oxidation, resist corrosion, enhance pour points, improve viscosity index emerged in the 1930s. In the 1950s, synthetic lubricants and multigrade engine oils were introduced and hydro-treating to improve lube oils in the 1960s. So came catalytic dewaxing and wax hydro-isomerization was used since 1993 to improve pour point.

* The increased use of lubricating oils generated the problem of the used oil and dumping in the environment. The first re-refining activities were reported in Germany in 1921 by simple treatment of used oil or using for fuel purposes. During the Second World War processing gained ground and the technology of simple distillation to acid clay treatment was used.

* The increase of oil prices and the tightening of environmental regulations stimulated growth in recycling and re-refining and the processes were developed to keep pace with the increasing quality demanded by the market. The first hydro-treating re-refiner was in the State of North Carolina which continued to work until 1983 where KTI process was developed and the first re-refinery was built in California. The newly acquired euphoria for re-refining was driven by further surges of oil prices in the early 1980s which led to higher base oil prices and better margins for re-refiners.

* In Europe, Germany has been re-refining used lubricants for more than 50 years and in Italy, Viscolube was founded in 1963 and Europe became the front runner of re-refining while processing for fuel continued. In Asia, the re-refining industry was slow to pick up.

* The collection of used oils is the hardest step in a chain of salvaging the resource whether for energy recovery or re-refining. The re-refining or fuel processing plant location should be decided to minimize the cost of convenient collection which must be regulated by the government.

* Used oil is mostly generated in the automotive and industrial sectors. They carry greater risk to health and environment as they contain additives that deteriorate during use and increase the pollutants level in the oil with dirt, metal scrapings, water and chemicals which can get into the oil and reduce performance. They represent the largest amount of liquid hazardous waste in the world which if dumped slowly leaches into the land and underground water resources.

* Regulations that ensures good housekeeping in generating points, in collection and transportation of the stuff and in receiving and processing into fuels or re-refined into base oils is absolutely necessary. Reduction of used oil and treatment on site is useful when possible.

* Oil degrades by absorbing moisture, picking wear particles and debris, deterioration of the additives, unburnt fuel, and carbon can in the presence of oxygen and heat reduce the effectiveness of the lubricant. Disposal is acceptable only if converting to fuel or re-refining is not practical.

* Synthetic motor oils are synthesised from the products of naphtha or condensate steam cracking and are entering the market due to their superior performance thereby reducing the impact on the environment.

* It takes one barrel of crude to produce the same amount of lubricant that can be obtained by re-refining one gallon of used oil, a source of conservation and the cost of re-refining is much less and so is energy use. Burning used oil in certain applications is a form of conservation but decreasing consumption and increasing collection of used oils are necessary.

* Some studies suggest that re-refining is better than burning for the resource conservation and environmental protection while other studies do not see any measurable difference with respect to environment. Re-refining is found to be much more favourable environmentally than the production of virgin base oils which must meet standard specification of authorized organizations with respect to constituents and viscosity.

* Advanced processing and additives made the drain intervals longer, reduced consumption and environmental load. Re-refined oils are now on par or better than virgin oils though the industry still suffers from the stigma that its products are recycled and may be sub-standard.

* Base oils are produced in a complex sequence of steps in a refinery by vacuum distillation of atmospheric residue, propane deasphalting, solvent extraction, dewaxing and hydro-finishing.

* The re-refining processes involve filtration and settling, removing water and light hydrocarbons, removing gasoil, rejecting heavy materials and contaminants and treating the remaining oil with solvent or hydrogen. There are three major categories of processes to treat used oils by sulphuric acid and clay, distillation and clay and solvent extraction or hydro-treatment.

* The acid clay process does not give good base oils and is environmentally risky. The Meinken process is the same but with clay only. CEP Mohawk Process is an improvement by using hydro-treatment and so are many others such as KTI, Hylube, Snam Progetti and Revivoil. Avista and Dollbergen processes use solvent extraction instead.

* The selection of environmentally sound re-refining process depends on feedstock quality and nature of contaminants, the desired quality and yield of base oil, the disposal of any hazardous waste, economic feasibility, availability of feedstock and consideration of the plant location. The national and local legislation and the Socio-economic benefits must be given consideration. The majority of modern plants are either solvent extraction or hydro-treating based.

* Used oil for fuel is a competitor to the re-refining industry where the used oil burned is near or much more than the oil re-refined. They are combusted in industrial applications such as cement kilns, blast furnaces, power plants, industrial plants boilers and space heating sometimes directly and others after settling, filtering and decanting.

* The prevailing view is that re-refining is uneconomic due to high investment as compared to burning applications, the lower prices in the market for re-refined base oils and the cost of getting rid of environmentally stressful waste in some processes.

* The price of crude oil affects base oil prices and lubricants demand in addition to other economic parameters. But high oil prices encourage investment in re-refining of used oil.

* The growth in the world lubricants demand is modest but the highest rates are in Asia - pacific and the Middle East. Forecasters remain different on how much growth is expected while additives are capturing increasing share of the lubricants market. Lubricants demand is forecast between 42 and 45.4 million tons in 2019

while production capacity is expected to be about 56.5 million tons indicating large surplus capacity and low utilization of plants.

* Most collection and re-refining schemes need the support and subsidy of governments or charges levied on lubricants consumers for the purpose. This is a social cost to avoid impact on the environment and the loss of resources.

* Italy is an example of success and cooperation between the government and the companies where in 1984 "The Compulsory Consortium of Used Oil (COOU)" was established to foresee the collection, testing and allocation of used oil to re-refiners. Financed by a levy on lubricants sale, the generators of used oils are obliged to give the oil without charge.

* Information about the lubricating oil industry in the Arab World is hard to come by. The expansion of the last few years is significant in adding capacity and shifting from Group I base oils to Groups II and III.

* The region is of low oil drain interval around 2000 to 3000 kilometers though this behavior is slowly changing. The virgin base oil production capacity in the Arab countries will be more than three million tons a year by the end of 2016 while consumption is about 1.7 million tons. Re-refining is gaining ground at slow pace where some operators strictly do filtration to remove insoluble and export the products to less demanding markets. Uncontrolled burning is also reported.

* The existence of five plants in Saudi Arabia having a total capacity of 100 thousand tons a year is much lower than other reported capacities. The UAE re-refining capacity at 200 to 250 thousand tons a yearis much higher than the domestically generated used oil. In both Saudi Arabia and the UAE, major lubricants manufacturers complain about the state of the re-refining industry with the growing issue of counterfeiting.

Chapter 1 - History of Lubrication and Re-refining

Lubricats are known to human activity ever since man invented machines. Before the modern age of petroleum, which started in 1859, lubricants were either made from animal fat or vegetable oil[18].

Petroleum based lubricants were a byproduct of refining crude oil to get kerosene for lighting and later gasoline for the upcoming motor industry[48]. The processing of petroleum based lubricants moved forward by 1880[1] as the quality and performance of the products proved its superiority. Solvent refining was developed in the 1920s. The US Society of Aoutomotive Engineers started in 1923 to classify engine oils according to their viscocity when engine oils contained no additives and had to be changed every 800 to 1000 miles[1]. Around the same time, lubricants manufacturers started using clay treatment, acid treatment and sulphur dioxide treatment to "remove some of the undesirable components such as aromatic and highly polar compounds containing sulphur and nitrogen"[1].

Later additives to inhibit oxidation, resist corrosion, enhance pour points, improve viscosity index, and more emerged in the 1930s[18] and their use increased thereafter to this day. The additives were found necessary "to prolong the performance and service life of automotive engine oils"[18] as proved by systematic oil analysis and performance testing.

In the 1950s, synthetic lubricants were developed for the aviation and aerospace industries and multigrade automotive engine oils were introduced by the development of viscosity improvers[18, 48].

The development of hydro-treating technology for petroleum products was developed in the 1950s and used for the improvement of lube oil stocks in the 1960s[1] for further purification of base oils.

Catalytic dewaxing and wax hydro-isomerization technologies were commercialized in the 1970s to improve middle distillates. But in 1993, an improved version was used to improve pour point of the base oil[1] by transforming the wax in lube oil cuts into high quality base oil instead of removing the wax by the more classical dewaxing processes.

Since the early days of this century, the lubricants technology continued its advance to develop products that are capable of meeting the rising demand for lubricants and more importantly to improve performance and reliability.

Naturally, the increased use of lubricating oils generated the problem of the used oil and how to get rid of it especially that drain intervals were relatively short. In the beginning dumping in the environment was the case that environmental laws and regulations were hardly in existence anywhere. It is not known when any commercial activity was made to use waste lubricating oils but it must have been limited and for the use of the waste as fuel only and before the advent of re-refining came into play.

However, the first re-refining activities were reported in Germany in 1921[20], and later developed into an industry largely on its own. It was also accompanied by the use of used oil directly as fuel or processed strictly for fuel purposes. At that time, lubricating oils contained little or no additives, which made their recycling possible by simple processes involving settling and filtering and then heating to remove volatile components followed by settling or centrifuging to remove the remaining insoluables[4].

During the Second World War processing used oil gained ground for the scarcity of crude oil resources[4]. The technology developed from simple distillation to acid clay treatment and so on.

The low oil prices until the early 1970s were not encouraging for the re-refining industry. However, the sharp increase of oil prices and the start of the tightening of environmental laws and regulations were the stimulant needed for growth in recycling and re-refining which to a large extent continues at different pace to this day.

However, the available processes were found to be increasingly not adequate for the modern needs of the lubricants manufacturers as they failed to keep pace with the increasing quality demanded by the market. However, these processes were not entirely discarded as many investors in the less stringent countries continued to use them.

For North America, the first hydro-treating re-refiner was the State of North Carolina as it started a plant using the Phillips Re-refined Oil Process (PROP) [41] where prison inmates were employed as operators and the plant continued to be used until 1983. The importance of this small plant (250000 gallons annually or close to 16 barrels a day) is that it demonstrated the "viability of hydro-treating to produce lubricants meeting API and military specifications."[41]

Further increases of oil price in the early 1980s encouraged new development of re-refining processes and their implementation. In 1983 the Kenetic Technology International (KTI) process was developed and the first commercial re-refinery was built in Newark, California and continues to operate to this day[41].

Mohawk Canada had originally licensed Phillips process (PROP) but this didn't work to their satisfaction. They redesigned the plant to include vacuum distillation and hydro-treating, and began producing top quality base oil around 1983 after their collaboration with Chemical Engineering Partners (CEP) of California.

The Breslube Enterprises of Canada was re-refining used oil since 1977 but in 1984 they added a vacuum distillation unit and installed a hydro-treater in 1985 to become the largest re-refiner in North America[41].

The newly acquired euphoria for re-refining was driven by further surges of oil prices in the early 1980s which led to higher base oil prices and better margins for re-refiners. Rising environmental concerns and the tightening of environmental laws and regulations played their part to improve the management of waste in general and used oil in particular. Harm from mismanagement of used oil causes air and water pollution while modern re-refining processes avoided all that and produced base oils at least equivalent to virgin stock.

The re-refining industry "was too small for the oil majors to deem worthy of significant attention and too complex for most used oil collectors to master[41]". Therefore the big oil companies generally stayed out though all of them have the capital and some have developed processes of their own. Perhaps they were afraid of the stigma associated with recycled products that the consumers have and the oil companies wanted to dissociate their own products from re-refined oil. The re-refiners on the other hand had to counter the stigma by spending money on testing and independent certification of their products. For example, in 1980, Shell Canada invested roughly $40 million in a used oil re-refinery in Toronto, Ontario, which was later sold, and eventually mothballed and scrapped.

The collapse of oil prices in 1986 slowed down development of re-refining schemes and "between 1991 and 2008, there were no new re-refineries in North America[41]."

Government support also came late and only in 1993 President Clinton signed Executive Order instructing government agencies to preferentially procure re-refined motor oil. The Federal Trade Commission ruled in 1995 "that motor oils were to be labelled according to their meeting the tests of the API's Engine Oil Licensing and Certification System (EOLCS), and not based on whether they were recycled or virgin."

The problems in the US are compounded by the demand for low cost fuel generated from used oil sources. This will remain a challenge to re-refiners anywhere as it will set the level of used oil prices.

The utilization of used oil in North America is essentially driven by economics of different disposal options. While the collection rates are comparable to those of Europe, more than 80 percent of the collected used oil goes to various fuel applications and about 12 percent is sent to re-refining[54].

In Europe, it is said that Mineralöl-Raffinerie Dollbergen GmbH in Germany has been re-refining used lubricants for more than 50 years[24] where it started its activities by manufacturing and using simple dewatering systems for the production of fuel oil. In Italy, the company Viscolube was founded in 1963 to re-refine used oil[15]. They started with a distillation and clay treating process and probably continue using this process in one plant in Italy now. However, they switched in 2005 to hydro-treating after a combined effort with Axens of IFP[1].

In 2008 the European Union 'Waste Directive' provided a new and formal impetus to re-refiners as it favored this over the processing for fuel[20]. Europe became the front runner of re-refining due to the strengthening of laws and regulations in many countries[54] yet the volume of processing for fuel is very close to the volume of processing for recovering base oils.

In Asia, the re-refining industry was slow to pick up steam due to the high investment cost and the lower prices of re-refined oils compared to virgin oils[26]. The lack of strong environmental regulations may have been a reason too. Yet in mid-1960s there were more than 150 re-refiners mostly small size but with a total combined capacity of 300 million gallons a year using mostly the acid clay process with its attendant sub-standard products and its environmental hazard of acid sludge and waste clay. In the 1970s, the Phillips PROP process was used[26] in Asia which is an improvement over acid clay but also had its own problem of high investment cost and waste disposal of "heavy metal laden precipitate"[26].

The future of re-refining used oils will depend largely on the price of crude oil and the competition with processing for fuels. As long as crude oil prices remain low, as they are today, not many re-refining projects will move forward except on enforced environmental regulation and the support of governments. The Industry has to take note of the advancement in lubricants specification and the increasing use of synthetic oils. Therefore the old and outmoded processes must be avoided in any future re-refining project.

Chapter 2 - Environmental Impact and Resource Conservation

Environmental awareness in the last few decades has been a major driver of the petroleum industry to produce better products and lessen their environmental impact. Resource conservation has become more desirable since the correction of crude oil prices in the 1970s where every country tried to use less to satisfy a growing demand. Used lubricating oils play a role in both the above targets as we shall see.

Collection of Used Oils:

The collection of used lubricating oils is probably the hardest step in a chain of salvaging the resource whether for energy recovery, re-refining or disposal. It is a logistical problem that requires careful study and consideration before any decision is made. The problem arises from the multitude of points of generation, small and big, around any country that may impact the method of utilization.

The distribution of lubricating oils should be the starting point because the volume of generated waste oil is proportional to that. The companies do have the data base for such information where a planning body can collate the numbers from different distributors. The re-refining facility or fuel processing plant location should be decided in such a way as to minimize the cost of collection, storage and final transportation to the facility or end user.

Used oil generating points should be provided with a storage tank or tanks proportional to the expected generation of the used oil. It is better to standardize these tanks and fittings so as the collection trucks may use the same procedure at each place.

If the distances to the re-refining facility are close the collection trucks can deliver directly there. But if the area covered is large, regional or national, then intermediate storage facilities are the norm before larger trucks can collect from these storage sites to the processing facility.

Concentration should be first on large volume used oil generators such as airports, the military; truck fleets garages, taxi company’s service stations before getting to the smaller points such as service stations, small lube change shops and so on. The American Petroleum Institute (API) points to the necessity of “providing convenient collection sites for the purpose of keeping used motor oil out of our waterways and ground water supplies and getting used oil into the recycling system."[23] The collectors must keep records of every load that is collected so that any problem found after testing in the plant can be traced back to the generating point and corrective measure is taken.

Used oil management imply to start with an effective collection system[1] that insures least cost and is environmentally sound and has "the ability to push volumes as high as possible in order to lower the fixed costs/volume ratio as much as possible.[35]"

Examples of Collection Management:

In any country, the collection step of managing used lubricating oil must be regulated by the government and municipalities in coordination with the industry. The size of the collection operation must be as large as the uses of used oil in burning for energy or in re-refining.

The cost of the feedstock to a re-refining or fuel plant is obviously very important and collection cost is a major part of it[20]. There is no rule in deciding what collection cost is or should be and it is country specific and differs widely between countries. "In Europe, the availability of public or private entities with the capabilities to collect waste oil and to make it available at reasonable costs to users varies significantly from country to country[20]." Citing the norms in few countries is indicative to understand the variance.

Portugal established (Sogilub) to manage used oil collection and disposal. Since 2005, lubricants manufacturers and importers pay a fee of €63/m^3 based on each company volume of sales in the market as a charge for the collection of used oils from generators[4].

The same system applies in France where a tax is levied on sales of finished lubricants, except those which generate no recoverable waste. 42% of used oil is re-refined by government directed re-refining associations[4].

In Spain, since June 2006, lubricant manufacturers are required to establish a non-profit organisation (SIGAUS) to handle used oil collection and disposal for a fee of €0.06 per kilogram of marketed oil of each manufacturer[20].

In Germany, all oil marketers must provide collection facility near the generation points of used oil such as garages and service stations and retailers pay for used oil pick up[4].

However, when there is no government intervention, it becomes the collector business to agree with the used oil generator. In The United Arab Emirates, the collectors pay the generator a cost to rid them of the used oil. The cost is somehow related to the price of oil in the market and it goes up and down with it. This practise tends to increase the cost of feedstock[20] on a re-refiner and is not helpful in the overall process. (Prices will be discussed somewhere else in this report). The same system applies in the US where collectors pay-for-oil to deliver used oil to re-refiners, fuel users or exporters.

Before the collapse of crude oil prices, a collector in Texas paid $1 a gallon or $42 a barrel to the generators to collect their used oils[76]. But as crude oil prices affect all users of used oil, the collectors are now generally moving into pay-for-collection and the Texas collector (re-refiner) is charging 10 cents a gallon or $4.2 a barrel to collect the used oil since December 2014[76]. Another re-refiner followed suite and since December 2015 is charging generators of used oil $80 per stop[76]. The re-refining industry is suffering from a decline in the fuel and export markets and the low prices of base stocks as a result of falling crude oil prices.

But the US is a large country and some states impose sales taxes to subsidise collections and some local municipalities fund collection activities[4]. These differences are due to the fact that the US has no central coordinating body that focuses on used oil management as in Europe[4].

Collection of used oil also impact employment opportunities where, for example in Europe about 2000 to 2500 local jobs are created in used oil collection while only 1000 to 1200 jobs in 28 re-refining plants[61].

<u>Sources of Used Oils:</u>

It is generally agreed that lubricants consumption in different applications is governed by the severity of the prevailing conditions and the type of application. Therefore, the generated used oil from various applications is also different.

Obviously countries are also different in this respect as one country may not have all the applications needing lubricants. Table (1) shows typical shares of used oils generated in different segments of use in a developed country that may have all the users in its economic development status.

Table (1)

Used Oil Generated in Different Applications %

Type of Oil	%	Notes
Transformer	95	Comparatively small consumption. Regeneration is often done in place with special equipment or in special re-refining plants if the contamination is severe.
Gear	75	They last longer but in motor's application the gear oil is often unnecessarily changed with the engine oil.
Hydraulic	70	Same as gear oil
Motor	65	Lost oil is high but consumption is highest among categories and therefore they contribute the highest volume in overall used oil collection.
Metal Processing	20	A lot is lost in this application.
Process	0	No used oil is generated in this application.
Source: Originally from CONCAWE cited in source 3 and elaborated by author.		

Sources[4, 64] generally agree that sectoral consumption of lubricating oils is on average composed of 56% automotive, 31% industrial, 10% process oils and 3% in greases. Therefore, the automotive sector is the largest contributor to the available used oils followed at a distance by the industrial sector. Because of the large dose of chemical additives in automotive gasoline and diesel engine oils, the used oil is therefore considered highly contaminated.

Evaluation of Used Oils:

Generators of used oils are encouraged to segregate them according to their application so as to make future treatment or use easier. But this is not always practical especially for the small generator in a garage or in the local collection centres where individuals take their used lubricants.

Therefore, used oil is usually composed of a combination of oils such as gasoline and diesel engine oils, transmission fluid, turbine and compressor oils, metalworking oils, industrial hydraulic oils, electrical insulating oil and synthetic oil[1]. However, only in a very large industrial place we are likely to find the used oil containing a portion of all the above. In a car maintenance garage perhaps only gasoline automotive oils are found and in trucking company workshops mostly diesel automotive oils are found and so on. Any combination of the above is not problematic for either the re-refining industry or for energy recovery by burning.

However, due to inexperience and sometimes carelessness of the operators or due to accidents, used oil is contaminated with solvents, water, glycols, kerosene and the like.

Table (2)

Used Oil Analysis – Re-refining

Parameter	**Unit**	**Value (Max)**
Water	% weight	15
Density at 15ºC	Kg/l	0.920
Total sediments	% weight	3.0
Viscosity	ºE at 50ºC	1.8
PCBs	mg/kg	25
Total chlorine	% weight	0.5
Sulpher	% weight	1.5
Diluents	% volume	5.0
Lead – Zinc	mg/kg	4000
Cadmium + Chrome + Nickel + Vanadium	mg/kg	50
Neutralization Nr	mg KOH/g	3.5
Saponification Nr	mg KOH/g	18

Used Oil Analysis – Burning

Parameter	**Unit**	**Value (Max)**
Water	% weight	15
Density at 15ºC	Kg/l	0.920
Total sediments	% weight	3.0
Flash Point	ºC	Min 90
PCBs	mg/kg	25
Total chlorine	% weight	0.5
Sulpher	% weight	1.5
Ash	% volume	1.5
Lead – Zinc	mg/kg	4000
Cadmium + Chrome + Nickel + Vanadium	mg/kg	50
Lead	mg/kg	2000
Fluorine	mg/kg	Traces

Source: 104

This is why simple testing is conducted at the generation point by the collector to see if the oil is collectable. Further testing at the storage tanks of the collector is done to determine the mixing of collected oils from different sources in order to normalize as much as possible the content before delivery to the larger depots where additional testing is done to determine the fate of the used oil whether it goes to re-refining, burning or destruction by incineration[104].

The decision is strictly made on analysis and Table (2) shows the characteristics of used oil acceptable for re-refining and that destined for burning for energy recovery in Europe.

To give an example, in Italy in 2009 the collected used oils in the final storage depots were about 195 thousand tons where 154 thousand tons were destined for re-refining, 40 thousand tons were committed to burning for energy recovery and about 400 tons were incinerated[104].

Environmental Impact:

There is no doubt that the production, storage, transportation, processing and distribution of all hydrocarbons imply a degree of risk and environmental impact that governments and the industry try to reduce to the minimum possible.

Lubricating oils are no different. "Used oil is any oil that has been refined from crude oil or any synthetic oil that has been used and as a result of such use is contaminated by physical or chemical impurities[1,13]". Therefore, used oils do carry greater risk to health and environment as a result of their degradation and the need to change them.

The additives in lubricating oils that deteriorates gradually during use increase the pollutants level in the oil. The deterioration is compounded by the fact that dirt, metal scrapings from machines or engine parts, water, the polyaromatic hydrocarbons (PAH) and chemicals can get into the oil and reduce its performance and render it more toxic, carcinogenic and harmful to human health and the environment than the original base oil[4]. This is especially true for passenger cars and diesel vehicles oils as the level of additives in lubricating oils has increased substantially, up to 30% sometimes, to improve performance[1] quality and longevity in combustion engines application[106]. Even for mammals and birds the toxic contamination can be devastating and specialized reports are very clear about this[4].

Quantitative Consideration:

Used lubricating oils represent the largest amount of liquid, non-aqueous hazardous waste in the world[61]. They are slightly biodegradable and their disposal in the natural environment is dangerous to natural systems[43].

Therefore, if used oil is disposed into landfills, an activity that some suggest must be avoided at all costs[60], it slowly leaches into the land and underground water resources.

Leakages of used oil, or deliberate dumping, into the sewage system can have devastating effects by impairing the operations of sewage treatments plants. Many sources confirm that one litre of oil contaminates one million litre of water[16] and oil polluted storm water and sewage systems can cause extensive damage by getting into rivers, lakes or coastal regions. Small amounts of oil on surface water can put a sheen (very thin layer) on large area which impairs the fisheries and other living organisims[13].

Steps to Protection:

One way to protect the environment from used oil handling is to start with regulations that ensures good housekeeping in used oil generating points, in collection and transportation of the stuff and in receiving and processing into fuels or re-refined into new base oils.

All the entities in the chain must be licensed by the right authorities and made aware of what is required of them to protect the environment and their operators. They must all keep records of their operations to refer to in case of any eventuality. Independent audits[60] of these operations is a necessity to keep all vigilant.

It is important to remember that some used oils can be reclaimed and treated on site in such a way as to lessen to a large degree their environmental impact by lessening the activities required to reclaim them. Reference is made here to the reclamation of transformer, hydraulic and turbine oils[60] as discussed somewhere else in this report.

Lube Oils Degradation:

Lube oils degrade for the following reasons[23, 67]:

- Oil is hygroscopic, meaning that it absorbs moisture easily. Burning fuel produces CO_2 and H_2O. When an engine is cold, the water generated can pass through to the lube oil.

- Oil picks up normal wear particles and debris as it circulates in the machine or engine. It is usually trapped by the filter except when it is very small.

- Dirt is carried by the air flowing into the reservoir and settles there.

- Unburnt petrol/diesel passes through to the lube oil during engine start-ups and contaminates lube oil.

- Carbon forms as a result of incomplete combustion when an engine is warming up and passes through to the lube oil.

- Some contaminants, such as chlorinated solvents, are picked up by waste oil during use or during storage while waiting for collection. However, some little amounts may come from additives in the original product.

- Deterioration of the additives where most contain complex chemicals necessary for the performance of the oil.

Table (3)

Typical Composition of Lubricating Oil

Component	**% by weight**
Base oil	71.5 – 96.2
Metallic detergents	2.0 – 10.2
Dispersant	1.0 – 9.0
Zinc dithiophosphate	0.5 – 3.0
Antioxidant/antiwear	0.1 – 2.0
Friction modifier	0.1 – 3.0
Pour point depressant	0.1 – 1.5
Antifoam	2 – 15 ppm

Source: 1 based on Lubrizol.

The combination of water, heat and oxygen enhances the deterioration and breaks up both additive and base oil. In the presence of oxygen, the oxidation products at elevated temperatures can form corrosive acids. Going forward, additives have increased their share of finished lubricants and are likely to do so in the future. Therefore, used oil contaminants are likely to increase with increasing additives share. Table (3) shows typical composition of lubricating oils with respect to additives.

Used engine oil is considered hazardous in Europe and in the US if contaminant levels exceed certain parameters. The Waste Oil Directive of 2008 gives priority to re-refining as long as there are no technical, economic or organisational obstacles[105]. Heat and energy recovery under environmentally acceptable and safe destruction conditions are second in the hierarchy. Disposal is acceptable only if the first two options are not practical[22]. This hierarchy is now the guideline in many countries where dumping in landfills is avoided or prohibited.

A comparison between virgin and used oil properties at this point is important to show the degree of deterioration of base oil as a result of its use under operating conditions and the accumulation of contaminants in used oil. Table (4) shows just that.

Impact of Synthetic lubricants:

Synthetic motor oils are manufactured or synthesized by "polymerising short chain hydrocarbon molecules called alpha-olefins into longer chain hydrocarbon polymers called polyalpha-olifins (PAO) [21]" and "PAOs do not contain the impurities or waxes inherent in conventional mineral oils[21]". PAO is mostly synthesised from the products of naphtha or condensate steam cracking in petrochemical plants[104].

Synthetic lubricating oils are increasingly entering the market and due to their superior performance they tend to increase the distances travelled before oil changes and therefore reducing the volume of lube oil used and used oil generated. From this point they have a positive role in reducing the impact on the environment compared to traditional lubricants[21]. Re-refining, used oil containing synthetic oils produces better re-refined base stock. However, their high price and the limited production capacity are not supporting further inroads into the market.

Table (4) Comparison of Virgin & Used Oil Properties		
Properties	**Virgin Oil**	**Used Oil**
Physical Properties		
Specific gravity	0.882	0.910
Viscosity @100ºF SUS		324
BS&W % v	0	12.3
Carbon residue % w	0.82	3.0
Ash yield % w	0.94	1.3
Flash Point ºF		348
Pour Point ºF	-35.0	-35.0
Chemical Properties		
Saponification number	3.94	12.7
Total acid number	2.2	4.4
Total base number	4.7	1.7
Nitrogen % w	0.05	0.08
Sulpher % w	0.32	0.42
Lead ppm*	0	7535
Calcium ppm	1210	4468
Phosphorus ppm	1397	931
Magnesium ppm	675	309
Barium ppm	37	297
Iron ppm	3	205
Sodium ppm	4	118
Potassium ppm	<1	31
Copper ppm	0	29
Source: 1 * Before lead removal from gasoline – author.		

The PCB Question:

Another important environmental and health hazard problem in used oil is that associated with PCBs. "PCB or polychlorinated biphenyl, is a class of synthetic chemicals consisting of a homologous series of compounds that do not occur naturally in petroleum but have been found as contaminants in used oil[1]." They have excellent dielectric properties that made them most satisfactory for use in electric transformers and capacitors[43]. They have been classified as health hazard and carcinogenic[43]. Therefore, if PCBs are found in used oil, over a certain limit, they increase the hazard and complicate the handling procedures.

Collectors and re-refiners have adopted safeguards and procedures to avoid having PCBs in their used oil especially that PCB's use has been outlawed as mineral transformer oil is now advanced enough to do the service without PCB and its associated hazard.

But remnants in old electric systems do exist and incidents occur. In the US, if PCBs are found in used oils above the allowed limit, the EPA does not allow even the dilution[50] of used oil by another to reduce the PCB concentration to less than 50 ppm before re-refining or using it as fuel and forces the companies to destroy the oil by special incinerators. The US EPA imposed heavy fine on a re-refining company unless it properly disposes of PCB contaminated oil by end of 2016[43]. However, the PCB rules in the US are now under review and the anti-dilution rule may be removed or revised.

Resource Conservation:

Crude oil is a precious resource that is very expensive to find and develop and its price often high especially for developing countries. Therefore, its conservation is a priority for most consuming societies.

It is said that it takes one barrel of crude oil to produce the same amount of lubricating oil that can be obtained by re-refining one gallon (1/42 barrel) of used oil[1]. Therefore societies need for lubricants could be tied to crude oil refining for virgin base oils supplemented by re-refining of used oil. Surely, on this point the cost of re-refining is much less though in refining crude oil we obtain other needed products as well.

At the same time, re-refining uses comparatively much less energy (one third) to produce base oils as compared to virgin base oil production.

The process of re-refining can be repeated many times as the oil is changed and the saving is substantial depending on the collection rate, the yield and the number of times the used oil is collected. The factor is reported to be more than 30 times in favour of re-refining over virgin production of base oils[1, 106].

Burning used oil in certain controlled applications is a form of conservation because the used oil is substituted for fuel oil, gasoil, natural gas or coal. But this is limited to only one cycle as compared to re-refining.

The key in conservation is to increase collection of used oils to the extent possible[104]. This will not only make more quantities conserved but avoid impact on the environment and provide more feed for re-refining[104] or fuel users.

One has to remember that reduction of lubricants consumption as a result of improved quality and enhanced performance is in itself a form of conservation of resources.

Re-refining Versus Burning:

Although re-refining and burning used oils are considered processes to conserve resources, they are in a way also environmental measures to keep out used lubricating oils from the environment. With the exception of acid clay process and distillation clay process, other re-refining processes produce very little waste or emissions. The acid sludge may be difficult and costly to treat but the clay is easier if it can be sent to cement and ceramic industries. There is a cost however.

Burning used oils in high temperature applications such as cement kilns does get rid of PCB, chlorinated compounds, halogens and so on. The metals stay with the cement and gaseous emissions are dealt with by the equipment provided for the cement plant off gases anyway.

In its Waste Oil Directive of 2008, the EU favoured re-refining of used oils over their use as fuel where this is technically feasible and economically viable[4]. The EU directed member states to align their laws accordingly[25]. However, the EU removed the priority given to re-refining in later directives because member states cited some life cycle analysis which did not give a higher order to re-refining against burning with respect to impact on the environment[1].

The EU Waste Incineration Directive of 2005 sets limits on atmospheric emissions from burning of waste and it applies to co-incineration plants such as cement kilns as well as dedicated incinerators[4].

Many studies suggest that re-refining is better for the resource conservation and environmental protection[104]. The life cycle analysis of Groupment European de l'Industrie de la Regeneration (GEIR)[1] demonstrates this on almost every count of global warming, nitrification, acidification, fine particulates (PM 10) and for carcinogenic risk. Studies related to California also showed more or less the same results[1]. However, not everybody agrees to this as mentioned with respect to the

EU countries earlier. In any case, there is no escaping the fact that the world burns five times the used oil that it re-refines.

Finally the re-refining of used oil to produce base oils is found to be much more favourable environmentally than the production of virgin base oils[106]. Global warming potential is 2 times less, nutrification is 3-4 times less, acidification and fine particulates (PM 10) is more than 5 times less and carcinogenic risk is 10-20 times less[106].

Quality, Groups and Drain Periods:

The purposes of lubricating oils are many[9]. They are expected to keep moving parts apart thereby reducing wear, reduce friction and improve efficiency, transfer heat, carry away contaminants and debris, transmit power in case of hydraulic oils and prevent rust and corrosion.

In order to do so, lubricating oils must meet certain standard specification that may have to be certified by an independent body with a well-equipped testing laboratory especially for engine oils.

The US Society of Automotive Engineers was the first to classify lubricating oils according to viscosity and consumers still see their symbol on lube containers to indicate the viscosity class.

However, the more famous specifications now are those of the American Petroleum Institute (API) and their comparative counterpart European Automobile Manufacturers Association (ACEA) in addition to the original equipment manufacturers (OEM) in some cases.

In the API system base oils are divided into five categories[1, 9, 21] according to constituents and performance level as measured by the viscosity index.

The API Groups:

Group-I: Base stocks with less than 90% saturated constituents or greater than 0.03% sulpher and have a viscosity index greater than or equal to 80 and less than 120. They are generally prepared by solvent extraction processes.

Group-II: Base stocks contain greater than or equal to 90% saturated constituents and less than or equal to 0.03% sulpher and have a viscosity index greater than or equal to 80 and less than 120. They are manufactured by hydro-treating and hydrocracking and either solvent or catalytic dewaxing to have better properties than Group I. They cost reasonably more but are increasingly demanded over Group I.

Group-III: base stocks contain greater than or equal to 90% saturates and less than or equal to 0.03% sulpher and have a viscosity index greater than or equal to 120. They are more refined than Group II by more sever hydro-treating to yield purer base oils. Some Group III manufacturers were able to produce base stocks equivalent in performance to Group IV below. The recent availability of gas-to-liquids (GTL) [28] base stocks have emerged as viable alternatives for the conventional Group III and Group IV lubricants[28].

Group IV: Base stocks composed of polyalfa-olefins (PAO). These are synthetic base oils which are suitable for more sever temperature applications and extreme cold conditions. Synthetic oils here are hydrocarbons molecules reengineered by certain processes and they do not contain contaminants such as sulpher and wax, which enables them to flow better at cold temperature[82]. PAO is mostly synthesised from the products of naphtha or condensate steam cracking in petrochemical plants[104].

Group-V: Base stocks excluding all components from the above groups but include base oils produced from silicone polymers, phosphate ester, poly alkylene glycol, polyol-ester, and oils made from biomass sources. They may be blended with other base stocks to enhance the properties of the base oil. They are more applicable to higher temperatures and will provide superior detergency compared with PAO synthetic base oil.

Table (5) summarizes the above groups.

Table (5)

Summary of API Lubricating Oil Groups

Group	Process	Saturates %	Aromatics %	Sulpher %	Viscosity Index
I	Solvent Extraction	<90	>10	>0.03	80 - <120
II	Hydro-processed	>90	<10	<0.03	80 - <120
III	Hydrocracked	>90	<10	<0.03	120+
IV	PAO	100	0	0	
V	Other synthetics				

Source: 1 based on API 1509 - 2012

Trends of Specifications:

While Group I lubricating oils are still produced to a large extent around the world, it is clear that this is changing. Group II are now much more favoured[1] in automotive oils for their quality and the fact that their relative cost is equal or only 5% over that of Group I.

Table (6) indicates the trend clearly where Group I share is likely to fall from 44% in 2014 to 26% in 2019. This trend is the result of "tighter emission regulations and rising economy specifications such as longer oil changes (or drain intervals) and better fuel efficiency[37]."

Only in China, about half a million tons a year of Group I capacity is expected to go offline in favour of producing higher grades[37]. In Saudi Arabia[57], Bahrain[37] and the United Arab Emirates[37] large Groups II and III production capacities are well underway. Therefore Group II share, excluding naphthenic oils, is expected to increase from 34% in 2014 to 48% in 2019 and the share would be much higher if naphthenic oils are included.

It is a question of cost and market why the higher synthetic oils are not increasing their share as fast. In spite of their advantages in protecting engines and improving fuel efficiency, they are judged by consumers to be very expensive. At the same time some Group III producers are improving final products by increasing severity to produce very high viscosity index products close to Group IV[32] specification at lower cost.

Table (6)

World % production of API Groups

Group	**2004**	**2014**	**2019**	**Relative Cost**
Mineral Oils				
G-I	46	44	26	1
G-II	47	34	48	1.05
G-III	3	11	13	1.5
Synthetic oils				
G-IV	2	1	1	2.5 - 3
G-V	1.6			5 – 10+
Naphthenic*		10	12	

Source:32 for 2004 & 31 for 2014 – 2019
*Naphthenic oils fall more into G II.

The Drain Interval:

In the early days of the lubricating oils, mineral oils were simple and contained no additives. Therefore they required frequent changes as their contamination and deterioration were faster. Engine oils were changed at that time at no more than 500 miles[30] (800 kilometres) distance travelled. However, with advancement made in production processes and the availability of chemical additives to improve performance, drain intervals became longer.

It is now the intention of many governments and the industry to reduce lubricating oils consumption by extending the drain period in all fields in order to conserve a valuable resource and to reduce the environmental load that is associated with the volume of used oils[4]. This is becoming a priority[32] and more and more possible by the availability of high quality lubricants and cleaner fuels[30]. It is especially true in developed countries of Europe and North America and the developing regions are catching up as outdated motor vehicles and machinery are replaced with products that require smaller amounts of better-performing lubricants[4].

In the advanced countries, in the heavy duty diesel engine category, oil drain intervals remain around 25,000 miles though it is possible to double this mileage[30] for normally running vehicles. However, for the same vehicles running in more severe and harsher conditions, an oil change by 15,000 miles is in order.

Tests conducted in 2010 on trucks with MaxxForce engines showed that oil change can range from 18,000 to 40,000 miles[30]. But in reality the answer lies in the operator's ability to monitor the quality of the oil through on board diagnostics or oil analysis to increase his fleet's drain period gradually and prudently.

In the passenger car field the majority of automakers today call for oil changes at either 7,500 or 10,000 miles[29]. This is in contrast to the US where the general practice is changing oil at an outdated 3000 miles target. Some manufacturers still recommend 5000 miles depending on the quality of oil. When synthetic oils are used the change interval can extend from 7500 miles to 25000 miles depending on the type of synthetic oil used[32].

The trend for extended oil changes has influenced lube oils producers to process more hydrocracked oils that have similar performance characteristics to those of synthetics as we saw earlier.

Industrial oils are not different. Comparative test life for turbine oils indicates that it is 4000 hours for solvent refined oil and 18000 hours for hydrocracked oil[32]. For hydraulic oils the comparative numbers are 2000 and 6000 hours respectively[32].

The Impact on Used Oil Re-refining:

It is clear from the evolution of lubricating oil specification and consumption trends that the used oil re-refining industry has to follow suite in order to be viable and able to compete. It is often reported that re-refined oils are now on par or better than virgin oils. But to satisfy the trend of moving away from Group I oils, only the processes using a hydro-treating step can now compete.

The technological advances in the last 15 years have shown that the re-refining industry has reached a stage where it can produce re-refined base stocks on par with virgin base stocks by following the hydro-treating route[54]. Consumer awareness of the quality of re-refined lubricants is spreading slowly but the industry still suffers from the stigma that its products are recycled and may be sub-standard and have to sell at a discount. This issue is particularly important in developing countries and in other low-cost markets[54].

The precipitous decline in crude oil prices since June 2014 and the subsequent decline of base oil prices are not helping the re-refining industry though regulations in some countries favors re-refined oils.

This is not to say that the more classical processes of distillation and solvent extraction are now redundant. They still can play a role for small capacity or for markets that still use lower grade finished lubricants.

The trend to extend the oil drain periods will enhance the re-refining industry to produce base stocks that are compatible with higher specification though the trend will reduce the availability of used oil in the long run.

Chapter 3 - Virgin and Used Oil Processing

Re-refining is defined as the chemical and physical processes that extract the lubricating base stock from used lubricants where water, fuels, additives remnants and sludge are separated from the base stock.

But it is perhaps better to consider first the steps to produce virgin base oils before embarking on the processes of re-refining used lubricants. There are some similarities between the two manufacturing processes that may be useful for the overall understanding.

البحث الأول

Virgin Base Oil Processing: [1, 2,49,84,85]

Base oil is the name given to lubricants grade oils which are produced, in the modern industry, in a complex sequence of steps in a refinery as shown in Fig (1). Their boiling ranges between 300 and 565ºC[1] and are produced normally by feeding reduced crude oil from the atmospheric distillation unit to a vacuum unit column to lower the boiling points and obtain distillates side streams. The vacuum residue bottoms still contain valuable high viscosity oil that cannot be distilled and have to be recovered by using a propane solvent in a de-asphalting unit (PDA) where the propane dissolves the oil leaving heavy asphalt cut to be produced. The oil produced so is de-asphalted oil (DAO) and propane is recovered and recycled.

The vacuum side streams and the DAO contain components that are undesirable in lube base stocks. Therefore they are sent in turn to an extraction unit, usually with a furfural solvent where the solvent absorbs the undesirables especially aromatics and gives a raffinate with an improved viscosity characteristic ready for the next step. The furfural solvent is recovered and the extract product is returned to be used as asphalt cutter or blended with fuel oil or as feed to conversion processes.

To get rid of the wax the lube streams are sent in turn to a dewaxing unit which separates the wax, to improve the pour point, either by refrigeration and filtration or by solvent, refrigeration and filtration. The solvent is often a mixture of MEK and toluene.

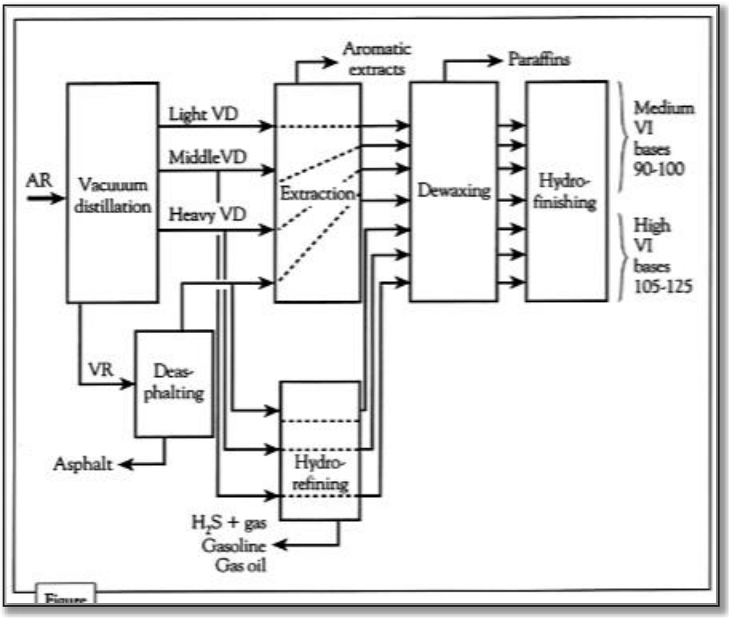

Fig (1) Virgin Lube Processing - Source: 2

Finally the lube cuts are sent in turn to a hydrofinishing unit to improve colour and remove sulphur and nitrogen compounds making the cuts ready for blending with additives according to the desired grades.

There are variations to the above steps where, for instance, the vacuum cuts and DAO can be hydrotreated to saturate aromatics and remove contaminants before the dewaxing stage and final distillation for the respective base oil cuts as shown in Fig (2).

Similarly catalytic dewaxing sometimes replaces solvent dewaxing and thus saving a lot in solvent cost. "Catalytic dewaxing was a desirable alternative to solvent dewaxing especially for conventional neutral oils because it removed n-paraffins and waxy side chains from other molecules by catalytically cracking them into smaller molecules."[1]

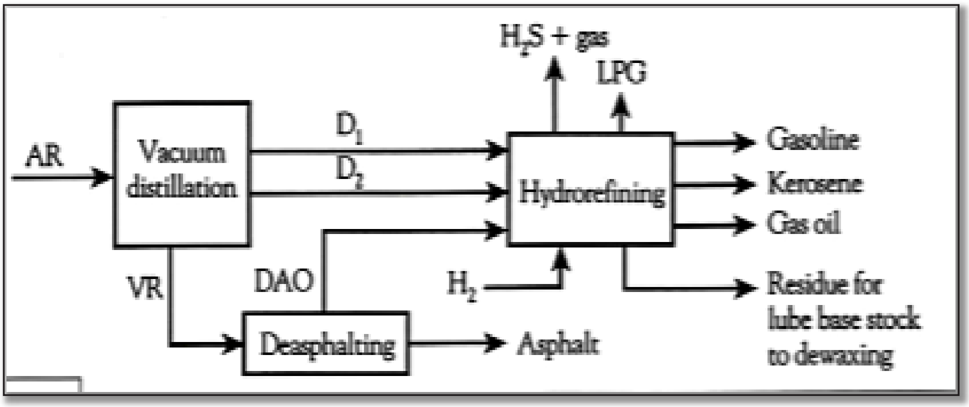

Fig (2) Alternative Virgin Base Oil Processing Source: 2

Used Oils Re-refining Processes:

Since base oils are not actually destroyed by use but get contaminated, the question of re-refining them may be called a cleaning process.

The first important step is testing the collected used oils "to ensure quality because used lubricating oil from a wide variety of sources may contain chemical or physical contaminants that are hazardous or prevent that oil from being used in the re-refining process."[1] This also relate to different regulations around the world.

Generally, the re-refining processes involve similar steps such as:

1- Filtration and settling of the collected oil.
2- Removing water and light hydrocarbons from the feed by pre-flash distillation.
3- Removing gasoil by feeding to a vacuum column.
4- Rejecting heavy materials and contaminants by vacuum distillation or wiped film evaporation or both.
5- Treating the remaining oil with solvent or hydrogen to get base stocks close to virgin oils.

Generally, there are three major categories of processes to treat used lubricating oils:

1- Treatment with sulphuric acid and clay.
2- Using a distillation process followed by activated clay treatment.
3- Treatment by solvent extraction to reject heavy residue, metals and other contaminants.
4- Using either 2 or 3 followed by hydro-treatment of the product to improve the quality further.

There are many processes for the treatment of used lubricating oils but here the most famous are discussed.

<u>The acid/clay process:</u> [1, 3, 107]

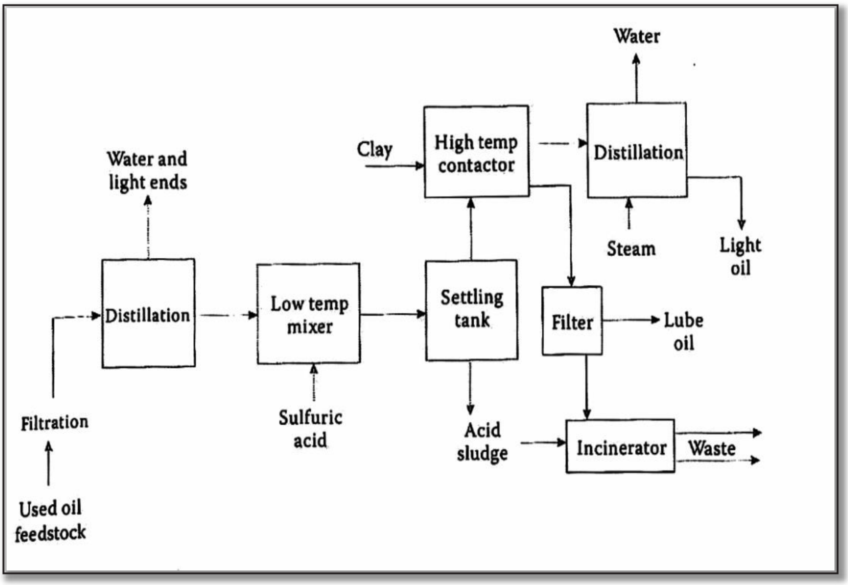

Fig (3) - Acid/Clay Process - Source: 1

Fig (3). After settling and filtering, the used oil is heated to 120ºC and distilled in a pre-flash tower to remove entrained water and light hydrocarbons. Contact with sulphuric acid follows to remove contaminants such as oxygen, nitrogen and sulpher compounds in addition to resins, asphalt and metals. The stream then passes through active clay at 270ºC to remove odour and improve colour.

This process, while simple, inexpensive, proven and easy to operate is mired with environmental problems due to acid emission and sludge. The sludge disposal is neither easy nor inexpensive. The spent clay goes to ceramic and cements industries or incinerated. The base oil quality is very low[1] and the yield is close to 60% because much oil remains with the sludge. The sulphur and polyaromatic hydrocarbons (PAH) in the oil cannot be separated as contaminants in the oil.

Therefore many countries banned its use though it is still popular in Brazil, China and India.

The Meinken Process: [1, 3, 107]

This is a distillation/clay treatment process. After settling, filtration and removal of water and light hydrocarbons in a pre-flash column, 4 to 5% clay is added to the dewatered oil before wiped-film evaporation under vacuum and 290ºC to draw asphalt and contaminants from the bottom and subsequent clay treatment and filtration of the side cut to finally get the base oil cuts. The process produces medium quality base oil that still contained sulphur and polynuclear aromatics (PNA) [1]. Polynuclear Aromatics (PNA) are complex hydrocarbons of many aromatic rings formed during the use of lubricating oils in severe engine conditions and some are formed in fossil fuel combustion or cracking processes. They are classified as carcinogenic which may cause cancer to humans.

No acid is required in this simple process suitable for small capacity plants. But the high clay consumption, low yield, inconsistent quality and the disposal of large quantity of spent clay is an environmental problem.

Three plants had been constructed in Germany, one in the United States, one in Taiwan, one in Brazil and two in Jedah, Saudi Arabia at 10 and 80 thousand tons a year capacity[1].

The Sotulub process: [1, 3, 107]

Fig (4). This process is developed for Tunisia and patented in France. The used lube oils are first tested to eliminate stocks of high gasoline, fatty acids and chlorine. After settling and filtration anti fouling is added to prevent fouling and blockage of equipment and the feed is heated to 140ºC and fed to a fractionation tower to remove water and gasoline and then gas oil is removed in the next vacuum tower operating at 280ºC. Finally a vacuum tower stage to produce the lube cuts as side streams and the bottom is asphaltic residue with all the metal contaminants.

The last vacuum column can either be replaced with or work with a thin film evaporator to improve quality of the lube cuts[1] or that the vacuum column and

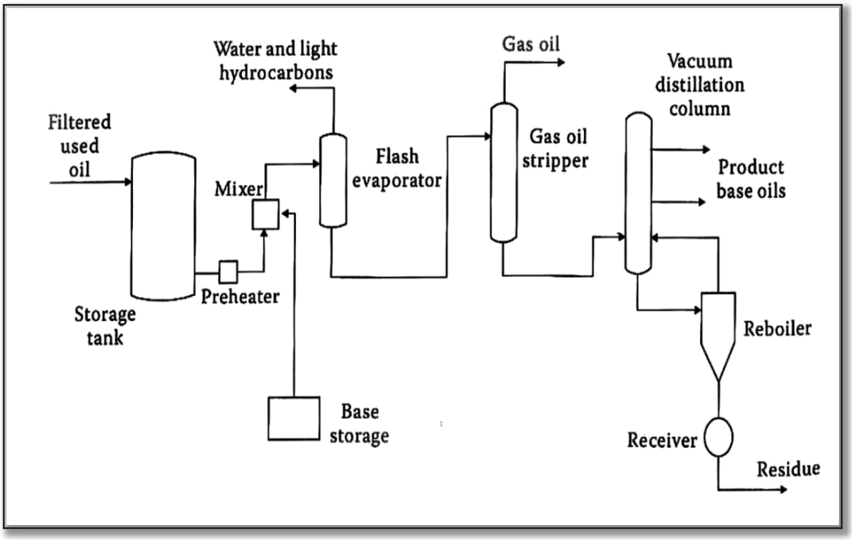

Fig (4) – Sotulub Process – Source 1

the reboiler can be replaced by a centrifuge to separate the asphalt and heavies[3]. The base oil yield is 62.76%[1].

Two units are reported, one in Tunisia at 16 thousand tons a year and in Kuwait at 20 thousands. But Tunisia is said to have added another stage later to hydro-treat the products and improve the quality.

The Mohawk and CEP Mohawk Process: [1, 3, 107]

In the early 1980s, a plant was constructed in Vancouver, Canada at 600 barrels a day to treat used oil by subjecting it to a chemical treatment by a hydroxide or a combination of this and a weak acid. Water and gasoline are then removed by flash distillation and then gasoil is removed by vacuum distillation. The final step uses another vacuum step and a thin film evaporator to get the base oil cuts and bottom's asphalt combined with the unwanted contaminants. The yield of base oil is 65%. A hydro-treating step can be added for the full base oils cut before final distillation breaks them into the desired cuts of Group I base oils as shown in Fig (5).

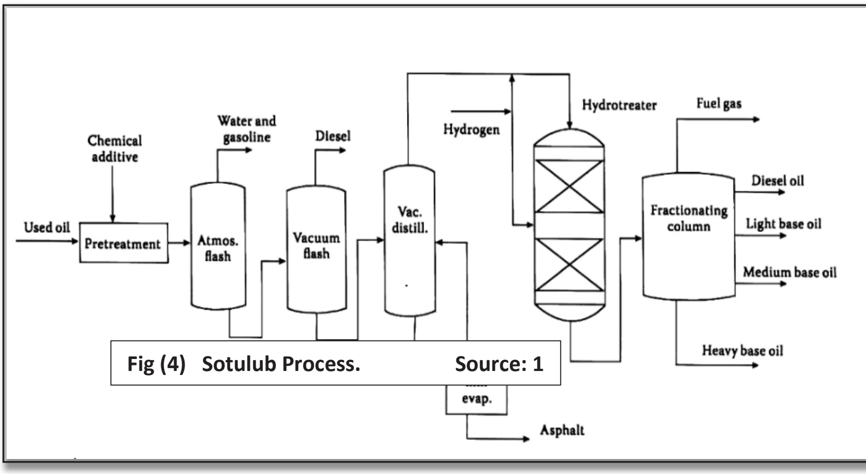

Fig (5) - Mohawk Process with Hydro-treater - Source 1

However, Mohawk and Chemical Engineering Partners (CEP) later combined to use the initial stages of the Mohawk process and adding a hydro-treating stage of three reactors in series operating at a pressure of 1300 psig and 315ºC to reduce sulpher and other contaminants and to improve base oil yield to the level of group II base stocks as shown in Fig (6).

CEP's leading technology since 1988 is said to produce API Group II quality base oil with recoveries in excess of 70%[93]. CEP licenses a number of re-refining plants where ten are operational globally and two more in design, approaching nearly a total of billion litres of re-refining capacity[93] which can produce Group II base oils.

The minimum economic size, according to CEP[1], is 15 thousand tons a year and the yield of base oil is 74%, 4% light oil, 4% gasoil and 13% asphalt, a great improvement over the original Mohawk. The process is used in Canada, USA and Finland, Australia (20 thousand tons a year) and Indonesia (50 thousand tons a year Mohawk).

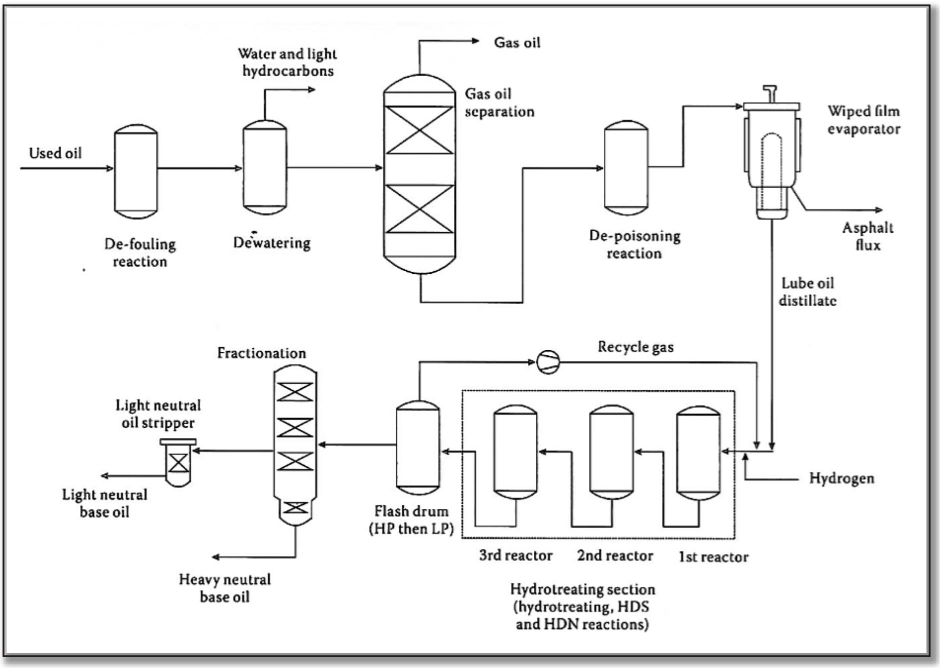

Fig (6) - CEP Mohawk Process - Source 1

The Avista process: [1,3,92]

Fig (7). Formerly Vaxon a Danish fuel preparation process. The process is modified and now licenced by Avista. After settling and filtration of the used oil feed water and light hydrocarbons are separated in a pre-flash distillation step. N-Methyl-2-pyrrolidone solvent (NMP) is then used to treat and remove contaminants of hydroxides, chlorides, metals and spent additives.

The operation of liquid/liquid extraction is conducted in a column where the feed rises from the bottom to meet the solvent coming from the top. In the following step, the solvent is stripped and recycled and the oil is distilled in a vacuum tower to recover the base oils as side streams and the asphalt from the bottom. Propane is used in other solvent extraction processes.

The process does not cause pollution except for some solvent losses and produces relatively good quality base oils. Avista Oil Company owns and operate a 35 million gallons a year re-refinery in the US and another three plants in Saudi Arabia (2003) and one in Denmark (2008).

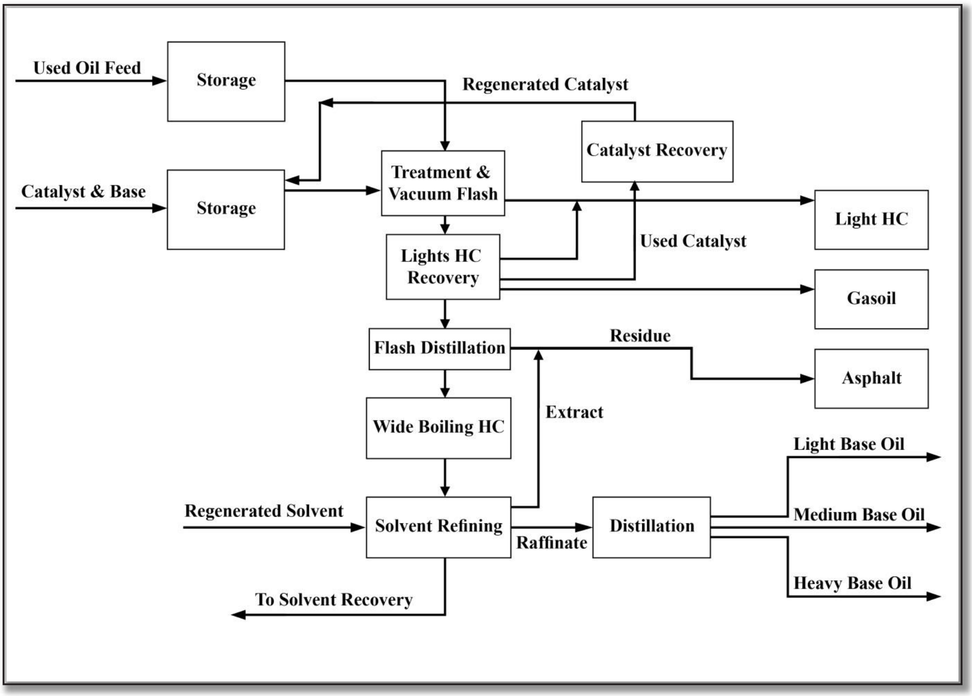

Fig (7) - Avista Process - Source 3

Viscolube and the Revivoil Process: [1, 15, 87]

Fig (8). The original Viscolube process is an example of chemical treatment, distillation and clay. After settling and filtration the used oil feed is treated with 30% caustic soda (sodium hydroxide) solution to neutralize fatty acids and chlorides before water and light hydrocarbon removals are made in a pre-flash tower operating under vacuum and 120 to 140ºC. The bottom of the pre-flash column goes to a settling tank where impurities are removed before the used oil is heated to 360ºC and flashed in a deasphalting and fractionating vacuum tower with a cyclone separator in its bottom. The side streams of base oils are stripped by steam in in the next columns and treated by clay to remove odour and improve colour. The light products can be used as fuel in the plant. The process is a noticeable improvement on acid/clay process with respect to environmental impact and its base oil yield is close to 72%. However, Viscolube no longer uses this process on its own except for plants less than 10 thousand tons a year[1]. The collaboration with Axens developed:

The Revivoil Process: [1, 3, 15, 87, 90, 91]

Fig (9) shows a simplified flow diagram of this process while a more detailed flow diagram can be found on the company's website[87]. In this process the first stage is more or less the same as the original Viscolube process but the second step is developed by Viscolube and is called thermal deasphalting (TDA). Axens hydrogenation at high pressure step is added to make the difference to produce Group II base stocks and raise the base oil yield to 79%[3]. Hydrogen saturates the unwanted aromatics and treats all other contaminants of sulpher, nitrogen and chlorine.

A "selectopropane" unit can be added to extract DAO from the residue to improve quality and yield to 95% (not shown in the diagram). The installation cost of such a facility of 100 thousand tons a year is $35 million (2004) while the same plant without the selectopropane would cost $30 million (2004) all ISBL (inside battery limit). This information is obtained privately from a re-refiner. The process is widely used in Italy (100 thousand tons a year), Spain (three plants at 20 thousand tons a year each), Poland (80 thousand tons a year) and Indonesia (40 thousand tons a year) with future expansion on the way.

The Snamprogetti Process: [1, 3]

Fig (10). Patented in 1979, this is a solvent extraction process but later modified to its present form to include a hydro-treating step. After settling and filtration, the used oil is heated to 180ºC and fed to a predistillation column to remove water and light hydrocarbons at the top and a de-watered oil at the bottom. The next step is a propane deasphalting column at 75-95ºC and 355-710 psi. The wide range is to cater for different compositions of used oil. The residue (mainly asphalt) is drawn from the bottom. The propane solvent is recovered from the top stream and the rest is heated again to 300ºC and fed to a vacuum tower to produce side streams of base oil cuts which are then hydrotreated to remove metals and treat contaminates of sulpher, nitrogen and chlorine in addition to saturating the aromatics.

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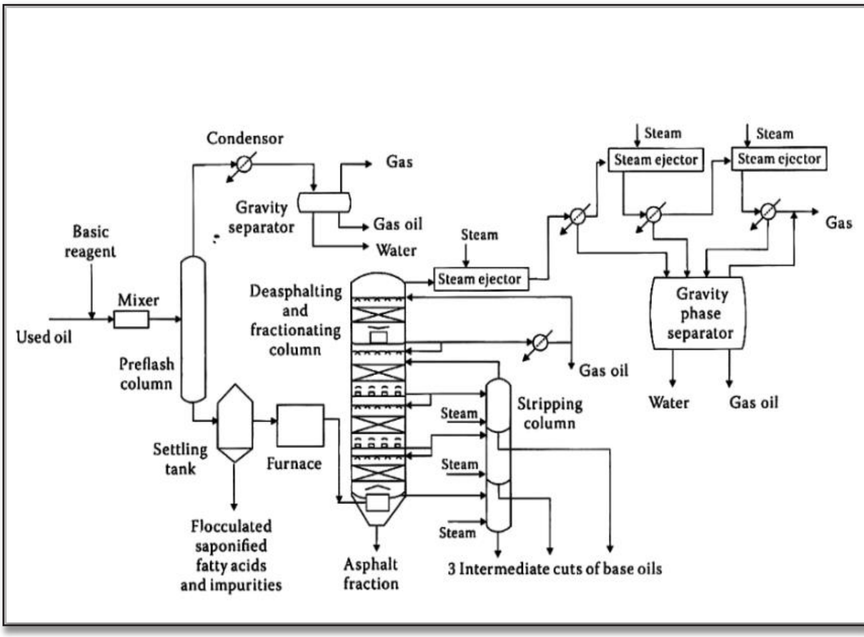

Fig (8) - Original Viscolube Process - Source 1

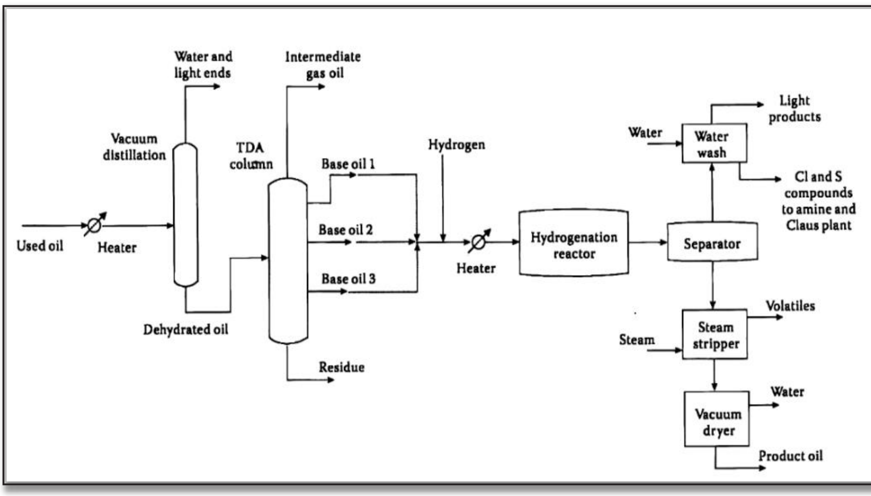

FIg (9) - Simplified Revivoil Process - Source 1

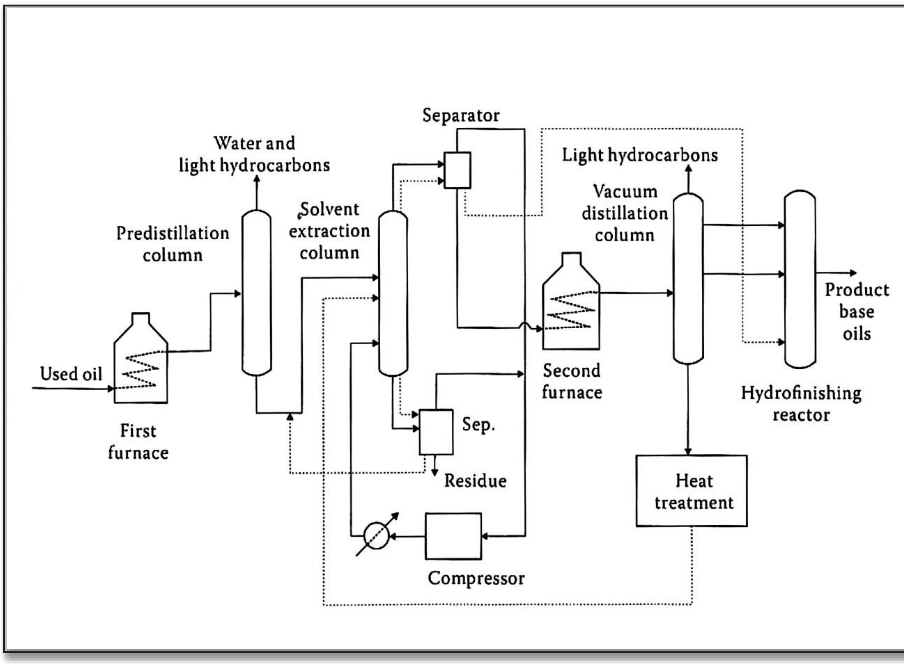

Fig (10) - Snamprogetti Process - Source 1, 3

The heavy base oil can be separately heated and recycled in batch mode to the solvent extraction stage to improve the cut.

The base oil yield is 87%. The hydro-treater operates at 250 to 450ºC and the hydrogen is reported to be between 15 and 850 normal litres/litre[1] of oil. One plant of 55 thousand tons a year is in Italy.

<u>The Kinetic Technology International (KTI) Process:</u> [1, 4, 67, 107]

Fig (11). Patented in 1990, this process passes settled and filtered used oil into a distillation column to separate water and light hydrocarbons, which are used as process fuel or burned in a special incinerator (not shown in the diagram). The pre-treated oil is then passed into a predistillation column operating under vacuum and 220ºC to remove a gasoil stream.

The bottom is partially re-boiled and sent back to the predistillation column and the other part goes in to a wiped film evaporator operating under very low vacuum and 345ºC. The bottom stream of the wiped film evaporator is an asphaltic residue carrying some contaminants and is partially recycled.

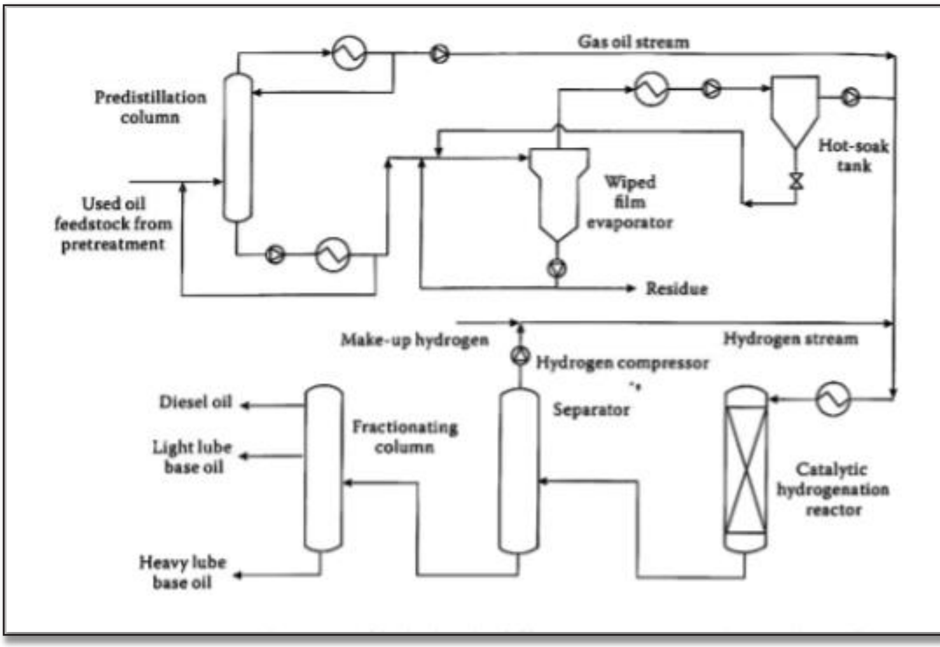

Fig (11) - The KTI Process - Source 1

The top stream is oil vapour which is condensed before entering a hot soak vessel where heavy impurities settle and recycled back to the front end of the wiped film evaporator. The hot soak vessel operates at 150 to 250ºC and the residence time is 11 to 30 hours depending on the quality of the feedstock. The overflow of the hot soak vessel joins the gasoil stream and goes into the catalytic hydro-treating reactor operating at 320ºC and 870 psi pressure to reduce or eliminate the impurities of metals, sulpher, nitrogen, chlorine and oxygen. The rest is to separate and recycle the hydrogen and a fractionation tower finally to separate the diesel, light and heavy base oils. The KTI Process recovers over 95% of lube oil components, much higher than other conventional processes though some sources quote 82%[4].

Like in other processes, the hydrofinishing step is capable of destroying PCBs and other similar carcinogenic contaminants. The waste water is treated according to local regulation of the plant. The base oil quality is equal or better than virgin base stocks.

Re-refining plants using this process are in Greece, Tunisia, California and Germany. The Greek plant (1992) is the first KTI license with 20 thousand tons a year capacity later raised to 40 thousand tons a year.

The Hylube Process: [1, 3, 86, 107]

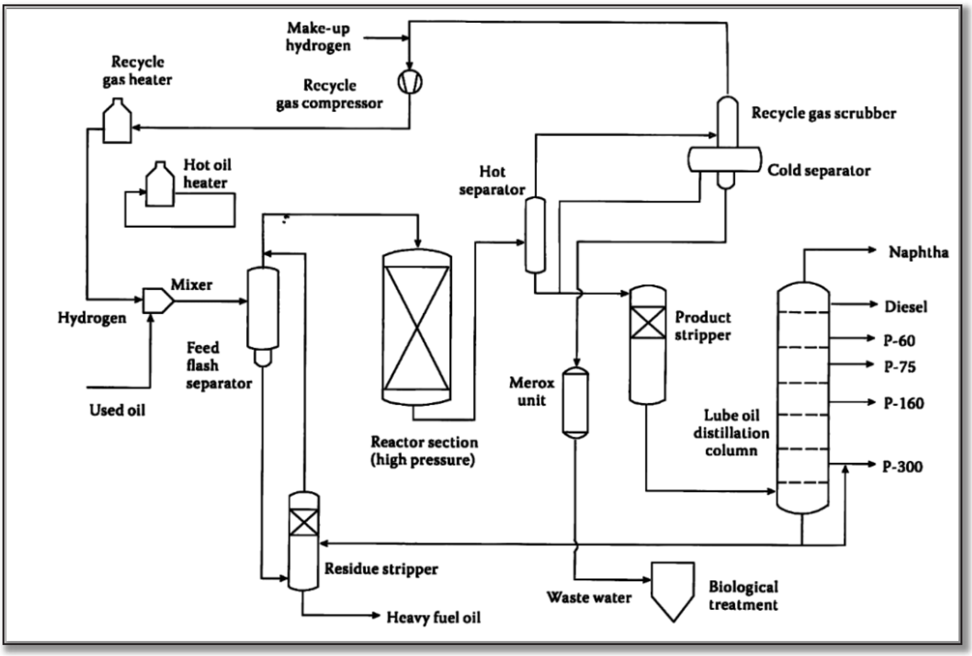

Fig (12) - The Hylube Process - Source 1

Fig (12). First patented by UOP in 1989 and went through many patented developments later. In this process the settled and filtered used oil is mixed with hot hydrogen and fed to the flash zone of a column maintained at 380 to 460ºC.

The bottom stream of the column is the heavy un-distillable portion of the feed while the top stream vapours are cooled to condense the undesirable heavy components and separated as low ash fuel oil. The top stream goes to the hydrofinishing reactor to reduce or remove other contaminants such as metals, sulpher, nitrogen, and chlorine and oxygen compounds. If PCBs are present in the feed, they are converted to un-harmful materials. The reactor effluent is cooled and hydrogen is recovered in a high pressure separator and recirculated. A low pressure separator follows where fuel gas is drawn from the top and the bottom stream is fractionated in a vacuum tower for naphtha, diesel and base oil cuts.

The process produces Group II+ quality base stocks. In the Puralube plant in Germany 45 thousand tons a year of high quality base stocks are produced in addition to 25 thousand tons of other products. The plant was completed in 2004 and duplicated in 2008.

Puralube[86] is planning with UOP to upgrade one of its re-refineries to produce 50 thousand tons of Group III base oils in the first quarter of 2017. But the fall in oil prices may put this plan on hold[86].

STP Process: [94, 107]

Fig (13). After settling and filtration, dehydration and removal of light ends is done in an atmospheric tower at 160ºC. The light ends may include gasoline, solvents and glycol.

The second step is a vacuum tower to recover gasoil before the third step of vacuum distillation accompanied by a thin film evaporator to recover vacuum gas oil (VGO) leaving the asphaltic residue with most of the contaminants (metals, polymers, carbon and dust) drawn from the bottom.

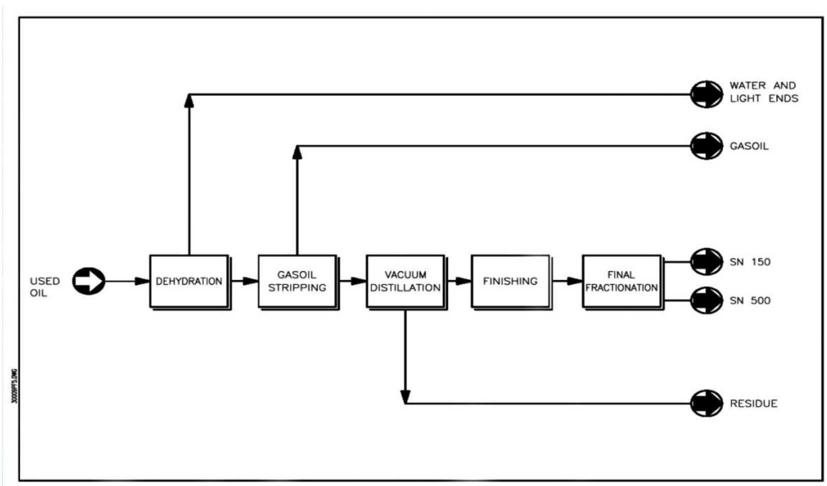

Fig (13) - The STP Process - Source 94

The VGO is then either treated chemically if the process is to produce API Group I base stocks or hydrotreated if API Group II are to be produced. The hydro-treatment process as usual removes further contaminants such metals, sulpher, chlorine, oxygen, PCBs and PNAs.

The final step is fractionation to recover further gasoil and produce light and heavy base stocks.

The yields are reported to be 7% water, 5% gasoil, 75% lube oils and 13% asphalt.

Many plants have been built by STP including three in Italy of total capacity 125 thousand tons a year, a plant in Canada of 60 thousand tons a year to produce VGO and a similar plant in France for 120 thousand tons a year. The company says that VGO is used as feed for further processing in a fluid catalytic cracking unit (FCC) or a hydrocracking unit (HC) [94].

The Dollbergen Process: [1, 24]

Fig (14). This process belongs to a re-refinery in Germany (Mimeraol-raffineirie Dollbergen) and was patented in 2004. It is based on distillation and solvent extraction processes. After settling and filtration, potassium hydroxide solution (KOH) is injected into the used oil stream to neutralize acids and help in the de-metalizing of the oil. The used oil then enters a distillation column at near atmospheric pressure and 140ºC to remove water and light ends. The second step is a vacuum column at bottom temperature of 260ºC to recover "light heating oil"[1], diesel and gasoil, and the third step is a thin film evaporator working under high vacuum (0.044 psi) and 385ºC to separate a heavy bottom product. The stream is then treated by N-methyl1-2-pyrrolidone (NMP) solvent in a solvent extraction column to extract contaminants and finally to recover solvent and base oil cuts by distillation.

The processors say that toxic components such as PNA and PCB if present in the used oil are thereby removed. They claim that the solvent extraction process is superior to hydrogenation in preserving components of synthetic base oil that may be present in modern lubricating oils.

A second thin film evaporator under higher vacuum is used to treat the bottoms of the first one to recover heavier base oil stock (not shown in the diagram). The base oil yield depends on the solvent to feed ration and can range between 84 and 92%.

The capacity of the re-refinery using this process is 230 thousand tons a year.[24]

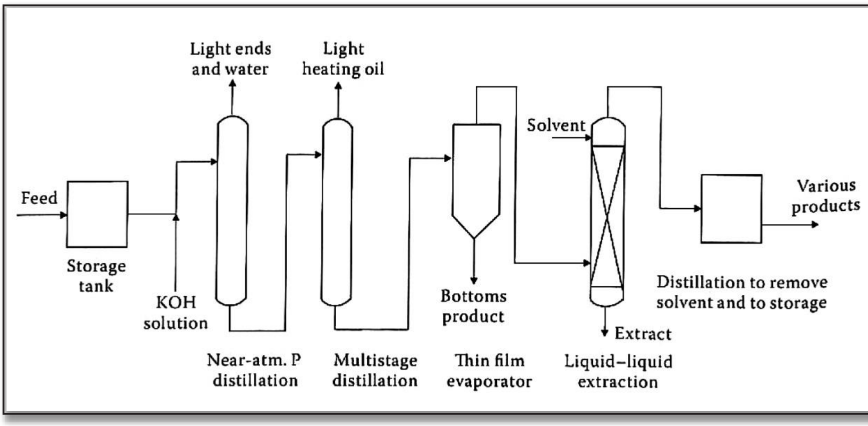

Fig (14) - Dollbergen Process - Source 1, 24

Other Processes:

There are other processes which are either not widely used or discontinued for various reasons or very expensive to build and run. Briefly some of these are:

1- The Phillips Petroleum PRPO process[1, 3] involves treatment with di-ammonium phosphate, clay and hydro-treatment and fractionation. It is expensive to build and run and the disposal of waste is environmentally problematic.

2- The Atomic vacuum Company Process[1, 3] involves treatment with polymers to separate sludge and then followed by molecular distillation and clay treatment to get refined base oils. Used in a plant in Mumbai, India.

3- The Interline Process1, 3 is an acid treatment process where the acid and contaminants are neutralized by ammonium hydroxide and potassium hydroxide. With the exception of a plant in Spain all the plants of UK, South Korea and US were closed for environmental reasons. Therefore, this process did not live up to the expectations, when it came in 1994, of low investment and operating cost in addition to its suitability for small plants.

There are other prototypes or pilot plants processes that have not been tried on commercial scale such as but not limited to the: Bechtel MP process, Kellogg ROSE process, Exxon process, German Entra process and so on.

Clarifying Industrial Oils:

It is imperative for good housekeeping sake, environmental protection and reducing expenses to use lubricants for as long as possible before changing or treating them.

A long time ago simple dewatering systems were used to treat used oil for it to be utilized as fuel oil[24]. There are mobile or fixed installation units for the purification or clarification of mineral oils (fuel and lubricating oils) used in marine installations and power stations. The heart of the unit is a centrifuge which separates water and sludge and circulates the clean oil back to the system.

Unit capacity can be up to two cubic meters per hour. Other manufacturers have mobile units mounted on trucks to do such service in many scheduled installations[95]. Oil testing by the client is important and even additives can be added to the cleaned oil. These services can be useful for turbine oil, transformer oil, hydraulic oil and some metal working oil. The practice is sometimes called “laundering”[107] as it refers to cleaning in place. By using these services and techniques, service life of the oil is extended, changes are minimized and resource conservation is enhanced and environmental load is lessened. Needless to say that engine oil is excluded due to the complexity and severity of its operating conditions and level of contaminants.

Process Selection Criteria:

The selection of environmentally sound technology (EST) for the re-refining of used oil is not a straight forward task. There are many aspects to consider before reaching a decision. As far back as 1995, the Basel Convention set the technical guidelines[70] for this task. The basic criteria are as follows:

- Feedstock quality and nature of its contaminants must be determined in addition to the environmental and health risks associated with handling and processing.
- Deciding on the desired quality and yield of base oil to be produced.
- The disposal of any hazardous waste that may be generated.
- The economic feasibility of the project and the availability of feedstock on sustainable basis.

• Consideration of the plant location and its relation to the efficient collection, storage and transport of used oil and whether the plant needs services or input from an existing facility. This is particularly important with respect to hydrogen.

• The national or local legislation in place.

• The Socio-economic benefits with respect to employment and others.

• Consideration and utilization of experience gained in other countries or plants.

It is important to understand that the traditional processing of used oils such as acid clay process or even distillation clay process are increasingly not desirable in many countries because of the hazardous waste they produce and the cost associated with its treatment. The distillation clay process may only be used for small capacity plants in any case.

Therefore we are really left with either solvent extraction or hydrogenation processes. Take the European Union as an example[1, 70]. In 2012, the solvent extraction processes total capacity was 581 thousand tons a year in eight plants and catalytic hydro-treating total capacity was 306 thousand tons a year in three plants. But the trend may be shifting in favour of the hydro-treating route due to the need to produce higher quality base oils such as API Group II & III.

In North and South America[1], four plants are using hydro-treating processes to a total capacity of about 655 thousand tons a year and two plants are using solvent extraction processes to a total capacity of 78 thousand tons a year.

In Asia Pacific and Australia, two plants are reported in 2012 using solvent extraction processes at a total capacity of 94 thousand tons a year. In Indonesia, 40 thousand tons a year plant uses hydro-finishing.

This is not to say that these are the only plants processing used oil. There are about 200 oil recyclers in North America but only three are primarily re-refiners, which recover lube oil for reuse. The others recycle waste oil by producing fuel for energy recovery[1]. The same goes for Europe where there are many plants processing used oil for fuel only[1]. Plants using old and no longer reliable processes are not reported in the statistics. Overall, there are 400 plants processing used oil for fuel or base oil production around the world[1].

Chapter 4 - Burning Used Oil for Fuel

Used oil for fuel is a competitor to the re-refining industry in many countries as we shall see. The European Union (EU), the U.S. Federal Government and other countries have given priority to the re-refining of used oils but most of the generated and collected used oil still goes to fuel[1, 4, 7, 22, 23].

Instead of re-refining, used lubricating oil for fuel and energy recovery is called recycling which means here, using a waste material to make something new and useful from it.

Therefore, used lubricating oils are often recycled to be combusted in high temperature industrial combustion systems to ensure complete combustion and avoid the release of harmful substances into the environment[4]. These systems include cement kilns, blast furnaces, power plants, industrial plants boilers and space heating[7].

While used lubricating oil can and is used directly as fuel, replacing coal or fuel oil in the above mentioned applications, there are processes that can treat the stuff for better fuel applications including diesel fuel or marine and railway engines fuel.

The estimation of global used oil generated globally is not an easy task “as users and recyclers either do not collect, or do not share, data.”[4] The same source estimates that about 5.25 million tons a year are “burnt as fuel and dumped and/or land filled[4].” With environmental regulations tightened in many countries, this estimate is conservative as we shall see later.

Direct Burning of Used Oils:

In the beginning, when heat value of used lubricating oils was appreciated, it was used without pre-treatment or processing and without any quality control or specification[1]. As environmental awareness spread, it was realized that such practise is harmful to health and the environment and had to be controlled. Perhaps the first kind of treatment was no more than settling in a heated tank at 70 to 80ºC, decanting to drain water and filtration to remove sludge and suspended matter[4].

Utilizing used oil for the partial replacement of fuel oil is now widely applied around the world[1] under controlled conditions in cement kilns, stone quarries, asphalt coating plants, smelters, coking plants, brickworks, large industrial boilers and power plants[1]. The word “partial” is not obligatory as some of the above applications can utilize only used oil if the volume is available. It was also thought that mixing used oil with virgin fuel will lessen the environmental impact of the former provided that ash content is limited and does not exceed some regulation[4]. In any case, the market for fuel oil far exceeds the availability of used oil for the purpose.

There are two applications of burning used oil that do not need much treatment except perhaps settling and dewatering which is known as mild processing[22]. Burning in cement kilns and hot mix asphalt plants does not cause too much environmental worries. Both applications "operate at high temperatures and have fairly long residence times to enable the destruction of most of the undesirable chemical compounds in the oil[1]". Therefore, the Polynuclear aromatics (PNA), chlorinated hydrocarbons and heavy metals are destroyed in cement production furnaces[1] and asphalt mix plants. The metals are said to be locked in the produced cement[22]. Especially in modern cement plants, there is efficient flue gas scrubbing equipment to reduce emissions to atmosphere.

There are further logistical advantages that are relevant here. Cement plants and asphalt mix plants are normally distributed around the country. Therefore, it is beneficial for used lube oils collection and transportation to go to the nearest fuel user. To show the extent of burning used oils in cement kilns, the Cement Bureau[104]said that 17% of fossil fuels used in the cement industry in Europe are replaced by burning used oil in 2003. In Germany 600 thousand tons a year of used oil is burned in cement kilns in 2002, which is equivalent to half of German requirements while three quarters of French requirements are met by burning used oil[104].

Heavy fuel oil is not immune from contaminants such as metals, sulpher and asphaltenes, which are detrimental to equipment in forming ash, slag and corrosion. Equally, used lubricating oils contain higher levels of metals and ash forming constituents. In applications other than cement kilns and asphalt mix plants, it is often necessary to have access to landfill sites with permits to handle the toxic ash[4,9].

No matter what, it is important to reduce the risk of burning used oil by settling, filtering and even centrifugation to remove solids and water. Distillation and solvent extraction are more sophisticated methods of producing better fuels. Mixing with virgin fuel and the installation of flue gas scrubbing systems reduces the environmental risk to a large extent.

It is also important to know what fuel used oil is actually replacing in burning applications. If it is replacing coal in a power station or any other application then it is considered better for the environment[97]. However, if used oil is replacing gasoil in asphalt mix plants then environmentally the former is better[1,97]. Perhaps the question must be asked as to why asphalt mix plants use gasoil instead of the much cheaper heavier fuel. It must be remembered that cement kilns sometimes use scrap tyers for fuel and used oil is certainly better environmentally[105].

Burning used oil in space heaters for small businesses recovers the heat value but is likely to cause local air pollution[22] and care must be taken here in the equipment and set up design[23].

Finally, low temperature burning of waste oil must be avoided due to the potential pollutants in gaseous emissions that can be released such as carbon monoxide, sulphur and nitrogen oxides, particulate matter (PM 10), toxic metals, organic compounds, hydrogen chloride and dioxins/furans[4].

Processing Used Oil for Fuels: [1, 107]

There are a number of processes that have been applied to condition used oil for fuel. The treatment is said to be severe processing[22] as compared to the mild processing needed for direct burning. These processes are in brief as follows[1, 4,107].

The Propak process:

Fig (15). This process involves thermal cracking of the used oil followed by distillation and stabilization to produce gasoil (diesel) and fuel oil. Used in Canada and Belgium but the product quality is poor with respect to sulpher. Gas fraction and naphtha may be used as process fuel.

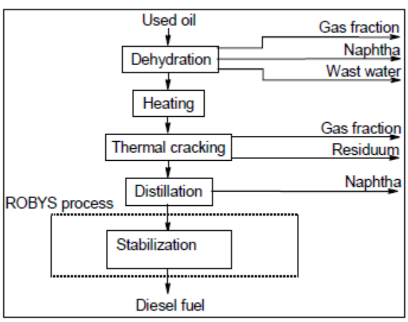

Fig (15) - Propak process – source 107

The Trailblazer Process:

Fig (16). This process is based on preflash to remove water and light ends followed by vacuum distillation to produce industrial or marine fuel close to virgin vacuum gas oil. The bottom of the vacuum step is asphalt extender. One plant in the US processes 170 thousand tons a year of used oil.

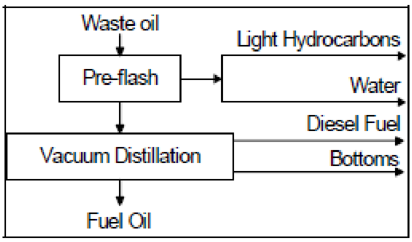

Fig (16) – Trailblazer Process – Source 107

The Zimmark Process:

Fig (17). This process involves coagulation and precipitation with chemicals to remove impurities by precipitation at elevated temperature. After days of settling, it is followed by distillation to produce desired cuts. The products qualities are poor and may be used as fuel or mixed with lubes for low grade applications. There are units in Canada, US, Mexico and Asia. Mobile units are reported in Canada to avoid transportation of used oil.

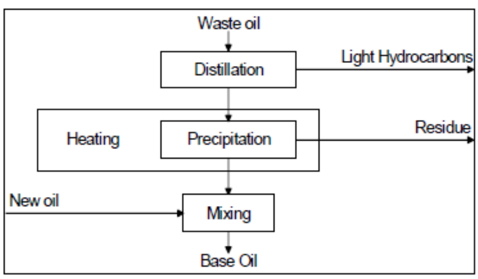

Fig (17) – Zimmark Process – Source 107

Fig (18). This is the most used process and it involves a preflash followed by thermal cracking performed in a furnace coil with soaking drums[4] to produce fuel oil and gasoil with poor quality. The process is said to be suitable for small plants of 6 to 15 thousand tons a year[4]. There are between 18[1] and 25[4] plants around the world with capacities ranging from 300 tons to 12 thousand tons a year[4].

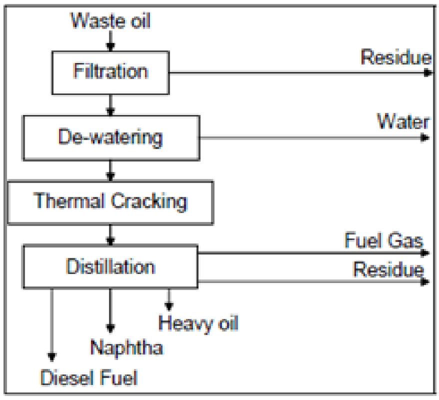

Fig (18) – SOC process – Source 107

The Spring Oil Conversion Process:

A variety of this process replaces the cracking furnace with a rotary kiln and is suited to larger facilities. A plant of 40 thousand tons a year was built in Belgium in 2001 with other plants in Canada[4].

There are many other prototype processes that have not been commercialized yet. Other than burning for heat and energy and re-refining for base oil, used oil is utilized for a number of lesser purposes such as road oiling in rural areas, asphalt cutter and the like.

In the European Union:

In Europe, the importance of burning fuel oil is well demonstrated in the statistics. Although CONCAWE[22] (which represents both lubricating oil manufacturers and re-refining plant operators) says that "Most have concluded that re-refining is 'better' than burning, usually on grounds of energy efficiency" but countries differ on this and some have "concluded that none of the possible disposal options had a clear advantage and that the results might well differ from place to place depending on local circumstances and the quantities of used oil available for disposal.[22]"

The EU Waste Directives 75/439/EEC as amended by 87/101/EEC and 91/692/EEC had given priority to re-refining[1] in the use of collected used oil. But individual countries couldn't meet this. These countries say that re-refining is uneconomic in their circumstance and that there is no clear cut environmental advantage over burning[1]. Conflicting studies could not resolve this issue and the EU "commissioned a review of existing environmental impact studies which was published in 2001 and applied life cycle analysis to used oil disposal and concluded that "priority to regeneration of waste oils over use as fuel is not justified by any clear advantage[4]." Members were quick to point out that life cycle assessment studies (e.g. Sofres)[4] reached similar conclusion and that environmental benefits come from increased collection rates of used oil rather than its final use.

البحث الأول

Table (7)

European Union Lubricating Oils Consumption and Disposition - 2006 - Thousand tons

Country	consumption	Collected	%	Burning	Process to Fuel	Rerefining	Export/ Import	Others
Austria	79	40	50	27	0	0	12	0
Belgium	142	60	42	1	25	0	15	20
Bulgaria	55	17	31	0	1	0	0	16
Cyprus	0	4		0	0	0	0	0
Czech R	111	33	30	32	0	0	1	0
Denmark	68	20	30	5	0	12	4	0
Estonia	19	5	28	5	0	0	0	0
Finland	79	23	28	23	0	0	0	0
France	765	225	29	93	7	94	5	25
Germany	1174	525	45	155	210	240	-105	0
Greece	100	36	36	0	0	36	0	0
Hungary	109	28	26	14	0	0	0	14
Ireland	38	20	53	0	0	0	0	0
Italy	542	216	40	33	1	173	0	1
Latvia	37	11	29	11	0	0	0	0
Lithwania	49	14	29	14	0	0	0	0
Luxembourg	10	5	54	0	0	0	5	0
Malta	4	1	30	0	0	0	0	0
Netherlands	252	50	20	0	0	0	50	0
Poland	351	77	22	13	0	49	15	0
Romania	130	28	21	19	6	0	0	2
Portugal	89	29	32	17	0	3	3	5
Slovenia	20	4	20	3	0	0	0	0
Slovakia	50	15	30	15	0	0	0	0
Spain	545	160	29	70	0	90	0	0
Sweden	148	45	30	37	0	0	8	0
UK	800	350	44	240	30	50	10	20
EU 2006	**5766**	**2040**	**35**	**827**	**280**	**747**	**24**	**102**

Source: 1 based on GEIR and collated by author.

The collection rates in individual EU countries in 2006 range between 20% for the Netherlands and 54% for Luxembourg. The EU average is 35%, well below the target of 50%. These collection rates refer to consumption and if they are referred to the theoretically collectable, they would be much higher (double or more than the above rates). The low collection rates reflect the difficulties of used oil management even in these well developed countries. The major countries collection rates are 40, 44 and 45% for Italy, UK and Germany respectively. There is a potential of at least another 0.9 million tons a year to be collected either for burning or re-refining in the EU. These rates have improved in later years for some countries.

Table (8)

EU Lube Oils Disposition – Million tons/y

	2006	2008
Consumption	5.8	5.7
Used Oil Collection	2.0	2.0
Burning	1.1	1.1
Re-refining	0.7	0.7
Others	0.1	0.2

Source: 2006 (1) & 2008 (61) - Both based on GEIR. Also (25)

In the United States:

The US Environmental Protection Agency (EPA) classifies waste oils, including used oils, into two categories. On-specification oils are those that do not cause much environmental concern while off-specification oils are those that do cause environmental concern due to higher limits of heavy metals, halogens, or the presence of low volatile fuels[4].

Specifically, any used oil that contains more than 5, 2, 10, 100, 4000 parts per million (ppm) of arsenic, cadmium, chromium, lead and halogens respectively is classified as off-specification[4]. The flash point must also be 38°C minimum to avoid possible explosion on ignition.

The EPA allows the burning of on-specification waste or used oils for heat recovery in specific equipment without limitation while the off-specification waste oils are allowed to be burned in smaller devices of “500,000 BTUs or less, vent to the outside and burn only oils generated on-site”[4,60].

Reviewed lube oils disposition in the US for 10 years did not show many changes with respect to volumes[1]. Therefore the 1995 numbers from a 2006 Department of Energy (DOE) study[1,3] are still representative, according to DOE, and shown in Table (9).

The disposed oil of the collected is reported to have declined from 0.426 billion gallons in 1995 to 0.348 billion gallon in 2002[1], a positive result of tightened regulations.

Table (9)		
US Lube Oils Disposition - 1995		
	Billion Gallons	**Million tons**
Consumption	2.5	8.32
Generated Used Oil	1.371	4.56
Collected Used oil	0.945	3.14
Burned for Energy	0.784	2.61
Re-refined	0.161	0.53
Disposed	0.426	1.4
Source: (1) & (3) – Based on DOE 2006 Study & author adaptation.		

It is clear that the US situation is more inclined on burning used oil which constitutes 83% of the collected oil and only 17% is left to re-refining. There is a potential of over one million tons a year for either application to avoid dumping in landfills and the environment.

However, the appreciation of crude oil prices after 2002 hence those of base oils, encouraged the expansion of the re-refining industry in North America where in 2012 re-refining capacity was just less than 800 thousand tons a year according to the consultants Kline[37]. The same source continues to say that by 2017, if all new capacities come on stream, North America's re-refining capacity is expected to reach more than 1.2 million tons a year. However, the decline of crude oil prices since June 2014 may have put this program on hold as no new plants are reported.

In the World

It is unfortunate that the statistics for other regions of the world are fragmented and very hard to find. But the world lube oil disposition is analysed in the famous Kline Report[3] of 2009 and its disposition is shown in Table (10).

The report says that 5.9 million tons could not be collected and nothing is known about its use[3]. Also of the collected used oil there is one million ton that is disposed. The total disposed used oil is therefore in the order of 6.9 million tons in 2009.

Similar to the trend in Europe and the US, the used oil for energy recovery is dominant at 12.9 million tons in contrast to 2.6 million tons re-refined. In the following Table (11), the world, US and EU numbers are used to generate an approximate, repeat approximate, idea of what is the position in the rest of the world.

Table (10)	
World Lube Oils Disposition – 2009 – Million tons	
Consumption	32.3
Generated Used Oil	22.4
Collected Used Oil	16.5
Burned for Energy Recovery	12.9
Re-refined	2.6
Disposed	6.9
Source: (3) based on Kline Report 2009 and author's adjustment for disposed used oil	

Table (11)				
Approximate Utilization and Disposal Of Used Oils – million tons/y				
	EU 2008	**US 1995**	**Others**	**World 2009**
Burning	1.1	2.61	9.19	12.9
Re-refining	0.7	0.53	1.37	2.6
Others	0.1	0	0.1	0.1
Disposed	0.9	1.4	4.6	6.9
Source: Authors adaptation based on previous Tables and disposed definition. Based on 32.3 million ton/y demand.				

Here again the burning for energy is much more prominent than re-refining and that greater effort must be made to reduce disposal into the environment the world over. It is to be noted that some sources[4] believe world lube oils demand is now over 40 million tons a year and therefore the disposed oil must be much higher by now. Even if the re-refining capacity of the US is adjusted as discussed earlier, the picture does not change much and burning used oil remains prominent.

However, there are secondary uses for used lube oils that are too fragmented to account for but may not be environmentally sound. For example, in Russia[52], out of 1.1 million tons a year of generated used oil only 0.055 is re-refined, 0.11 is burned for energy and 0.935 is disposed of into the environment. But the same source suggests that "25 percent of Russia's used lubes get filtered and then reapplied as insulation or electric transformer oils or as coolants."

No matter what, burning of used oil for energy recovery is to be treated seriously and must be given consideration in any future study for re-refining.

Chapter 5 - The Economics of Re-refining

For a long time, the prevailing view is that re-refining of used oils is uneconomic[1] due to the multitude of factors that work against the industry such as the relatively high investment required as compared to burning applications, the costly collection system that has to be financed by the industry, consumers or the government, the lower prices in the market for re-refined base oils as compared to virgin base oil prices and the cost of getting rid of environmentally stressful waste in some processes.

The research studies are divided on the economic viability of re-refining but a general rule cannot be made and the re-refining projects remain country and site specific that takes all the parameters into consideration. However, this does not rule out the possibility of economic attractiveness in certain situations if the choice of a suitable process, plant location and plant size are made correctly.

But first, let us see the factors that influence decision making on a re-refining project.

The Impact of the Price of Oil:

The price of crude oil and its products has and will always be a factor in consumption of petroleum products and lubricants are not excluded. Only the degree of impact may differ from one product to another but the general principle and direction is the same for all.

Crude oil prices directly affect base oil prices which are the largest cost component of finished lubricants. Therefore, when oil prices are high, consumers tend to use less fuel, and therefore less lubricant, due to conservation and the need to balance the disposal of income among different requirements. At the same time high oil prices may slow down the economy and therefore fuels and lubricants used in transportation and industry are reduced accordingly.

This revelation is very well demonstrated in the OECD countries where reliable statistics are available. Fig (19) shows the evolution of lubricants consumption against the benchmark Brent crude oil prices as developed from the International Energy Agency (IEA) statistics[77] for lubricants.
When crude oil prices were low between 1984 and 2002, lubricants consumption in the OECD region was generally rising though with some variations up and

down due to other reasons. But when crude oil prices started rising as of 2002 lubricants consumption reacted sharply by falling. The price effect is clear though the fall in consumption of lubricants may have also been affected by the improved quality available to consumers. But the quality effect does not act as fast as the price effect.

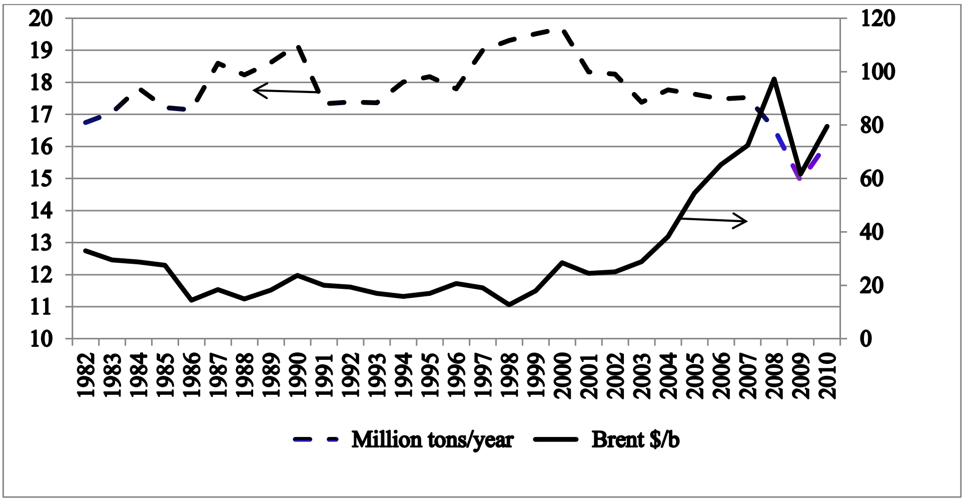

Fig (19) - OECD Lubricants Consumption Vs Brent Crude Price - Source 77

The high price of crude oil while impacting lubricants consumption negatively, it encourages re-refining because it makes base oil derived from re-refining less expensive than virgin base stock. This was clearly demonstrated by the expansion of the re-refining industry in North America during the high crude oil prices period before 2014.

At the same time, crude oil prices impact the prices of virgin and re-refined base stocks. Fig (20) developed from data by ICIS the lubricants consultants and price reporters, as obtained privately from a re-refiner in Europe. When the price of crude oil was relatively stable during January 2013 to June 2014, re-refined base oil prices in the domestic and export markets were reasonably high and also relatively stable. But they started falling after June 2014 following the fall of crude oil prices. On average, there is about $16 a barrel (about $115 a ton) difference between domestic and export prices of re-refined base oils in Europe.

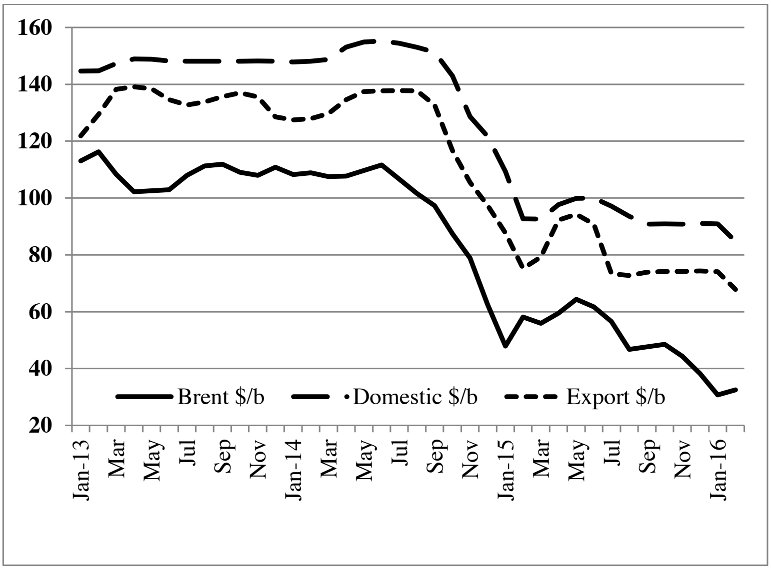

Fig (20) - Dated Brent Vs. Re-refined Base Oil - Source ICIS*

It is concluded here, that high crude oil prices may contribute to the decline in lubricants demand especially when coupled with the availability of better grades of lubricants. At the same time low crude oil prices reduces base oil prices, virgin or re-refined and makes the re-refining projects less attractive if any.

Lubricants Supply & Demand:

The country, regional and world demand for lubricants is dependent on many factors among which are economic growth, population, environmental regulations, oil prices and the degree of development with respect to industrialization and urbanization. Another important factor came along as a result of technological advances in processing, additives technology and the trend towards increasing drain periods.

It is not the intention here to discuss in details the evolution of lubricants demand but to see how the forecasts might affect the re-refining industry. In any case there are more specialized consultants on the subjects and in Table (12) a construction of the evolution and forecast of lubricants demand from 2002 to 2019 is indicated.

This is collated from the various forecasts of the Freedonia Inc.[72, 73, 74], the US consultants on lubricants.

Table (12)									
Lubricants Demand 2002 - 2019 - Million tons a year									
	2002	**2007**	**2009**	**2012**	**2014**	**2017**	**2019**	**Growth % / y**	
Region								**2002-2019**	**2014-2019**
Asia-Pacific	9.9	13.3	13.5	15.7	16.5	19.0	19.5	4.000	3.400
North America	10.7	10.0	8.8	10.3	9.9	9.6	10.1	-0.003	0.004
Western Europe	5.4	5.3	5.0	5.1	4.9	4.6	4.9	-0.005	0.000
Eastern Europe	2.9	3.4	3.5	3.6	3.8	4.0	4.1	2.000	1.500
Africa/Middle East	2.9	3.4	3.3	3.6	3.8	4.1	4.3	2.300	2.500
Central & South America	1.8	2.1	2.0	2.3	2.3	2.7	2.6	2.200	2.500
Total World	**33.7**	**37.5**	**36.1**	**40.5**	**41.1**	**43.9**	**45.4**	**1.700**	**2.000**
Source: 72, 73 & 74 Freedonia Group Inc. Slight modifications and growth rates by author.									

It is clear that the growth in the world lubricants demand is modest at 1.7% a year for the whole period and 2% a year for the forecast period from 2014. The growth in North America and Western Europe is very slight if any as these regions are mature, consuming higher grades of lubricants[73,74] and perhaps exercising much better conservation and drain periods where consumers also seek to reduce handling and disposal costs[72].

The highest growth rates are in Asia - pacific of 4% a year for the whole period and 3.4% a year for the forecast period with expanding numbers of motor vehicles and continued industrialization[72]. The growth in the remaining regions is above the world average and below that of Asia – Pacific. These developing regions of Central and South America, Africa and the Middle East are expected to exhibit gains due to economic growth, greater manufacturing output and increased motor vehicle ownerships[72]. Fig (21) shows the trend clearly.

However, the above forecasts are believed to be optimistic by others in the business. Kline & Co believe that lubricants demand to be 39 and 42 million tons a year in 2014 and 2019 respectively[72]. This is about 2 to 2.5 million tons a year difference.

Reports by Fuchs Petrolub[89] in Feb 2016 gives demand for lubricants – excluding marine oils - at 36.0 and 35.6 million tons a day in 2007 and 2014, which are much lower than Freedonia's especially for 2014 even if marine oils are included. In another report[64], Fuchs Petrolub forecast 2017 demand at 41.3 million tons a year, again much lower than Freedonia's.

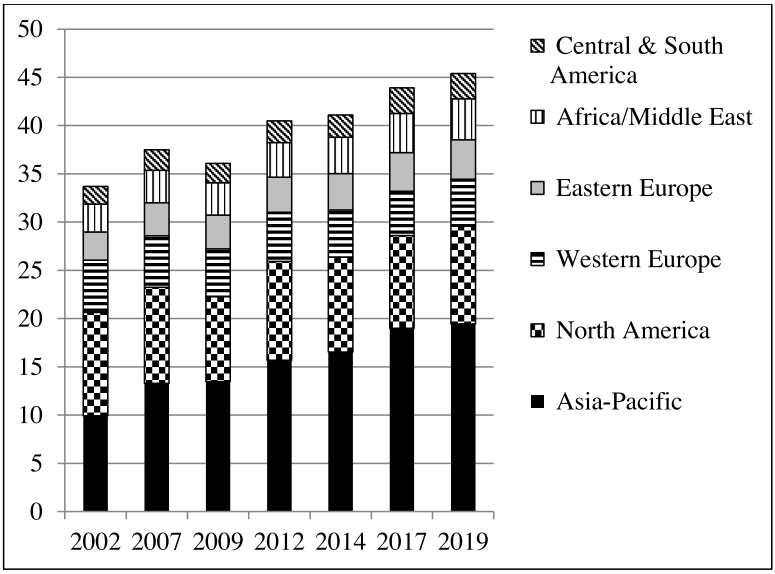

Fig (21) - Sources: 72, 73 & 74

In 2007[75], the Freedonia's forecasts were higher but the economic and financial crises of 2008 reduced expectations as evident by the declining demand numbers of 2009. Consumption then was expected to reach 46.6 million tons a year in 2015[75], a number that is unlikely to be reached in the period under discussion.

It is to be understood that additives are capturing increasing share of the lubricants market as their rate of growth surpasses that of base oils[71]. The new performance standards and the extended oil drain periods require better lubricant's packages and therefore higher groups and more additives.

According to Kline & Co.[71], the additives market in 2014 was 4.2 million tons of 39.4 million tons of finished oils, or 11%. The same report suggests that additives demand is expected to grow at 1.6% while base oils demand growth may only be at 1.2%. This will exacerbate a base oil industry likely to suffer from excess capacity.

Base oils capacity surplus was 6.5 million tons a year in 2000[64] but the surplus disappeared in later years, due to capacity rationalization, only to start appearing again recently.

Table (13) shows global base oil refining capacity[103] in various regions of the world, which is much higher than the demand projections provided above. In a January 2016 article about ICIS lube conference in Dubai[42], it was suggested that base oil facilities were operating at 65% of capacity in 2015 and that the surplus capacity stood at 19 million tons a year. The surplus is forecast to grow to about 22 million tons a year by 2020. The new capacity additions in groups II and III are about 7.5 million tons a year by adding up the new capacities between 2013 and 2016 only[37]. Some rationalization is expected especially in phasing out group I capacities but the fact remains that surplus capacity is going to weigh on the market and this does not bode well for the re-refining industry.

Table (13)

Global Base Oil Refining Capacity 2014 - 1000 barrels/day*

	Group I	Group II	Group III	Naphthenic	TOTAL	Additions 2014 - 2015**
North America	75.0	157.8	2.0	48.1	282.9	2.4
Western Europe	113.6	5.5	8.6	10.4	138.1	14.0
Central & Eastern Europe	86.0	1.4	2.6	0.0	90.0	7.0
S.Asia/Pacific/Australia	63.7	46.8	16.0	0.0	126.5	5.2
Middle East & Africa	68.9	6.0	30.2	0.0	97.1	11.0
China	39.5	68.6	7.0	23.7	138.8	34.3
Japan & Korea	32.5	60.3	50.9	3.6	147.3	13.0
TOTAL	479.1	346.3	117.3	85.8	1020.6	86.9
TOTAL Million tons a year	**24.4**	**17.7**	**6.0**	**4.4**	**52.1**	**4.4**

* Includes only solvent extraction and hydro-finished re-refining capacity

** This list is not exhaustive and there could be more

Source: (103) Lubes'N'Greases 2014 Guide to Global Base Oil Refineries

The Impact of Process Selection:

Process selection by itself depends on many factors and not just economic. Is the project in a country with a good and well controlled collection system? Are the laws and regulations supportive of a re-refining project? Apart from the used oil feed, are other raw materials available or not? Is the project inside or close to a petroleum refinery where exchange of materials, reduction of safety and security cost is possible? This is particularly important with respect to hydrogen supply if the selected process is of the hydro-treating type. How big is the re-refining project under consideration? To start with it should be as big as the collection system can support in a sustainable manner. At the same time some processes are suitable for large plants and others for small plants. The modern plants which produce good quality hydro-finished oils are much more economical than small plants of the same technology.

All these questions have to be answered up front before alternative processes can be pursued.

Different processing schemes were compared in a report that was presented to the European Union in 2001 by the consultants TN Sofres[1] after surveying the existing re-refining plants at the time. The results of this important report found:

- New plant economics were not favourable without an initial subsidy of 10 to 100 Euros per ton of feed.
- Re-refining plants cannot compete with the fuel combustion option due to its low investment and sometimes tax advantages over lubricants. Thermal cracking to make fuels were economic and needed no subsidies.
- The collection and delivery cost was in the range of 25 to 100 Euros per ton of feed.
- Consumers are apprehensive about re-refined lubricants which makes re-refined base oil prices 10 to 25% less than those of virgin base oils.

The data presented in the study was used to generate parameters for 100 thousand tons a year re-refinery using different processing scheme as shown in Table (14).

The so called waste oil fee or used oil fee is the difference between cost and revenue. When this parameter is negative it means the plant does not need subsidy contrary to when the value is positive. The breakeven point is when the used oil fee is zero. If all conditions remain the same and the re-refining plant size reduced to 35 thousand tons a year all the processing schemes will need subsidies to be viable as shown in Table (15).

Table (14)							
Derived Used Oil Fee Euro/ton for Various Processes **100 thousand tons/y Plant**							
	Acid Clay	**TFE+ Clay**	**TFE+ Hydro**	**TFE+ Solvent**	**TDA+ Clay**	**TDA+ Hydro**	**PDA+ Hydro**
Capacity 1000 ton/year	100	100	100	100	100	100	100
Capital cost million Euro	34	37	57	49	45	69	61
Operating Cost Euro/ton	152	165	214	202	280	304	248
Revenue Euro/ton	177	203	251	226	211	252	224
Used Oil Fee Euro/ton	**-25**	**-37**	**-37**	**-24**	**69**	**52**	**24**
TFE = Thin Film Evaporator							
TDA = Thermal Deasphalting							
PDA = propane Deaspahlting							
Source: Adaptation from (1). Simple averages of cited plants in Europe. Based on GEIR, CONCAWE & TN Sofres. Plants capacity has been normalized to 100 to make the comparison more representative.							

Table (15)							
Derived Used Oil Fee Euro/ton for Various Processes **35 thousand tons/y Plant**							
	Acid Clay	**TFE+ Clay**	**TFE+ Hydro**	**TFE+ Solvent**	**TDA+ Clay**	**TDA+ Hydro**	**PDA+ Hydro**
Capacity 1000 ton/year	35	35	35	35	35	35	35
Capital cost million Euro	17	19	29	25	23	35	31
Operating Cost Euro/ton	244	265	343	323	449	399	399
Revenue Euro/ton	177	203	251	226	211	252	224
Used Oil Fee Euro/ton	**67**	**63**	**92**	**98**	**238**	**52**	**175**
Used Oil Fee Comparison of Two Capacities							
Capacity 100	**-25**	**-37**	**-37**	**-24**	**69**	**52**	**24**
Capacity 35	**67**	**63**	**92**	**98**	**238**	**147**	**175**
Source: Adaptation from (1). Simple averages of cited plants in Europe. Based on GEIR, CONCAWE & TN Sofres. Plants capacity has been normalized to 35 to make the comparison more representative. The used oil fee is compared for two cases.							

Comparison of the two cases reveals that all processes need subsidy when the plant is of small capacity and that subsidies per ton of used oil feed increase when the plant is smaller as displayed in Fig (22).

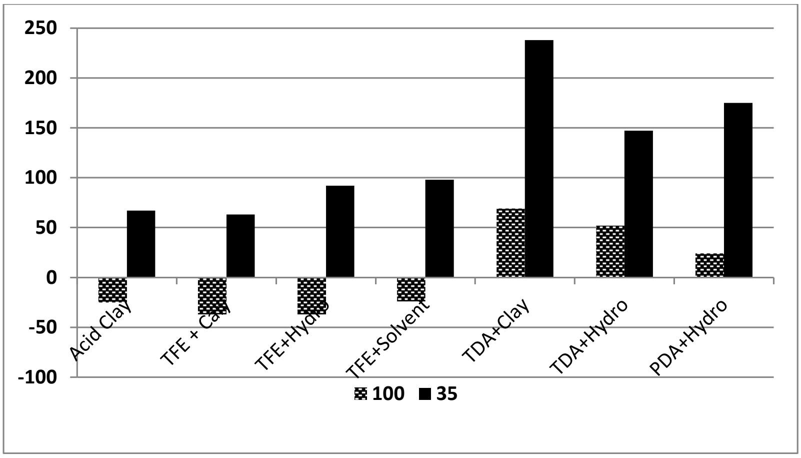

Fig (22) Used Oil Fee (Subsidy) for Different Capacity - Euro/ton

In the original analysis, the product prices used to calculate revenue per ton are kept constant and the same is done here in the reduced model. Using today's prices of products makes the situation even worse.

The only criticism of this analysis that may come to mind is that the report is old and probably needs updating. However, this report is often cited in new studies which means at least in direction and conclusions the findings are still valid.

Fees and Subsidies:

Conservation of resources and environmental protection with respect of re-refining used oil has been discussed at length earlier. Suffice it to say here that used oil is a resource that should not be wasted by dumping in landfills where its impact on the environment and human health is quite risky. At the same time energy requirement in re-refining is much less than that needed for virgin base oil production and here also there is environmental and human health gain.

However, resource conservation and environmental and health protection are externalities as far as the consumer is concerned who cares only about the quality and cost of the lubricant he uses for his applications.

In economics, according to Wikipedia, an externality "is the cost or benefit that affects a party who did not choose to incur that cost or benefit." But society as a whole does bear the cost of conservation or the lack of it by using more or less raw materials, in this case crude oil, and environmental protection cost must be incurred as well to avoid the consequences of extra health and clean up services.

These externalities set the case for the so called subsidies that governments tender to collectors of used oil and re-refining companies in order to save resources and protect the environment. In fact some analysts and leaders in the industry[104] do not use the term "subsidy" but "compensation for the disposal of waste oil collected." Moreover, used oil is a pollutant and according to the "polluters pay principle" the consumer must be made to pay for abating the risk of his used oil.

All the above works in favour of the re-refining industry if the generated revenues from consumers and governments are managed properly to promote and serve the re-refining industry.

A questionable economics[1] shall not be made responsible to forego sustainability of resources and environmental and health protection. If not, collectors and re-refiners may cut corners to reduce cost at the expense of quality and controlled services.

These considerations are also recognized by the International Environmental Technology Centre of the United Nations Environmental Program (IETC/UNEP) which was developed to test the Sustainability Assessment of Technologies (SAT) in the selection of re-refining process[1,4]. In licensing new projects or even assessing existing ones, governments are advised to consult the SAT especially that used oil recovery methods may differ from country to country and that there is no single model of implementation[3].

Examples of Economic Studies:

It is useful to cite here some examples of economic studies or indicators for projects of re-refining used oils in some countries.

- A feasibility study for 80 thousand tons a year re-refining plant in Turkey called for the use of solvent extraction technology. The study recognized cases where burning used oils is advantageous in terms of total environmental impact[3], energy efficiency and conservation of resources. It is in any case the preferred method in Turkey and the study wanted a re-refining plant as a complimentary way in the Istanbul region. There are 15 plats in Turkey based on distillation and clay treatment but the product is destined for fuel[3].

The capital cost of the plant was estimated at $53 million (2012), operating cost at $23 million a year and revenue at $61 million a year making the profit before tax at $38 million a year. As good as it is the project did not attract investors yet.

- In the United Kingdom, a study[1] was conducted in 2001 for the Department of Environment, Food and Rural Affairs (DEFRA) to compare alternatives for disposal of used oil. They compared two cases for a 35 thousand tons a year re-refining plant, the first with a clay treatment costing an average of 9.225 million pounds and the other with hydrogen treatment costing an average of 16.8 million pounds. For a targeted 15 to 25% rate of return to encourage investors they found that the two schemes are money losers or they would need 4 and 5.5 pence per litre in subsidies to break even.

  Even when an existing site was considered the economics improved but remained sceptical. In a scenario when the rate of return was reduced to 10%, the two schemes improved but remained border line and in any case 10% rate of return is unlikely to encourage any investor.

  Perhaps this is why until today no new re-refining plant is built in the UK where the country burns its used oil and import additional quantities for the same purpose.

- In 1995 a study in Saudi Arabia was conducted in King Fahad University and compared tow processes, Meineken and CEP-Mohawk for 50 thousand tons a year re-refining plant[6, 1]. The capital cost was estimated at $28.75 and $17.71 million for the two processes respectively and the rate of return came to be 11.24 and 45.36% respectively. However, this study is old and may need major revision.

Table (16)					
Capital Cost for Various Projects Adjusted to 2015					
	Capacity Kton/y	**Year**	**Capital $ million**	**capital Adjusted to 2015**	**K$/ton/y**
USA	250	1991	120.0	217.0	0.9
USA	17	1994	7.0	11.8	0.7
USA	8	1994	3.5	5.9	0.7
USA	36	1994	15.0	25.2	0.7
Saudi Arabia	50	1995	28.8	47.1	0.9
Saudi Arabia	50	1995	17.7	29.0	0.6
UK	35	2001	13.8	19.6	0.6
UK	35	2001	25.2	35.6	1.0
Bahrain	36	2011	9.0	10.2	0.3
Turkey	80	2012	53.0	57.1	0.7
France	120	2013	72.5	76.2	0.6
Uzbekstan	45	2014	15.0	15.4	0.3
Australia	88	2014	65.0	66.6	0.8
Belarus	15	2015	20.0	20.0	1.3
Source: various					

- A collection of capital cost data over the years and different countries does not reveal a definitive trend because the processes are not always known and the circumstances of the projects may be different. However, Table (16) shows the data with the capital cost adjusted to 2015 by using an inflation factor of 2.5% a year.

Italy: Example of Success

The experience of Italy in re-refining used oils is very relevant as an example of a successful effort and cooperation between the government and the lube manufacturing and re-refining companies.

The operation is helped by laws and regulations that evolved over the years in the European Union or in Italy itself driven by environmental concerns and resource conservation[104].

The latest development in the legislative frame work is the follow up on the EU Waste Framework Directive where re-refining used oil is at a higher priority than burning for energy recovery though not compulsory. The Directive seeks the reduction of waste production, preparing for re-use, re-refining or energy recovery or disposal[104].

<u>Collection and Disposal:</u>

To support the industry, the Italian government established by law in 1984 "The Statutory Consortium of Used Oil (COOU)", a non-profit making organization made up of lubricants manufacturers, collectors and re-refiners to foresee the collection of used oil, its testing and allocation to re-refiners, according to their capacity or requirement[104], and other users with priority of 90%[1,4,104] to re-refiners. COOU is also in charge of mapping out collection centres and regulating their equipment and also those of the collection trucks in addition to licensing collectors[104].

COOU is financed by per ton contributions of its members in accordance with their sales in the market whether virgin and re-refined. This has been introduced by COOU to subsidize collection and re-refining with the agreement of the lubricants producers. The contribution value varies year by year according to some parameters including the price of the base oils.

In the early 2000s, contributions to COOU were 325 Euro per ton where 94 and 40 Euro is paid as subsidy to re-refiners and fuel plants respectively[4]. But the contribution has been falling over time to 155 Euro per ton in 2010[104]. In 2002, collectors were paid 166.5 Euro per ton collected in addition to subsidies paid to testing agencies[1]. The generators of used oils are obliged to give their collected used oil without charge.

Additional advantage to re-refined products comes from a 50% reduction of the excise duty applied to virgin lubricant, if the base oil is produced in Italy. The European Union has requested Italy to ease this law to include imported re-refined base stocks[4]. This tax relief is later abolished and replaced by a unified duty on all lubricant base oils whether virgin or re-refined.

The success of COOU is measured by the increase in collected used oil where the rate has increased from 42.6 to 48.7% of lubricants consumption in 2008 and 2009 respectively or 95% of the collectable used oils[4]. COOU website[106] says that 5.378 million tons were collected between 1984 and now and the regenerated used oil was 4.432 million tons or 82.4%. The base oils produced as a result were 2.49 million tons in addition to other products. In 2014, COOU collected 167 thousand tons where 91% were regenerated to produce 111 thousand tons of base oils making 25% of Italy's base oil requirements[106]. More than 56 thousand tons of asphalt and gasoil were also produced. The maximum collection of used oil was in 2006 at 216 thousand tons[106].

Collectors (72 companies 6 of them national and the others regional) take the used oil from the generators to their small storage depots and then transfer it again to the larger COOU depots (5 depots) and in both steps relevant testing is conducted.

Lubricating oils consumption in Italy has been declining from 650 to 399 thousand tons a year between 2000 and 2009 respectively[106] and further down to 383 thousand tons in 2014 due to a combination of economic conditions and due to improvement of lubricants quality and the longer distances travelled between oil changes.

Re-refining of Used Oils:

Re-refining used oil in Italy goes back to the Second World War when used oil was primitively treated for reuse due to the scarcity of resources at that time. However the modern re-refining industry was established in 1963 when Viscolube was founded as a result of environmental awareness and the necessity to conserve resources.

Presently there are five active lubricant re-refining plants, one for re-refining transformer oil only[1], with a combined nameplate capacity of about 260 thousand tons a year[4] though GEIR reports a total nameplate capacity of 303 thousand tons a year as shown[1] in Table (17). Either way there is excess capacity in Italy.

Due to the economic and financial crisis of 2008, the availability of used oils[15] has declined as a result of reduced consumption of lubricants as stated earlier. It is to be noted that 80% of used oil collected in Italy is re-refined by Viscolube where in later years the company treated 130 thousand tons a year of used oil to produce about 90 thousand tons a year of base oils[104]. The surplus in the capacity of re-refining plants is very clear.

The success of the re-refining industry in Italy spilled over to many countries in the world. Viscolube's Revivoil process technology is now licenced in Poland (80 thousand tons a year), Indonesia (40) and three plants in Spain at 20 thousand tons a year each with other under design or planning for Indonesia and Pakistan[15]. However, Viscolube effort to expand into China with 40 thousand tons a year plant is still under consideration by the parties. Plants of 40 and 80 thousand tons a year in Venezuela and USA respectively have also been licensed.

Table (17)		
Re-refining Plants in Italy		
Plant	**Authorised Capacity Ktons/y**	**Notes**
Viscolube (Lodi)	130	This plant evolved from propane solvent extraction to thermal de-asphalting and high pressure hydro-treating and the Revivoil process to produce Group II base oils
Viscolube (Frosinone)	84	Produces Group I base oils. Uses double propane deasphalting followed by low pressure hydro-treating.
Ramoil (Naples)	35	Produces mainly fuel and a limited quantity of Group I base oils. Uses thin film evaporator and acid clay.
Siro (Milan)	9	Re-refining of transformer oil only with acid clay process.
TOTAL	**258**	
Source: Adapted from GEIR Statistics 2010 as reported in (1) and elaborated by author. 103 and 104. Also private information.		

Important Economic Model:

In the book "Refining Used Lubricating Oils"[1] the authors James G. Speight and Douglas I. Exall used an extensive model to study the economics of re-refining projects and made the model available on the Internet for the book readers to use. The model for a small plant is with distillation and clay treatment while the model for a large plant is for hydro-treating. Both models can be downloaded using the link:

https://www.crcpress.com/Refining-Used-Lubricating-Oils/Speight-Exall/9781466551497

It is generally accepted that for smaller plants of up to 20 thousand tons a year, the simpler type of plant such as distillation/clay treatment may provide better economic returns, and larger throughputs may justify the use of a hydrogenation step.

The two models are summarised in the following Table (18).

Table (18)								
Base Case Major Parameters of Two Re-refining Plants								
Plant	**Process**	**Capacity Mil L/y**	**Capital Cost $ Million**	**Used Oil $/L**	**Base Oil $/ton**	**Oil Price $/b**	**IRR %***	**NPV** K$**
Small	Clay	20	6	0.27	700	98	27	3172
Large	Hydrogen	50	45	0.27	610	85	32	117377
* Internal rate of returns on Investment ** Net Positive Value of cash flow (15% discounted) L= liter								
Source: 1 & https://www.crcpress.com/Refining-Used-Lubricating-Oils/Speight-Exall/9781466551497								

However, the model as it is needs some adjustments to separate the impact of base oil prices from those of crude oil prices but it remains a useful tool for initial analysis and could be adjusted further to suit the situation at hand. Many scenarios can be run for the same process or for different processes to make meaningful comparison for decision making.

There are major parameters that affect the economics of re-refining projects but some have bigger impact than others, which necessitate a sensitivity analysis to set the priorities of caring for these parameters.

Distillation/Clay Treatment Plant Economics:

The discount rate that makes the net positive value equals to zero is the internal rate of return that makes the project over the considered period breaks even. Obviously the investors want a higher rate of return and a higher number for the net positive value. In fact some investors not only seek a higher internal rate of return but also target a value for the net cash flow.

In the case of the small plant of distillation and clay treatment the economics is most sensitive to the price of base stock. Only a 6% decline of base oil prices sends the cash flow to zero while 11% increase of used oil cost is the second parameter with respect to sensitivity. Other parameters (capacity and capital cost) are not as sensitive. The results are shown in Table (19). In the same table current conditions are used to generate economics for 20 and 30 thousand cubic meter plants. Base stock price is current (April 2016) and capital cost adjusted by 10% for the Middle East location. Used oil cost is $23 a barrel as discussed in the next chapter.

The internal rate of return is 19% and net positive value is $1.103 million. Used oil cost can increase to $24.5 a barrel before NPV falls to zero. For a larger plant, the IRR is 23% and NPV $3.853 million and an increase of used oil cost to $27 a barrel would make NPV equals zero. In such a case subsidies would be in order to encourage investment.

Table (19)

Small Plant (Clay Treatment) Sensitivity Analysis - 10 years

	Base Stock $/ton	Capacity ML/Y	Capital Cost M$	Used Oil $/L	IRR %	NPV K$	% Change
Base Case	700	20	6	0.27	27	3172	
Base Stock Change	656				15	0	-6
Capacity Change		15			15	0	-23
Capital Cost Change			8		15	0	38
Used Oil Change				0.3	15	0	11
Current Example 1	500	20	6.6	0.15	19	1103	
Current Example 1 S	500	20	6.6	0.16	15	0	
Current Example 2	500	30	8.6	0.15	23	3853	
Current Example 2 S	500	30	8.6	0.17	15	0	

M= million L= litre IRR= internal rate of return NPV= net positive value
Used oil cost $23.85/b including transportation.
Source: Author Development

Distillation/Hydrogenation Plant Economics:

The parameters in this case are more numerous as can be seen in Table (20). In a similar manner as said above, the economics are sensitive to base oil price, capacity, used oil cost and capital investment in that order. The plant is not sensitive to hydrogen cost due to the relatively small quantity required.

Applying the model for a 50 thousand cubic meters a year plant and to current values, the IRR is found to be 12% but the NPV is negative at minus $4.922 million. For the plant to break even the cost of used oil has to fall to close to $20.7 a barrel and to make reasonable profit used oil cost has to fall further or subsidies by government would be necessary to encourage investment.

For a smaller plant of 30 thousand cubic meters a year, the situation is much worse as the IRR is 2% and NPV is negative at $16.037 million. To break even, used oil cost has to fall to $7.95 a barrel which makes the case for subsidy even more apparent.

Table (20)

Large Plant (Hydro-treating) Sensitivity Analysis - 10 years

	Base Stock $/ton	Capacity ML/Y	Capital Cost M$	Used Oil $/L	Oil Price $/b	Hydrogen $/CM	IRR %	NPV K$	% Change
Base Case	700	50	45	0.27	98	0.5	20	8602	
Base Stock Change	648						15	0	-7
Capacity Change		44.7					15	0	-11
Capital Cost Change			51.5				15	0	14
Used Oil Change				0.3			15	0	11
Oil Price Change					76		15	0	-22
Hydrogen Change						63.4	15	0	12584
Current Example 1	600	50	50	0.15	40	0.5	12	-4922	
Current Example 1 S	600	50	50	0.13	40	0.5	15	0	
Current Example 2	600	30	36	0.15	40	0.5	2	-16037	
Current Example 2 S	600	30	36	0.05	40	0.5	15	0	

M= million L= litre b= barrel CM= cubic metre IRR= internal rate of returns
NPV= net positive value k= 1000 Used oil cost = $23.85/b including transportation.

Source: Author Development

In this report, the model in its original format, with the exception of the small modifications mentioned earlier, has been used in this analysis. However future users may improve the model by segregating and reporting expenditures prior to the start of production instead of including all these as "capital" in year 1. This is likely to give better and more encouraging economic results. At the same time the analysis may be extended to 15 or 20 years and this also will give better economic returns.

البحث الأول

Notes for Economic Consideration:

1- The problem of stigma and hesitation of consumers will not go away easily. A recycled product is in their mind inferior and thus it suffers a price reduction in the market. In well-developed markets, this can be avoided by obtaining relevant certification from authorised bodies such as API. But this is a high cost for the re-refiner. While such a certificate may cost half a million dollar[1], the six months test period makes the re-refiner discount the price of his product or stockpile it at additional cost that may reach $2 million[1].

2- In any country or region, economics stress the need to size the re-refining plant to be flexibly compatible with the size of the collection system to avoid over or under capacity. Over capacity reduces the efficiency of investment while under capacity may leave feedstock to competitors in the industrial fuel sector. The strong buying power of heavy industries gives them advantage against re-refiners.

3- In the majority of cases, a re-refining project needs the support of governments through regulations and subsidy. The subsidy can either be direct or through taxation on the consumed lubricants and the tax returns goes to collectors and re-refiners. Governments should also give priority to re-refined lubricants whenever their grade is approved.

4- The re-refining industry must contend itself with the availability of surplus base stock capacity[78] in the world and therefore, its expansion should be directed to solve environmental problems and the needs of individual countries or regional groups if cross border trade in used oil is allowed.

Chapter 6 - The Lubricating Oil Industry in the Arab Countries

Information about the lubricating oil industry in the Arab World is hard to come by. It is often fragmented and not from direct and reliable sources. There are many reasons for this but the most important is that there is no professional body or association that can collect and report development on a timely basis as is the case in Europe for instance. Even regional organizations such as the Organization of the Arab Petroleum Exporting Countries (OAPEC) do not have information regarding lubricants like they have for other petroleum sectors.

The following survey is the result of Internet research augmented by some information obtained privately by contacting people in the industry.

The Virgin Base Oils Facilities:

Table (21) gives a brief summary of the base oil production facilities in the Arab countries. Facilities under commissioning or very close to completion have been included.

The base oil refining industry may have started in Egypt in the late 1930s or early 1940s followed by Iraq in 1957. But the expansion of the last few years is very significant not only because it added or will add capacity but because of the quality shift from Group I base oils to Groups II and III. This, by the passage of time, will improve the quality of the finished lubricants and it is necessary to make consumers aware of the new upgraded quality by education and by pricing policy aimed at avoiding early oil change and thereby reducing the used oil quantity and hazard at source. This is especially important because the region is a low oil drain interval which is around 2000 to 3000 kilometers only[45] though this behavior is slowly changing as a result of following car manufacturer’s instructions.

The virgin base oil producing Arab countries are destined to have a production capacity of 3.128 million tons a year by the end of 2016. If Baiji plants in Iraq are still not operative, capacity will be 2.878 million tons a year. But the more important aspect is that the greater portion of this capacity is for the higher performance groups II and III. This should reflect on the behavior of consumers with respect to extending the drain period.

Table (21)		
Base Oils Production Capacities in the Arab Countries – 1000 ton/year		
Country/ Plants	**Capacity**	**Notes**
ALGERIA	**183**	
Arzew[98]	183	Two production lines. Consumption grew from 148 to 156 .thousand tons a year between 2007 and 2014[89]. Private sector active in formulation and blending.
BAHRAIN	**400**	
Sitra[58]	400	Joint Venture between Noga, Bapco and Neste oil. Very High Viscosity Index (VHVI) Group III base oils from hydro-cracking and ISO dewaxing Technology. Consumption in 2015 was 18 thousand tons a year[55].
EGYPT[98]	**291**	
Alexandria	115	Consumption grew from 370 to 390 thousand tons a year between 2007 and 2014[89].
El Mex	72	
Ameriya	104	
IRAQ[62]	**471**	
Daura	25+36+60	Lube Producer since 1957. First line in Baiji damaged extensively in 1991 war. Second line unknown condition since June 2014. Consumption grew from 185 to 195 thousand tons a year between 2007 and 2014[89]. Consumption 2015 is 216 thousand tons[55].
Baiji	125+125	
Basrah	100	
MOROCCO[98]	**125**	
Mohammadiya	125	Consumption grew from 74 to 117 thousand tons a year between 2007 and 2014[89].
SAUDI ARABIA[57,98]	**1058**	
Jeddah	276	Jeddah 1978 and Yanbu 1997. Yanbu 2 is about to start operations producing Group II and III base oils[57]. Consumption grew from 296 to 390 thousand tons a year between 2007 and 2014[89]. Consumption in 2015 is said to be 342 thousand ton a year[55].
Yanbu	282	
Yanbu 2	500	
UNITED ARAB EMIRATES[99]	**600**	
Ruwais	600	Expected to start operations by end of 2016. Group III will be 500 thousand tons a year and Group II will be 100 thousand tons a year. Consumption grew from 99 to 104 thousand tons a year between 2007 and 2014[89]. 2015 consumption 108 thousand tons a year[55].
TOTAL	**3128**	**About two thirds Groups II and III.**
Sources: As indicated. Group I quality unless otherwise stated.		

Consumption of lubricants:

The countries with the production of lubricating oils as shown above are at the same time the major consumers of lubricants in the Arab world. Data is difficult to obtain for some other countries. However, in Table (22) the UN statistics is used to fill some of the gaps in consumption numbers. The available numbers are for 2011 and they have been adjusted to 2014 by a growth rate of 2% a year to be compatible with the consumption numbers that we have for the producers' consumption cited above. This is an approximation which should be used with care.

Table (22)

Lubricants Consumption in the Arab Countries Ktons/Y

	2011*	2014**
Algeria		87
Bahrain		17
Egypt		390
Iraq		195
Jordan	16	17
Jibouti	7	8
Kuwait		
Libya	31	33
Lebanon		
Mauritania	7	7
Morocco		117
Oman	69	73
Palestine	5	5
Qatar		
Saudi Arabia		390
Somalia		
Sudan	18	19
Syria	54	57
Tunisia	35	37
UAE		104
Yemen		
TOTAL	**242**	**1557**

Source: * From UN Statistics ** From previous table and from adjustment of UN Statistics numbers. Blanks are for countries with no available data.

The probable consumption in the Arab countries could be about 1.7 million tons a year, which by the end of 2016 is almost half of the production capacity. This will open opportunities of trade among Arab countries in addition to exporting to international markets[45] especially for the high quality products such as Group III[42]. The higher quality of the new plants in Bahrain, Saudi Arabia and the UAE is also likely to improve consumer's behavior towards extending drain periods if a pricing policy and public awareness campaign is on the cards.

Re-refined Oil Facilities:

This section is much more difficult to fill in comparison to the production capacity section. The information is so fragmented and statements by the re-refiners, if any, are often half-truths and lacking details. Contacts with some re-refiners yielded no answers by telephone or e mail. Papers presented in some conferences were not made available publicly.

However, there are reports suggesting that re-refined used oil is gaining ground in the Middle East though it still suffers from image and quality issues[68]. There are operators who strictly do filtration to remove insolubles and export the products to less demanding markets. Uncontrolled burning is also reported which may produce hazardous emissions in the hot Middle East climate[68]. The author was privately told that in an Arab country, used oil is the preferred fuel for bakeries and is a cause for the higher rate of cancer in that country. In such uncontrolled burning the contaminant metals simply settle on the bread.

As said earlier there is a lack of accurate information. Some sources[68] report the existence of five plants in Saudi Arabia having a total capacity of 100 thousand tons a year. This is much lower than other reported capacities. The same source reported UAE re-refining capacity at 200 to 250 thousand tons a year[68], which is much higher than the domestically generated used oil.

Table (23) is a construct of what the industry is to the best available information. The total re-refining capacity is probably over 400 thousand tons a year. Again this number should be used carefully because it is not really well documented and some old capacities may not be operative. But In any case there is a potential for new re-refining capacity as the collectable used oil could be close to 900 thousand tons a year (just over half of the estimated consumption).

As the quality of virgin base oils in the Arab producing countries move forward to higher groups of II and III, the new re-refining projects must be top quality as well. It is not advisable to produce low grade base oil when the market is moving away from it. Producing lower grade base oils may still have export opportunities but for how long? Even some importers in Africa and Asia are moving in the direction of using better lubricants as they change their transportation stocks and industrial plants. The gap in the price of Groups I and

Table (23)		
Base Oil Re-refining Capacity in the Arab Countries – Thousand tons a year		
Country	**Capacity**	**Notes**
ALGERIA*		Plans to build 30 thousand tons a year plant in El Kantara were reported by an engineering company. However, no implementation and the used oil is collected and exported to Tunisia for re-refining*. Recently the petroleum products distribution company NAFTAL issued a tender to specialized companies to form partnership in used oil collection and re-refining*.
BAHRAIN[34, 53]	**36**	
Sitra	36	Started operations in 2011. Based on distillation and thin film evaporation it produces Group I base oils. Privately owned and costed $9 million[34, 53].
EGYPT[100]	**30**	
Alexandria	30	A 1996 plant said to be based on KTI process[100].
IRAQ*		A pilot attempt in the early 1970s to treat used oils by redundant preflash and clay percolation equipment was a success in quality but later abandoned due to difficulties in collection*.
KUWAIT	**47**	
KNLOC	20	Old plant by Burgan Oil based on Sotulub process.
KLOC	27	Completed in 1998. Based on clay treatment[94].
SAUDI ARABIA	**190**	
Lubrec	10 80	The oldest re-refining plants in Jeddah. There is a joint venture agreement with Hyflux of Singapore to convert the plant to membrane technology[102]. The agreement since 2008 is to produce 48 thousand tons a year in two phases.
Unilube Jubail[56]	100	Commissioned in 2002 is said to use Vaxon solvent extraction technology to meet specification internationally recognized but does say which. Collection centers in Dammam, Riyadh and Jeddah. Said to have a new plant in Riyadh but no details.
Zahara[27]	NA	Is said to have a plant in Riyadh to treat used oil into marine fuel, solvents and fuel oil.
Note		Ocean International planned a 20 thousand tons a year plant in Rabigh.
TUNISIA	**16**	
	16	Based on Sotulub process with hydro-treating later added[1,3].
UNITED ARAB EMIRATES	**120**	
Cyclo Oil[63]	22	Founded in 2007 and commissioned in 2014. Uses thin wiped film evaporators. Yields are 75% base oil and 15% asphalt flux. The rest light oils used as fuel and gasoil.
Pan United[27]	72	Founded in 2013 and claims to use distillation and solvent extraction process.
Zahara[27]	NA	Is said to have a plant in Sharjah to treat used oil into marine fuel, solvents and fuel oil.
Vision Recycling	NA	In Fujairah. Believed to be a waste oil treatment plant and not just used lube oil*.
Dure Oil	10?	Operate especially in Abu Dhabi city. Collection made by Tadweer, the official body in charge of the activity.
Gulf Petrochem	2000 l/h	Sahrjah plant using thin wiped film evaporator.
Source: As indicated * private information.		

II base oils is also getting smaller which will encourage the use of the latter at the expense of the first.

Saudi Arabia & the UAE:

In terms of capacity the largest re-refining plants are in Saudi Arabia and the United Arab Emirates. The two countries were driven by tighter environmental regulation, improved quality of virgin oils and hence used oils, rising crude oil prices before June 2014 which made re-refining attractive.

In the UAE, the collectors are in 20 companies and more numerous than processors, which are in 8 companies[33]. Most collected used oil was burned for energy, producing lower grade base oils or blending with other fuels[33].

The domestic demand for lubricants in the UAE is estimated at 108 thousand tons a year in 2015 and therefore the collectable used oil is probably not more than 55 thousand tons a year. Yet the "collected" used oil is estimated[33] to be between 200 to 250 thousand tons a year. The majority is believed to come from importing used oils from other Arabian Gulf countries or even further afield. Perhaps even some marine oils from the ports are also included here.

But there is now a law prohibiting the import of used oils into the UAE which will put a strain on capacity utilization. This will impede further investment to improve processing to produce better grades of base oils from used oil feed. It is the opinion of this writer that the ban should be lifted and substituted by additional testing and controls on the imported used oil and its utilization.

In the UAE collectors pay the generators a price for their used oil in Dirham/ 200 liter drums. The price is said to be somehow related to the crude oil price.

Data privately obtained from a large used oil generator is compared to Brent crude oil rice in Fig (23) for the period shown from January 2015 to January 2016. While in direction the relationship of between used oil and crude oil prices is clear but a direct relationship with crude prices with reasonably stable differential is not there. The average of the data is $50 and $22 for Brent price and used oil collected price respectively. The fuel oil price in the same period was probably around $40 a barrel and therefore it seems that used oil is priced below fuel oil prices. This is a good policy because it prevents generators from adding fuel oil to their generated oil. Cost of transportation has to be added for delivery to a re-refiner or a fuel user, which on average will probably make the landed cost of used oil at a plant no more than $23 a barrel.

UAE re-refiners are reported to export their products to Africa, China and Vietnam[33], which most probably goes to burner fuel.

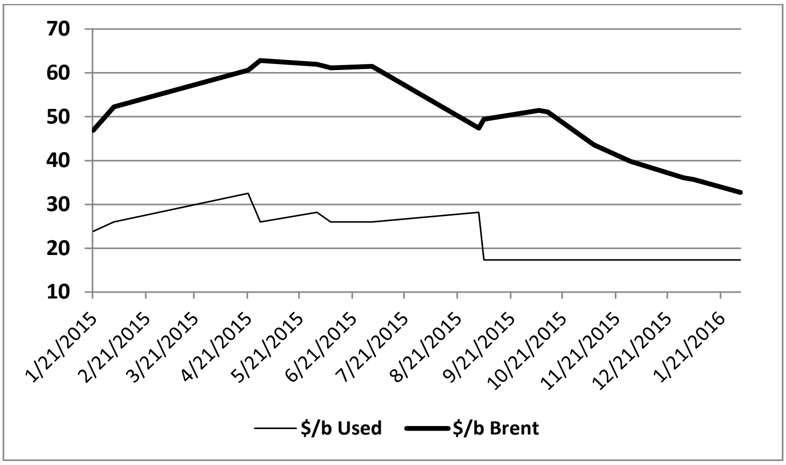

Fig (23) Brent & Used Oil Prices in UAE

In both Saudi Arabia and the UAE, major lubricants manufacturers complain about the state of the re-refining industry with the growing issue of counterfeiting[89]. The writer met with some major manufacturers who refuse to have anything to do with re-refining because of the risk that its image may affect their own products. This is in contrast to what is happening in some well developed countries where governments give priority to re-refined oil in its facilities and where all lubricants manufacturers share in supporting the collection and proper utilization of used oil as we saw in the case of Italy and others.

"There are estimates by the Ministry of Commerce in Saudi Arabia that the country may have a significant percentage of counterfeit products in its lubricants market"[89]. Some blenders in the UAE are not far from that too.

Financial Impact and Final notes:

There is a long way for the re-refining industry in the Arab countries to grow horizontally and vertically. Horizontally, because many countries do not have plans to regenerate used oils yet and no information on its use or abuse is available. The consumption in the Arab countries of about 1.7 million tons a year may give a collectable used oil of 0.9 million tons a year, which may be considered as the ultimate potential for the feed of a growing re-refining industry.

The average OPEC crude oil price in 2016 so far is around $31 a barrel which makes fuel oil prices close to $25 a barrel or about $150 a ton. This price is the theoretical maximum that used oil can be priced at and therefore the estimated maximum value of the generated waste oil in the Arab countries would be around $134 million. This is a saving even if all this money goes to local generators, collectors, transporters and processors. Crude oil prices may not stay at this low level and therefore the potential for revenue from used oil is likely to increase substantially.

Probably the environmental benefits far exceed this revenue and therefore collection is profitable whatever the final use is. Naturally if the used oil is totally converted to base oil the added value will play its part in insuring higher revenues.

However, the real financial saving is in promoting longer drain periods as the region is known to be very conservative where users generally change oil at 2000 to 3000 kilometres for gasoline engine cars and 5000 to 10000 kilometres for diesel driven trucks. With the advent of public awareness and better grade oils available it is not an exaggeration to suggest that these drain periods can be doubled as is evident in other regions of the world. If this can be achieved, a saving of some half a million tons a year can be realized where at today's average base oil prices can be worth $300 to $500 million a year and much more at finished lubricants prices. In addition to this financial saving, used oil quantity will decline and the risk to human health and the environment would decrease too.

As for re-refining, some countries consumption is small and does not support viable modern re-refining plant, collected oil should be exported to a plant nearby in a country where re-refining capacity is established or the used oil is delivered to a legitimate fuel user. In this way, investment is optimized, resource conservation is maintained and above all the environment is protected. In all cases the storage and collection system should be designed for re-refining to keep in mind future possibilities and to avoid mixing with other kinds of waste oils.

This can only be done by having a trade association of lubricants manufacturers, collectors and re-refiners to coordinate with the health, environment and trade ministries to issue and inforce the needed legislation and put the industry on the right path. Especially in the major base oil producing countries such as Saudi Arabia, Bahrain and UAE the re-refining industry and its products should be closely watched and regulated to avoid negative impact on the virgin base oil production.

Chapter 7 - Conclusions and Recommendations

In this report, the question of used lubricating oils has been discussed from all angles relating to its impact on the environment and the risk to human health.

The problems of used oils are now almost an international issue where governments must do their best to contend with. Even the United Nations Environmental Program (UNEP) and the Basel Convention on waste disposal are active on the program of utilizing used oil and the disposal of it.

As the world moves forward in its economic development, population increase and urbanization it is more likely that environmental laws and regulations will be tightened further especially in countries where these are still lax. The questions of waste in general and used oil in particular will get more and more attention with the attendant objective of preventing the dumping of used oil on the environment.

The conclusions and recommendations emanating from this report can be summarized as follow:

1- There is no doubt now about the environmental impact of disposing used oil into the environment even in well-designed landfills. Small quantities of used oils in water supplies, rivers, lakes and the sea can make tremendous damage. Carcinogenic pollutants in used oil are a risk to human health beyond doubt. Therefore it is incumbent on government to promulgate the necessary laws and regulations to ensure keeping out used oil from the environment.

2- The argument for re-refining used oil or burning it in specialized industries is not going to be settled soon. Countries have their special circumstances that must be taken into consideration. The most important thing is to ensure high collection rates of used oils and burn them for energy recovery until there is sufficient volume to support a re-refining plant.

3- Transportation of used oil across international borders must be controlled to make sure that it is intended for legitimate use. Having this in hand helps countries with small used oil collection to find a useful way of getting rid of it and saving resources.

4- With the advances made in engines design to improve efficiency and prolong service life, it is equally important to compliment this with the use of higher grade of lubricants. Therefore any used oil re-refining plant must take this point into consideration in selecting re-refining processes. Solvent extraction and hydro-treating process are becoming the alternatives of choice as other processes add hydro-treatment step to stay in the reckoning.

5- While economics of re-refining and even burning for energy recovery is very important, it should not be the only deciding factor as to the solution of used oil disposal. Government should seek to support the industry through surcharges on lubricants use (pollution pays principle) or by straight subsidy to the operations of collectors, re-refiners or fuel processors. As said in the report, this is a charge to dispose of used oil and protect human health and the environment on the way.

6- Every effort must be made to make the public aware of the dangers of disposing used oils into the environment. Heavy fines must be introduced and at the same time reasonably easy to access collection centres must be provided for those who change oil by themselves. The small maintenance shops must be prevented from changing oil unless they can deliver the used oil to a collection centre properly.

7- The system of making used oils generators charge the collectors encourages the generators to collect the oil and manage it properly. However, it is also seen as a way for the generators to cheat by mixing other waste oils or even water with the used oil. This can be avoided by having collectors test the used oil and have the right to refuse collection of tampered with used oils and report the generator for further action by the authorities.

8- The system of imposing surcharges on lubricants manufacturers according to their sales is much more widely used and seems to be the better way to use the revenue generated as such to support collectors or

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processors of used oil and also make consumers aware of the cost they incur for changing oil prematurely.

9- Even in some advanced countries (the US for example) there is a large waste in lubricants consumption especially in the transportation sector of the economy by accepting low drain intervals. Consumers must be educated as to the negative impact of this behaviour and at the same time pricing policy should be used to curtail such waste. If only equipment manufacturers recommendations are followed great savings can be made in lubricants consumption and reduction of used oil generation.

10- In the Arab countries, all the above points are equally applicable and important. There is a need for more government intervention and regulations to ensure the proper collection and disposal of used oil and to hold the licenced companies to a well-established practises that takes into consideration the rights and interests of all stakeholders.

11- The environment and health ministries in every Arab country must initiate a study of the used lubricants question and update regularly to keep abreast of all changes. They should make use of the experience of other countries and organizations and the UN programs.

12- Particularly with the question of low drain intervals in the Arab countries, every effort must not be spared to make consumers avoid this by following the manufacturer's recommendation and by using the pricing policy to its effect.

13- It is important to form a trade body of lubricants producers, blenders, marketers, collectors, re-refiners and used oil fuel consumers to be a reference of the needed organization and discussions aimed at governments and their respective ministries. Such associations in well developed countries have been instrumental in improving the overall management of used oi

14- l. Perhaps the next step for OAPEC is to lead the effort of creating such trade organization.

Acknowledgments

To be provided later

البحث الأول

References

1 Refining Used Lubricating Oils – James G. Speight & Douglas I. Exal

2 Petroleum Refining – Crude Oil, Petroleum products and process Flow sheets – J. p. Wauquier – Editions Technip – IFP Publications.

3 Selection of the Most Appropriate Technology for Waste Mineral Oil Refining Project Technical Research – Petrol Sanayi Derengi - Turkey

4 Compendium of Recycling and Destruction Technologies for Waste Oils – UNEP 2012

5 Techno-economic study of re-refining waste lubricating oils in the Arabian Gulf countries - M.I. A1-Ahmad and I.S. AI-Mutaz – King Saud University.

6 TECHNO-ECONOMIC EVALUATION OF WASTE LUBE OIL RE-REFINING IN SAUDI ARABIA - Mohammad Farhat Ali, Abdullah J. Hamdan and Faizur Rahman – King Fahad University

7 Automotive Oil Recycling – Wikipedia - https://en.wikipedia.org/wiki/Automotive_oil_recycling

8 American petroleum Institute – Used motor oil collection and recycling - http://www.recycleoil.org/

9 Lubricant – Wikipedia – https://en.wikipedia.org/wiki/Lubricant

10 PCBs Still a Risk to Rerefiners - Joe Beeton • April 10, 2013 – Lubes & Greases

11 Total – Used Lubricants Collection - http://www.total.gr/en/lubricants-industry-eng/our-services-industry/used-lubs-collection.html

12 UK Oil Recycling Association (ORA) - http://www.oilrecyclingassociation.co.uk/about-ora/

13 Best Practise for Waste Oil management - Machinery Lubrication (6/2015)

14 Ecotec Technology - http://www.utopiakorea.net/technology/sub00.html

15 The Virtuous Circle of Regeneration – Robert Rizzo - http://renewablematter.eu/art/27/The_Virtuous_Circle_of_Regeneration

16 Oil Recycling – Natasha Ewendt – Port Lincoln Times - http://www.zerowaste.sa.gov.au/at-home/oil-recycling

17 Synthetic Oil – Wikipedia - https://en.wikipedia.org/wiki/Synthetic_oil

18 Isel Lubricants – History - https://iselinc.com/technology/brief-history-lubrication/

19 Re-refining of Base Oils – LUBE – Feb 2013

20 Greener Oil – Insight – Infineum - http://www.infineuminsight.com/insight/sep-2013/greener-oil#heading-3

21 A REVIEW OF THE POTENTIAL HUMAN AND ENVIRONMENTAL HEALTH IMPACTS OF SYNTHETIC MOTOR OILS - APRIL 2007 - Karen Randles et al - California Environmental Protection Agency - http://oehha.ca.gov/risk/pdf/SyntheticsFINAL-040607.pdf

22 Disposing of used lubricating oils – CONCAWE - https://www.concawe.eu//uploads/Modules/Publications/cr92-usedlubeoils-2003-01929-01-e.pdf

23 Recycling Used Oil Saves Energy, Protects the Environment – American Petroleum Institute - http://www.americanpetroleuminstitute.com/Oil-and-Natural-Gas-Overview/Fuels-and-Refining/Engine-Oil/Recycling_Used_Oil_Saves_Energy

24 New Oil for Old – Michael Lawton – Alfa Laval - http://www.alfalaval.com/media/stories/crude-oil-refinery/new-oil-for-old/?id=9835. Also http://www.alfalaval.com/products/separation/centrifugal-separators/Separators/MAB/#sthash.PeqpLalN.dpuf. Also http://www.alfalaval.ae/#sthash.xW3m44np.dpuf

25 European Union Favours Re-Refining Used Oils – Lube Report – March 11 2009 –

26 Re-refining of Used Lubricating Oil – Manoj Praharaj Bhatangar et al - http://www.slideshare.net/palekaravadhut/presentation-on-re-refining-of-lubricating-oil-by-avadhut-pravin-manoj

27 Refining the Oil Industry – Gulf News – Nov 5 2013

28 Transparency Market Research - wayne collins - 28.07.2015 - http://www.transparencymarketresearch.com/pressrelease/base-oil-demand-market.htm

29 Breaking the 3,000-Mile Habit - Philip Reed, Ronald Montoya http://www.edmunds.com/car-care/stop-changing-your-oil.html

30 Optimizing Oil Change Intervals in Heavy-Duty Vehicle - Bennett Fitch - Machinery Lubrication (10/2012)

31 Evolution of the Global Base Oil Pool – Lubes & Greases - No. 78 - Dec 2015

32 New Lubes Last Longer - Michael Khonsari, E.R. Booser - http://www.machinerylubrication.com/Read/618/new-lubes

33 The future of waste oil refining in the UAE - Arabian Oil & Gas - Apr 24, 2014

34 Bahrain opens $9m refinery to recycle used oil - ARAB NEWS - 19 January 2011

35 LARGE GRASSROOTS LUBE REREFINERY IN OPERATION - Safety-Kleen Corp. - Oil & Gas Journal - 08/19/1991

36 NEW EXTRACTION-BASED RE-REFINING PROCESS SAVES MONEY - Oil & Gas Journal - 05/30/1994

37 Base Oils 2013: Performance shift spurs new investment - ICIS Chemical Business - 18 February 2013

38 Re-Generate Used Oil – IFP - http://ifp-petro.com/Rerefine.htm

39 Adoption of the EU Circular Economy Package highlights the need to shift focus from waste to resource management - http://www.cepi.org/node/17978#sthash.LG1EjAa3.EoMQfymp.dpuf

40 Groupment Europeen de l'Industrie de la Regeneration – GEIR - www.geir-rerefining.org

41 The Challenges of Re-Refining, Again - Greg Ray – February 2014 - http://www.crystal-clean.com/about/ILMA_Compoundings_Voices_and_Views_February_2014.pdf

42 Macroeconomic Factors Shape Middle East markets – mark Townsend – Lubes'N'Greases – 1 Jan 2016. http://viewer.zmags.com/publication/526abaed#/526abaed/24

43 PCBs Still a Risk to Re-refiners – Joe Beeton – Lubes'N'Greases – 10 April 2013.

44 Enoc to Become Largest Emirates Producer – Joe Beeton - Lubes'N'Greases – 10 June 2015

45 Middle East Transitions to Base Oil Exporter - Lisa Tocci - Lubes'N'Greases – 8 April 2015

46 Used Lubricants Collection [in Greece] - http://www.total.gr/en/lubricants-industry-eng/our-services-industry/used-lubs-collection.html

47 Oil Recycling Association (ORA) - http://www.oilrecyclingassociation.co.uk/about-ora/

48 A Century in Oil – Shell 1997 – Stephen Howarth

49 Our Industry Petroleum – BP – Fifth Edition – 1977

50 The Road to Reform – Steve Shimberg – NORA – Liquid Recycling – Issue 1 – 2015.

51 Re-refining of Base Oils – LUBE – Feb 2013

52 Russia Moves Slowly on Oil Recycling – Boris Kamchiev - Lubes'N'Greases – 1 July 2015

53 Rerefinery Opens in Bahrain – Tim Sullivan - Lubes'N'Greases – 25 May 2011.

54 New Age for Lubricants Marketing - Geeta Agashe - BLM Abu Dhabi 2015 - Geeta Agashe & Associates, LLC.

55 UAE Base Oil Movement – Mehrdad Vajedi - BLM Abu Dhabi 2015

56 WHY RE-REFINE USED-OIL? – United Lube Oil Co. – Saudi Arabia

57 LUBEREF – Saudi Arabia - http://www.luberef.com/en/production.aspx

58 Bahrain Lube Base Oil Company - http://www.noga.gov.bh/index.php?page=524

59 Managing Industrial Oil - Oil Life Extension and Recycling – Donald Smolensi – General Motros - http://www.machinerylubrication.com/Read/815/industrial-oil-recycling

60 Tricks and Traps of Oil Reclamation – Machinery Lubrication - http://www.machinerylubrication.com/Read/266/oil-reclamation

61 Waste Lube Oil Management in Europe - Glykeria Archontaki – GEIR – Bucharest – 28 May 2015.

62 Prospects for the Lubricating Oil Industry in Iraq – S.A.Al Fathi – 6th ICIS Middle Eastern Base Oil & Lubricating Conference – October 2009.

63 CYCLO OIL LLC Used Oil Re-refining Plant - UAE - http://www.cyclooil.com/images/companyprofilecyclooil.pdf

64 Emerging Trends and Opportunities for the Base Oil and Lubricant Industry - Apu Gosalia - FUCHS PETROLUB AG, Germany

65 FUCHS PETROLUB AG - The leading independent lubricants manufacturer of the world - Dr. Alexander Selent & Dagmar Steinert

66 Re-refined Oils Gain Traction in the Middle East – Mark Townsend - Lubes'N'Greases – October 2015 - http://viewer.zmags.com/publication/ed05d83c#/ed05d83c/1

67 REREFINING CASE STUDY: EVERGREEN OIL REREFINERY - John Fok, Evergreen Oil-http://infohouse.p2ric.org/ref/30/29100.pdf

68 Re-refined Oils Gain Traction in the Middle East – Mark Townsend - Lubes'N'Greases – October 2015 - http://viewer.zmags.com/publication/ed05d83c#/ed05d83c/1

69 Analysis and Comparison of Regenerative Technologies of Waste Lubricant - YU-LUNG HSU et al - Department of Resources Engineering - National Cheng Kung University – Taiwan

70 BASEL CONVENTION TECHNICAL GUIDELINES ON USED OIL RE-REFINING OR OTHER RE-USES OF PREVIOUSLY USED OIL – Basel Convention / UNEP Secretariat – 1995.

71 Will Additives Outpace the Lube Markets – Joe Benton – Lubes'N' Greases – January 2016.

72 Forecast: Demand Tops 45M Tons in 2019 - GEORGE GILL - JANUARY 13, 2016 – Lube Report - http://www.lubesngreases.com/lubereport/16_2/trends/-9829-1.html

73 Lube Demand: Quality vs. Quantity - JOE BEETON • AUGUST 7, 2013 – Lubes'N'Greases - http://www.lubesngreases.com/lubereport/13_30/other/-1210-1.html

74 Study: World Lube Demand Slows - George Gill • March 18, 2009 - Lubes'N'Greases - http://www.lubesngreases.com/lubereport/9_11/other/-3097-1.html

75 Lubes: a 62 Billion-dollar Baby by 2015 - George Gill • May 2, 2007 – Lubes'N'Greases - http://www.lubesngreases.com/lubereport/7_19/other/-2398-1.html

76 Rerefiners Reshuffle for Success - Caitilin Jacobs – January 6, 2016 – Lubes'N'Greases - http://www.lubesngreases.com/lubereport/16_1/rerefining/-9801-1.html?ET=lubesngreases:e497:40682a:&st=email

77 IEA Statistics – Oil Information 2012 - www.iea.org/media/training/presentations/.../oilinformation.pdf

78 The Collapse in Crude Oil Prices: How is it Impacting Base Oil and Lubricants Markets? - Ian Moncrieff – October 2015 – Kline & Co.

79 Global Lubricant Demand Flattens Out - GEORGE GILL - JANUARY 19, 2016 - Lubes'N'Greases.

80 Vertex to Enter Finished Lubes Market - GEORGE GILL - JANUARY 20, 2016 - http://www.lubesngreases.com/lubereport/16_3/trends/-9866-1.html?ET=lubesngreases:e513:40682a:&st=email

81 Valvoline: Hands-on Expertise - http://www.valvoline.com/

82 SynLube - http://www.synlube.com/usedoil.htm

83 Re-refined Basestocks Reach Par with Virgin Basestocks – Machinery Lubrication 2009 - http://www.machinerylubrication.com/Read/26663/Study-basestocks-reach-par

84 Separation Processes – J.P. Wauquier – Editions Technip – IFP Publications

85 Refinery Operations and Management – J.P. Favernnec – Editions Technip – IFP Publications.

86 Rerefiner Aims to Make Group III in 2017 - GEORGE GILL • JANUARY 27, 2016 - http://www.lubesngreases.com/lubereport/16_4/rerefining/-9903-1.html

87 Revivoil – Viscolube – Company Brouchore.

88 Calif. Bill Targets Oil Drain Intervals - KIARA CANDELARIA • FEBRUARY 3, 2016 - http://www.lubesngreases.com/lubereport/16_5/legal/-9955-1.html?ET=lubesngreases:e524:40682a:&st=email

89 Sustainability Gains in Middle East Lubes Industry – Mark Townsend – Lubes'NGreases EMEA – February 2016 http://viewer.zmags.com/publication/8d07eabd#/8d07eabd/28

90 2004 Refining Processes Handbook – Hydrocarbon Processing

91 2011 Refining Process Handbook – Hydrocarbon Processing

92 Defining the Re-refining – Avista Oil Group. http://www.theuesrefinery.com/

93 Engineering, Licensing and Technology agreements with CEP Corporation www.hydrodec.com.

94 Used Oil Re-refining - STP -Studi Tecnologie Progetti Srl

95 Chem-Ecol – Industrial Lubricants Oil Recycling - http://www.chem-ecol.com/

96 Used Oil Re-refining Study – US Department of Energy. 2006 http://www.fossil.energy.gov/epact/used_oil_report.pdf

97 Critical Review of Existing Studies and Life Cycle Analysis on the Regeneration and Inceneration of Waste Oil – Dec 2001 – Taylor Nelson Sofres – for EU.

98 2015 Base Stock Guide – Lubes 'N' Greases

99 ADNOC Base Oil Plant. http://fuelsandlubes.com/adnoc-base-oil-plant-to-stream-later-this-year-2/

100 Petroleum Lubricating Oil and Grease Manufacturing in Egypt. http://www.mbendi.com/indy/oilg/lubs/af/eg/p0005.htm#companies

101 Balagi Consultants. http://rerefining.in/re-refining-projects.html

102 Lubrec – Hyflux. http://investors.hyflux.com//newsroom/Hyflux_Misc_SEDCO_LUBREC_8May07.pdf

103 Lubes'N'Greases - 2014 Guide to Global Base Oil Refineries

104 Global Risk-Based management of Chemical Additives – Chapters on Lubricants' Additives and Italy Experience with used Oil. Bernd Bilitewski, Rosa Mari Darbra and Damia Barcelo.

105 IFEU Final Report - Ecological and energetic assessment of re-refining used oils to base oils:
Substitution of primarily produced base oils including semi-synthetic and synthetic compounds- 2005.

106 COOU website - www.coou.it

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Re-Refining of Used Lubricating Oils and its Economic and Environmental Implications

* **Jamal Al Harbey**

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Glossary of Terms and Abbreviations

ANGED	Agence Nationale de Gestion des Dechets
AOG	Arab Oil and Gas
CEP	Chemical Engineering Partners
DOE	Departement Of Energy
EGPC	Egyptian General Petroleum Corporation
EPA	Environmental Protection Agency
CP	CentiPoise
GCC	Gulf Cooperation Council
GEIR	Groupement Europeen
IFP	Institut Français du Pétrole
IRR	Internal Rate of Return
INSEE	Institut National de la Statistiques et des Études Économiques
KTI	Kinetics Technology International
LCA	Life Cycle Analysis
MRD	Mineralol-Raffinerie-Dollbergen
MTPY	Metric Tons Per Year
PROP	Phillips´Re-refining Oil Process
PCBs	PolyChlorinated Biphenyls
ROI	Return On Investment
SOTULUB	Societe Tunisienne des Lubrifiants
STP	Studi Tecnologie y Progetti

TÜV	Technischer ÜberwachungsVerein
UNEP	United Nations Environment Programme
UOP	Universal Oil Products

Abstract

This paper discusses the commonly used re-refining technologies that are used to regenerate used lubricating oils into a marketable product. The current technologies and regulations relating to used lubricating oil have been reviewed. The study provides insights into the economic viability of re-refining. Among the economic advantages it provides, re-refining represents an economic opportunity to convert a dangerous waste (low value) stream into high value petroleum product. The environmental benefits deriving from the application of recycling used lubricating oils thru re-refining are reviewed. This recovery method is recognized to mitigate the environmental impacts. It is a well established fact that reprocessing to base oil lubricants emits less atmospheric pollutants and consumes less energy than the refining of virgin oil into lubricants or burning it for energy recovery.

Also, the regulations and legal frameworks applicable for the management of used oil have been reviewed. It also identifies obsta

cles and misconceptions facing the re-refining industry. These primarily include access to used oil and consumer acceptance of re-refined lubricants.

Overall, findings suggest that re-refining represents an economic opportunity for recycling a low value stream into a high value petroleum product and for reducing the environmental impacts.

Re-refining is the best option for recycling used lubricating oil.

1 Background

Lubricating oils have been primarily used for reducing friction between moving metal parts of engines and machinery. As a result of the lubricating action, lube oil get contaminated and degraded. Like most products, lubricating oils possess a life cycle which is characterized by the end-of-life at which point the product reaches the end of its useful life, and must be changed and safely disposed of. During normal use, impurities such as dust, dirt, metal scrapings, water or chemicals, etc., can get mixed in with the lubricating oil or be generated in it due to thermal degradation or oxidation. Used lubrication oils contain water, salt, broken down additive components, varnish, gum and other materials (Durrani et al, 2011). During operation, the lubricant loses its initial properties; it becomes a "used lubricating oil" and must be replaced. The US Environmental Protection Agency defines used oil as "any oil that has been refined from crude oil or any synthetic oil that has been used and as a result of such use is contaminated by physical or chemical impurities". Basel convention states that " used oil, as referred to in these technical guidelines, is an oil from industrial and non industrial sources which has been used for lubricating or other purposes and has become unsuitable for its original purpose due to the presence of contaminants or impurities or the loss of original properties".

While many petroleum products such as gasoline, jet and diesel fuels are lost after being used (i.e. combustion), lubricating oils can be recovered and regenerated to the quality equal to or better than its original virgin form by using re-refining technologies (Park, 2012).

The process by which the used lubricating oil is returned to a usable condition is called re-refining. It is a process of repeating some of the basic refinery processes adapted to upgrading the base oil to a usable condition. In reprocessing used oils, contaminants are removed and the initial properties of the base oil restored. When re-refining is conducted properly, the base oil properties are comparable with those of the virgin base oil, as will be demonstrated later.

2 Historical overview of used lubricating oils re-refining processes.

The recycling of used lubricants has been practiced since the 1930s and particularly during the Second World War when the scarcity of adequate supplies of crude oil during the conflict encouraged recycling of all types of materials including used lubricants (Tiwari et al, 2012). In the 1960s, the re-refining industry experienced a slowdown due to the combined effect of the availability of large quantities of virgin lube oils and the failure of the re-refining industry to provide consumers with high quality products (Cukor et al, 1973). In those days, acid/clay based technologies- which were based on the use of large amounts of acid and clay to reprocess the used oil- were for many years the standard method for regenerating used lubricating oil. These acid-based technologies not only produced base oils with lower properties than virgin base oils, but also were the source of environmental pollution. During the re-refining processes (e.g. acidification, clay treatment), hazardous by-products were produced, including acid tar and oil saturated clay, thereby creating waste disposal problems and environmental drawbacks. Consequently, the technology failed to find widespread acceptance for various reasons including high processing costs, and therefore high selling prices, and inadequate removal of impurities (Avaduth, 2011).

The energy crisis of the seventies has generated renewed interest in re-refining. A series of technical innovations based on technologies borrowed from crude oil refining were introduced in the re-refining industry. Vacuum distillation, for example, was adapted to re-refining through the use of specialized equipment (Rudnick L, 2011). Also, developments in catalysts and hydrofinishing technology have enabled the industry to partially overcome the environmental challenge so that re-refiners were able to produce good quality base oils.

In the 1980s, the level of awareness on environmental issues increased significantly as more stringent environmental regulations were introduced in developed countries. As a result, many re-refiners, not being able to abide by those costly-to-implement-regulations, were pushed out of business (Wolfe, 1992). In particular, acid/clay re-refining plants, mainly in the USA, were the main casualty of these new tough environmental regulations as many were forced to shut down (EC, 2006).

The re-refining industry has come a long way since the early days of acid-based technologies. Today, re-refining processes are considerably different, and much more advanced, than when re-refining first began back in the 1930s. Over the years the re-refining technology has evolved from simple distillation over clay and sulfuric acid, to thin film evaporation with solvent extraction, through to the hydro-treatment process technology of today. Thanks to advanced technologies such as hydrogenation-based technologies and solvent-based technologies but also to adequate state-sponsored legislations, re-refined used oil is starting to be accepted as equivalent in quality and price to most virgin lubricating oils.

3. Sources and evaluation of used lube oils.

3.1 Sources of used lubricating oils

Used lubricating oils can come from different sources. As illustrated in Figure 1, the automotive industry generates the highest amount of used lubricating oil. It is by far the largest segment. The used lubricants consist of crankcase oil and transmission fluids and it can be sourced from service stations, do-it-yourself oil changers, motorists, etc. Second only to the automotive industry is the industrial sector. Industrial waste oils may be either lubricating or non-lubricating and include turbine oils, gas engine oils, refrigeration oils, heat transfer oils, compressor oils, hydraulic oils and metal cutting oils, among others. The other sources of used lubricating oils are the marine and power sectors which represent a non-negligible portion of the used oil generated.

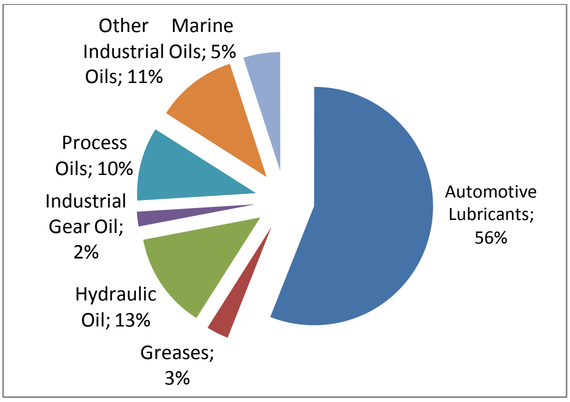

Figure 1 Breakdown of the sources of used lubricating oils
Source: Bharat Petroleum Corporation as cited in UNEP (2012).

As mentioned in the Basel convention, used lubricating oils represent a significant portion of the volume of organic waste liquids generated worldwide. While used oils of industrial origin are slightly deteriorated and can be easily regenerated through a simple purification process, those originating from the automotive segment are darker and require more sophisticated processes in order to be regenerated into useful base oils.

3.2 Composition of used lubricating oil

Figure 2 shows the percentages of the components of used lubricating oil. It contains at least 70% of base oil, while the remaining 30% is comprised of various components such as water, asphalt and gas oil. Re-refining is all about recovering this base oil cut and upgrading it to a usable product.

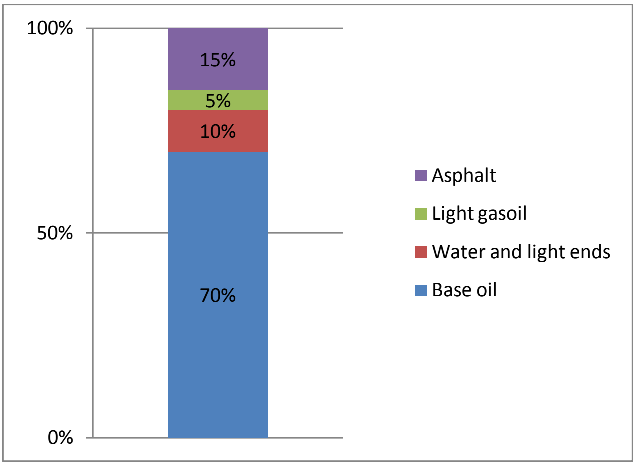

Figure 2 Used lubricating oil composition
Source: Own elaboration with data from Krishnan (2013)

3.3 Estimation of used lubricating oils generated in Arab countries and worldwide

3.3.1 Used lubricating oil generated in Arab countries

While the environmental impact of used oils was recognized in many Arab countries, re-refining was perceived- at least in some oil-producing countries- as a competition to the existing lube oil producers (AOG, 2014). Most of these countries, if not all, are faced with several challenges, including the absence of surveys and statistics about used lubricating oils, the lack of enforcement of environmental regulations and the lack of awareness, which is perhaps the most challenging barrier. Although adequate legislations for waste oil management do exist in those countries, effective implementation and control are non-existent due to reasons outlined above. As a result, haphazard handling of waste oils is still a day-to-day practice. Despite the existing challenges, a few countries have managed to tackle the problem through the establishment and effective implementation of laws and regulations, largely inspired by the European directives and/or the US EPA directives.

In this section an attempt will be made to appraise the present situation of the re-refining potential in Arab countries and also to provide some insights into used oil management practices in these countries.

Algeria

In Algeria, around 180000 metric tons of lubricants are sold annually. Currently about 90000 metric tons of used oil are generated and only 18000 metric tons are collected and about 900 tons are exported (Leconews, 2015). The state company NAFTAL is responsible for collecting used oil. Legislation was issued in 2004 on the waste oil management. The waste oil directive is adopted as Decree Nº 04-88 dated 22/03/2004. As of now, there is no re-refining facility for the treatment of waste oil. While the state-owned company NAFTAL acts as a used oil collection center, collection is carried out by a dozen waste oil collectors agreed by the ministry of environment.

Egypt

In Egypt, lubricating oil consumption amounted to about 450000 metric tons of base oils in 2015 and generated about 240000 metric tons of oil waste, of which 80,000 metric tons were recycled, and the rest was exported. The Egyptian General Petroleum Corporation (EGPC) has made it mandatory for filling stations to have a collection tank for waste oil. Alexandria Petroleum Company which is one of the EGPC affiliates handles re-refining of used oil in Egypt. Under the environment law 4/1994, waste oil is classified as a hazardous waste. Law 9/2009 (amended Law 4/1994) regulates collection, treatment and disposal of hazardous waste (Articles 29-33). Oil marketing companies are not granted a license to operate unless they present a sound strategy for the safe disposal of waste oil (Egypt, 2010).

Jordan

According to the country report an estimated 15000 metric tons of waste oil is generated each year (Jordan, 2014). This amount is either dumped in the sewer system or directly on open land, burned directly as a fuel or collected for further treatment and processing such as re-refining. Waste oil generators handover their waste oil to licensed collectors. Collected used oil is then transported and sold to treatment plants for further processing. The ministry of environment is in charge of regulating, monitoring and enforcing hazardous industrial waste management requirements through the waste oil handling and management instructions of year 2003.

Kuwait

In Kuwait, the lubricants market amounted to 50000 metric tons in 2011 (Kamshev, 2012). Assuming an average growing rate of 2.5%, the market is expected to reach 55000 metric tons in 2015. Assuming that only 50% are available for collection, then the collectable amount would be about 28000 metric tons and the amount of used oil collected is expected to be around 19300 metric tons per year (assuming 70% collection rate). The re-refining installed capacity stands at 27000 MTPY. The management of hazardous wastes is regulated by Law No. 21/1995 as amended by Law No. 16/1996 and Decision 210/2001. This categorizes wastes including used lubricating oil as hazardous or non-hazardous according to the Basel Protocol and the Kuwait EPA regulations (KOC, 2003).

Morocco

In Morocco, the lubricating oil market size stands at 100000 MTPY. The estimated quantity of used oil that is collected and recycled to cement plants for burning is only 10000 metric tons per annum. The difference, 90000 metric tons, is unaccounted for. Most of the waste oil collection and disposal is handled by the informal sector (Morocco, 2014)). Used oil legislation on the collection, transportation and treatment of certain waste oils was adopted in 2011 as Decree N° 2-09-85 dated 06/09/2011. As part of an agreement signed between the Department of the Environment, cement producers and oil companies, PolluClean, a private company, is responsible for collecting waste oils to be used in cement factories (ActuMaroc, 2012). The collection rate is very low and stands at about 10% of the collectable quantity. Used lubricating oils are handled in accordance with Law 28-00 on Waste (2006) which covers waste oils and lubricants, which are itemized as either hazardous or non-hazardous waste per Annex I, under Code 13.08 of Decree No. 2-07-253 dated 18 July 2008 on the Moroccan Waste Catalogue.

Oman

The principal legislation is Sultani Decree Nº 114/2011, the law on conservation of the environment and prevention of pollution, which replaces the previous environmental law, Sultani Decree 10/1982. Hazardous and non hazardous wastes legislation is governed by Ministerial Decisions MD 17/93 (Eldridge et al, 2009) and MD 18/1993 (Management of hazardous waste). According to local regulations used oil shall be collected in special containers and placed on cement-lined floor. Disposal of such waste shall be in accordance with the regulations promulgated by the Ministry of Regional Municipalities & Environment. According to Fincorp (2009), approximately 37000 metric tons of lubricating oils were sold in 2009. Taking into account a moderate growth rate of 3%, the market is expected to grow to 42000 metric tons in 2015. If we assume a 50% collection rate, the amount of used oil collected is expected to reach 21000 metric tons annually.

Palestine

According to the country report, used lubricating oils are part of the hazardous wastes and all what applies to hazardous wastes applies to oils and lubricants (Palestine, 2014). Hazardous waste legislation is drafted by the Environmental Quality Authority (EQA) and is based on the Palestinian Environmental Law 7, 1999. According to the draft master plan on hazardous waste, total generation of used mineral oil from vehicles is 20,000 ton annually. The country report indicates that 20% of used oil is illegally dumped or disposed in sewerage; 10% is burned in traditional bakeries, stone factories, and metal processing factories and 70% is to be used as source fuel.

Qatar

Waste management in Qatar is being regulated by Decree Law Nº 30 of 2002 for the environment protection and the Executive By-Law for the environment protection (2005). Qatar Petroleum supervises all waste management activities for hazardous wastes (Qatar, 2014). There are about 4 waste oil collectors. Waste oils are collected and taken offsite by contractor for recycling. The lubricants market is expected to reach 27000 metric tons in 2016 (Kamshev, 2012). Assuming a 50% collection rate, the expected quantity of used oil to be collected amounts to 13000 metric tons. According to Al-Haya (2013), there exists one plant with re-refining capacity of 8000 metric tons per year.

Saudi Arabia

Saudi Arabia is the largest lubricant market in terms of consumption. The market adds up to 420000 MTPY (Marcopolis, 2015). According to the same source, the available used oil generated annually exceeds 200000 metric tons. According to our estimation the re-refining capacity now stands at 95000 metric tons per year. The waste management policy is set by the Meteorology and Environmental Protection Administration (MEPA) through the environment protection standards including the National Material Recovery and Recycling of Waste Guidance Document. Waste oil disposal is handled in accordance with the requirements set forth in Hazardous Waste Disposal Standards 1413-03/1992, Regulations and Procedures for Hazardous Waste Control (Document No. 01-2002) and Environmental Standards on Material Recovery and Recycling of Waste 2012.

Tunisia

In Tunisia, about 50000 metric tons of lubricating oils are consumed annually. Using 11 collection centers located across Tunisia, collection has reached 15000 metric tons which represent 60% of collectable quantity. Only 10000 metric tons are re-refined by SOTULUB (Société Tunisienne des Lubrifiants) which is also responsible for collecting and transporting used oil. There exists a re-refining plant with a new revamped capacity of 20000 ton per year. The Tunisian authorities have set up a public system, called Eco-Zit, for the collection and the regeneration of the lubricating used oils. It is financed by contributions from oil companies. Used lubricating oils are governed by Law 1996-41 of 10/06/1996 on waste control, use and disposal and the waste directive N°2002-693 dated 01/04/2002. ANGED (Agence Nationale de Gestion des Dechets) monitors, controls and implements the national strategy (Anged, n.d)

United Arab Emirates

The UAE is the main lubricants producer in the MENA region with an estimated annual capacity of 1500000 metric tons, part of which is destined for export (Bambridge, 2015). Local lubricants consumption is estimated to be around 200000 MTPY (Isaac, 2015). According to AOG (2014), of the total used oil generated about 75% is collected, 25% are combusted or discarded inappropriately and the rest is supposedly destined for re-refining. Furthermore, market estimates reveal that between 100,000 and 150000 metric tons of waste oils are collected annually (AOG, 2014). By correlating the data, the amount of collected used oil can be estimated to be around 150000 MTPY, while the burned quantity would stand at 50000 MTPY. The re-refined quantity would stand at 100000 metric tons per year. Presently, there are about 20 collectors and 8 active re-refiners converting waste oil into base oils and furnace fuels. Hazardous waste management practices are governed by the Executive Order of Federal Law No. 24 for Regulation of Handling Hazardous Materials, Hazardous Waste and Medical Waste (2001). It dictates that waste is to be processed in the most environmentally friendly way.

It can be noted that used oil handling practices vary from country to country with Tunisia, Saudi Arabia and the UAE, having probably the most integrated used oil management system.

According to data gathered from a variety of sources, total market demand for lubricants in Arab countries stands at about 1.6 million metric tons per year, with Egypt, Saudi Arabia, the UAE and Algeria amongst the highest consumers. This figure is expected to grow as a result of the demand from the industrial and transportation sectors which represent key growth drivers. As shown in Table 1, the used oil recycling industry is comprised of 21 plants with a processing capacity of ca. 304000 metric tons per year. Most of the re-refining industry is concentrated in the GCC countries where the installed capacity reaches 120000 tons per year. A significant amount of new re-refineries is projected to come into operation in the near future, which should increase current capacities to 350000 metric tons per year.

Table 1 lists some of the re-refining plants in some Arab countries.

Country	Re-refineries	Re-refining capacity(t/y)
Bahrain	1	36000
Egypt	1	25000
Jordan	1	8000
Kuwait	4	77000
Qatar	1	9000
KSA	8	95000
Tunisia	1	16000
UAE	5	38000
	21	304000

*Projected

Table 1 Re-refining installed capacities in Arab countries

While lubricating oil production and consumption can easily be estimated, the quantity of recycled used lubricating oil is difficult to figure out. In most Arab countries, no or very little public information is available regarding the collection, treatment and disposal of the used lubricating oils, notwithstanding the existence of legislation and regulations. The lack of reliable data means that the problem of used oil management is not well controlled and/or the laws and regulations are not implemented with determination and consistency. In our appraisal of the re-refining situation in the Arab countries, all the figures quoted are based on documented sources, unless otherwise indicated. Where country data are not available, the quantity of used lubricating oil was derived or estimated from the market size of virgin lubes based on the following assumptions: It is assumed that only 50% of virgin lube oils are collectible as used oils, out of which only 50% are actually collected, and only 50% are re-refined into base oil (UNEP, 2012).

The findings, displayed in Table 2, show the lube oil consumption per country, and collection and recycling of used oil in some Arab countries based on limited data made available in recent years.

Countries	Consumption A(tons)	Available Collection		Collected		Destination of used oil	
		B/A(%)	B(tons)	C/B(%)	C(tons)	Re-refined	Used as fuel/Unknown
Algeria	180000	50%	90000	20%	18000	0	90000
Egypt	450000	53%	240000	33%	80000	25000	215000
Jordan*	25000	60%	15000	50%	7500	3750	11250
Kuwait*	55000	50%	27700	70%	19390	9695	18005
Morocco	100000	90%	90000	11%	10000	0	90000
Oman	42000	50%	21000	70%	14700	7350	13650
Palestine	20000	100%	20000	100%	20000	0	20000
Qatar*	25000	72%	18000	70%	12600	6300	11700
Saudi Arabia	420000	52%	220000	70%	154000	77000	143000
Tunisia	50000	50%	25000	60%	15000	10000	15000
UAE	200000	75%	150000	75%	112500	100000	50000
*Estimated	1567000		916700		463690	239095	677605

Table 2 Used lubricating oil management in selected Arab countries
Source: Own elaboration

Keeping in mind, the uncertainty of the data collected from various sources, the situation of used lubricating oil management in the Arab countries can be summarized as indicated below:

- It can be stated that the use of re-refining, in Arab countries, is not yet the preferred waste oil handling alternative.
- Only a limited amount of used oil is actually re-refined as most of the collected used oil is at best burned as fuel and at worst illegally disposed of.
- The collectable amount, on the MENA regional level, has been estimated to be around 0.92 million metric tons, which is 58% of the total consumption.
- The quantity of used lube oil actually collected is estimated to be around 464000 metric tons; this represents 50% of the amount available for collection.
- The re-refined quantity is estimated to be around 239000 metric tons, which is 26% of collectable quantity and 51% of the collected quantity.
- About 74% of collected used oil is used as fuel or improperly disposed of.
- On the MENA regional level, Palestine, Saudi Arabia, the UAE have the highest collection rates, with 100%, 75% and 70% respectively; Saudi Arabia and the UAE have the highest re-refining rates with 50% and 36% respectively.

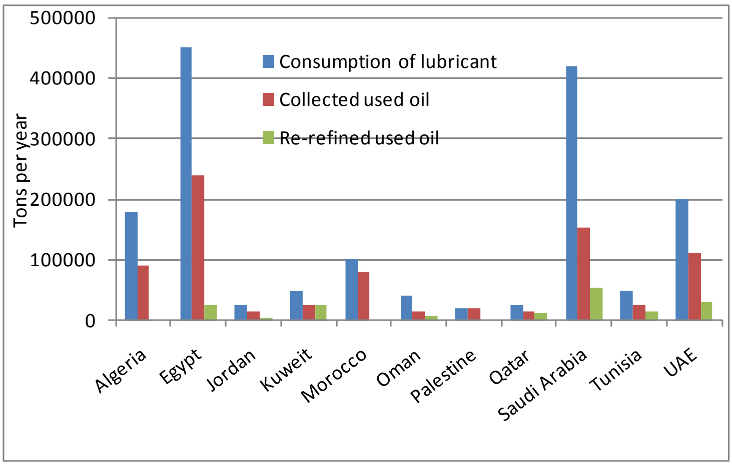

Figure 3 Consumption of lubricants, collection and valorization of used lubricating oil in Arab countries
Source: own elaboration

It can be stated that in the present situation, the re-refined base oil output in the Arab countries is insignificant and that there is a great potential for growth in the re-refining industry. Both the percentage of used lube oil that is collectable and the percentage that is actually collected can be improved. Improvement can only be achieved through the implementation and enforcement of appropriate measures including an efficient collecting system, a state financial support through taxes and levies and regulations to encourage investment in re-refining.

3.2.2 Used lubricating oil generated worldwide

The global lubricant consumption stood at 39.4 million metric tons in 2014 (Kline, 2015). Assuming that 50% of the global consumption is lost due to evaporation, leakages, spills, and other factors, a maximum of 19.7 million metric tons is available for collection. According to Kline (2014), about 74% are collected and only 16% of collected used oil is re-refined into base oils, 78% is burned as fuel and 6% disposed of. In other words, of the total used oil collected, only about 2.3 million tons is sent for re-refining. This represents only 16% of used oil collected, 11.8% of collectable used oil and 6% of global consumption.

Figure 4 illustrates the global lubricant consumption breakdown by regions.

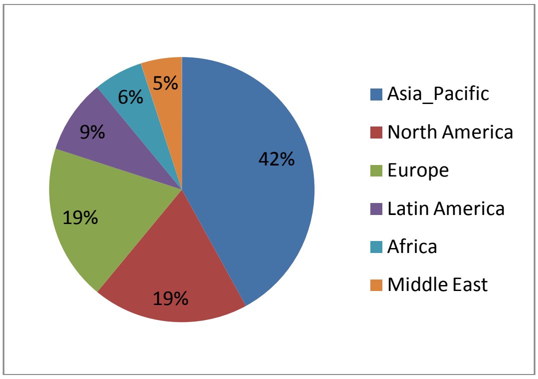

Figure 4 Global Lubricant consumption by region during 2014
Source: Statista (2015)

Asia-pacific is the largest lubricant consuming region accounting for 42% of global demand. About 7.9 million metric tons are generated annually. Of which, 5.6 million metric tons are collected. Only 8% (445000 tons) are re-refined (Kline, 2010).

البحث الثاني

North America, the second largest market in the world, accounts for 19%. Of the approximately 3.6 million metric tons of used oil generated annually, 3 million metric tons are collected, of which about 1.5 million metric tons are re-refined into base oils and intermediate products, while the rest is burned or improperly disposed of (VERTEX,2016). Currently there are 9 re-refiners with a daily re-refining capacity of 18000 barrels per day of used oil (Infineum, 2013).

In Europe, which is considered to be the front runner of the re-refining industry, the lubricants consumption stood at about 7.5 million metric tons; representing 19% of the global consumption. The waste oil recycling industry is comprised of 28 plants processing ca. 1.3 million metric tons per year (Kupareva et al, 2013). About 30 per cent of all base oils consumed in the EU are made from regenerated waste oils. Currently 81% of used lubricating oils are recycled out of 2.2 million tons collected annually (Kernies, 2013). About 728000 metric tons (35%) of the collected used oil are re-refined into base oils and 1149000 metric tons (55%) are burned as fuel. The rest is of unknown destination.

In Latin America, over 2.1 million metric tons are consumed annually. About 0.56 million metric tons are collected per year and only 0.3 million tons are re-refined.

In Asia Pacific, the largest lube oil market, about 12.5 million tons are consumed per year and 3.6 million tons are recovered. Only 0.67 million tons are re-refined.

Africa and the Middle East region account for 11% of the global demand.

While demand for the lubricants is expected to remain unchanged in the industrialized world, in the developing world the demand is expected to grow. The Asia-Pacific region, and to a less extent Latin America and Africa/Mideast regions, will remain the fastest growing regions, due mainly to increasing industrial output and expanding motor vehicle parks.

Figure 5 shows the regional lube oil consumption, collection and recycling of used oil.

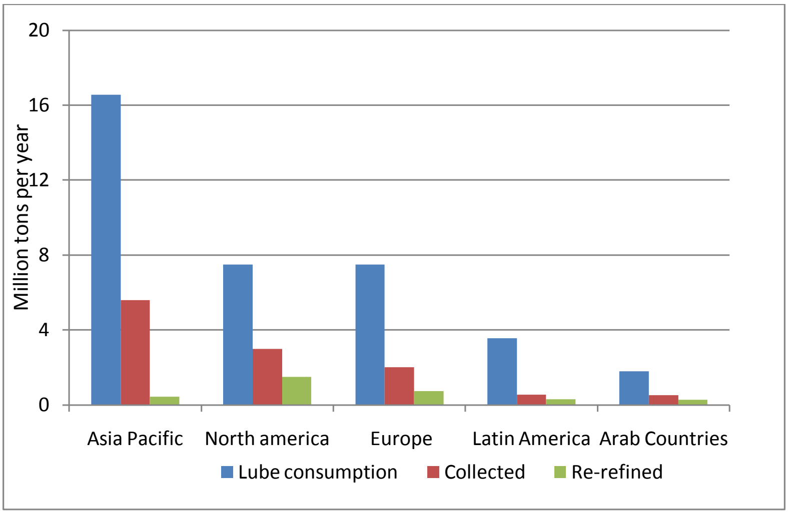

Figure 5 Regional lube oil consumption, collection and recycling of used oil
Source: Own elaboration; data collected from Vertex (2016); Statista (2015);UNEP(2012); Kline (2010)

3.2 Lubricating Oils chemistry and composition

3.2.1 Lubricating oil

Lubricant base oil is a heavy petroleum fraction and boils in the range of 300-400ºC under vacuum. The hydrocarbon composition of base oils consists primarily of complex molecules including saturated hydrocarbons, aromatics and parrafins. In order to make it suitable for use, this oil fraction, once separated from crude, undergoes further treatment whereby a large number of additives are added to the base oil. While reducing friction is a key objective of lubrication, there are many other benefits that can be accrued from it provided that additives are added to the base oil. These additives can enhance or suppress properties within the base oil. A typical lubricant may contain 90% base oil and 10% additives. The base oil, in combination with the additives, determines the flow characteristics of the finished lubricant, its volatility and its oxidation stability (Randles, 2007).

Additives include, but are not limited to, the following:

Antioxidants: They prevent decomposition occurring in lubricants as a result of oxidation in the presence of air.

Detergents: Detergents are alkaline in nature and react with acids which form during the combustion of fuel.

Anti-wear agents: They keep soot and combustion products in suspension thereby preventing their precipitation as sludge.

Corrosion inhibitors: They protect metal surface from corrosion

Viscosity improvers: They are additives that increase the viscosity of the fluid throughout its useful temperature range.

Antifoam additives: these substances prevent foaming which can occur as a result of air entrapment in lube oil.

Pour point depressants: they are used to prevent rapid increase in the viscosity which can occur due to crystallization, at low temperatures, of the paraffinic waxes present in lube oil.

3.2.2 Contaminants of used lubricating oil

As pointed out earlier, lubricating oils lose their initial properties as a result of accumulation of contaminants and chemical changes experienced during their use. The presence of degraded additives and by-products of degradation render used lubricating oils more toxic and harmful to health and environment than virgin base oils (Motshumiet et al, 2013). The main types of contaminants of potential concern are caused due to the following reasons (UNEP, 2012):

- Normal engine wear produces metallic particles w
- hich contaminate the lubricating oil.
- Water resulting from the combustion of fuel in the engine may pass into the lubricating oil and can ultimately lead to sludge formation.
- Incomplete fuel combustion in the engine may result in the contamination of the lube oil
- As a result of the combustion process, carcinogenic substances such as Polycyclic Aromatic Hydrocarbons (PAH), are formed.
- Soot and carbon may form as a result of incomplete combustion, especially during warm-up with a rich mixture.
- Unburnt gasoline or diesel can pass into the lubricant.
- Metals (Iron, Copper, and Aluminium) which are released due to normal engine wear, road dust, can find their way into the lubricating oil.

- Additives present in the lubricant will oxidize and form corrosive acids at elevated temperatures.

3.3 Characteristics of used lubricating oil versus virgin and re-refined oils

Abro et Al (2013) carried out an experimental work to determine the effect of re-refining on the properties of used lubricating oil. The re-refined oil's properties such as, specific gravity, ash content, viscosity, flash point, and metal content were analyzed and compared to those of virgin oil. The findings are presented in Figure 6 and Figure 7.

Figure 6 shows that the specific gravity of re-refined oil (0.88) is sensibly equal to virgin oil (0.9) and lower than the used oil (0.93). The ash content of the re-refined used lubricating oil was significantly reduced from 2.02% to 0.09%.

As illustrated in Figure 7, viscosity, which is an important parameter for consideration when it comes to choosing lubricating oils, has been decreased from 120 cP(used lube oil) to 94 cP(re-refined lube oil). The flash point of the re-refined oil was significantly improved from 120ºC (used oil) to 150ºC (re-refined oil) while iron content was reduced from 50 ppm to 13 ppm.

From these results it can be stated that re-refining effectively removed impurities from contaminated used oil. It can also be said that the quality of re-refined used lubricating oil is comparable to virgin lubricating oil.

3.4 Types of used lubricating oil suitable for re-refining

Generally speaking, only used lube oils with high viscosity index and less contaminant are suitable for re-refining (Fiedler, 2005). Based on the European waste category, the European re-refining industry association (GEIR) considers the following used lubricating oils suitable for re-refining:

- Engine oils without chlorine
- Hydraulic oils without chlorine
- Non-chlorinated mineral oils

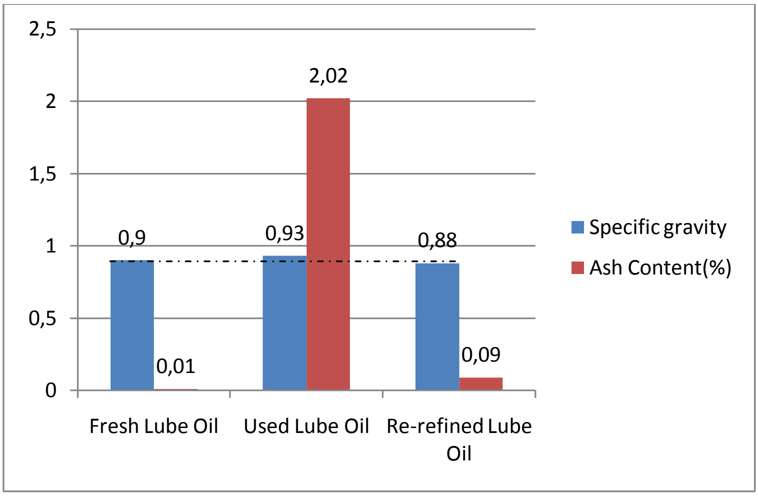

Figure 6 Comparison of Specific Gravity and Ash content before and after re-refining

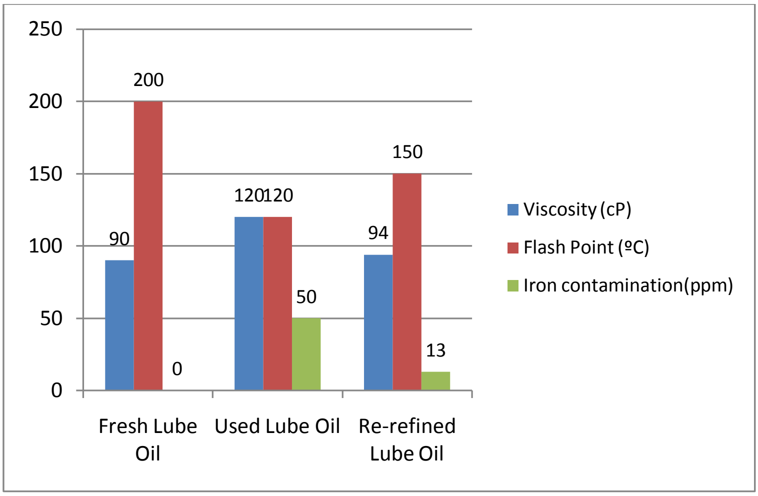

Figure 7 Comparison of Viscosity, Flash Point and Iron content before and after re-refining. Source: own elaboration with data from (Abro et Al, 2013)

4 Types of used lube oils re-refining processes

Present day re-refining technologies provide a wide range of possibilities for recovery of valuable base oil in a manner that is economically viable and environmentally acceptable. As pointed out earlier in Chapter 2, many technologies were developed in the late seventies and early eighties, which were based on existing oil refining technologies such as vacuum distillation, solvent extraction and hydrotreatment. When a re-refining project is contemplated, the investor is confronted to a wide variety of choices when it comes to technology selection. The choice is no easy task as there exist several competitive technologies and it is not within the scope of this study to analyze all the available technologies. In this section, we will provide a general summary and outline the key features of the processes with commercial applications.

4.1 Safety Kleen Technology

In 1998 the Safety Kleen process was used in the largest used lubricants re-refinery in the world. The plant is located in East Chicago, Indiana with a capacity of 250000 metric tons per year.

4.1.1 Process description

The Safety Kleen process is based on a combination of wiped-film vacuum distillation and fixed bed catalytic hydrotreatment. Key processing steps are as follows:

Dehydration
The used oil is first dehydrated by evaporation to remove any water present in it.

Light ends recovery
The light fuels are removed in an atmospheric flash drum and collected. The vacuum column/fuel stripper removes most of the fuel and heavier solvents.

Vacuum distillation
Next, the dewatered oil undergoes higher vacuum distillation to remove the lube cut of feedstock while the by-products are used to produce asphalt extender.

Hydrofinishing
Then, the lube cut undergoes hydrotreating to remove residual polymers and other chemical compounds. In this step, sulphur, nitrogen, chlorine, heavy metals and other impurities are removed. The color, the odor and the corrosion performance of the base oil are also corrected.

Finally, the re-refined base oil is separated into different oil grades: Light viscosity lubricants suitable for general lubricant applications, low viscosity lubricants for automotive and industrial applications and high viscosity lubricants for heavy duty applications (Fernatt, 2013).

The process main steps are outlined in Figure 8.

4.1.2 Process features and drawbacks

It is claimed that the base oils recovered by this process meet API standards for base oils. Lubricants made from Safety Kleen base stock include engine oils, gear lubricants, power transmission fluids, hydraulic oils, and industrial oils, all of which meet industry standards and specifications and therefore do not jeopardize warranties or the performance of equipment (UNEP, 2012).

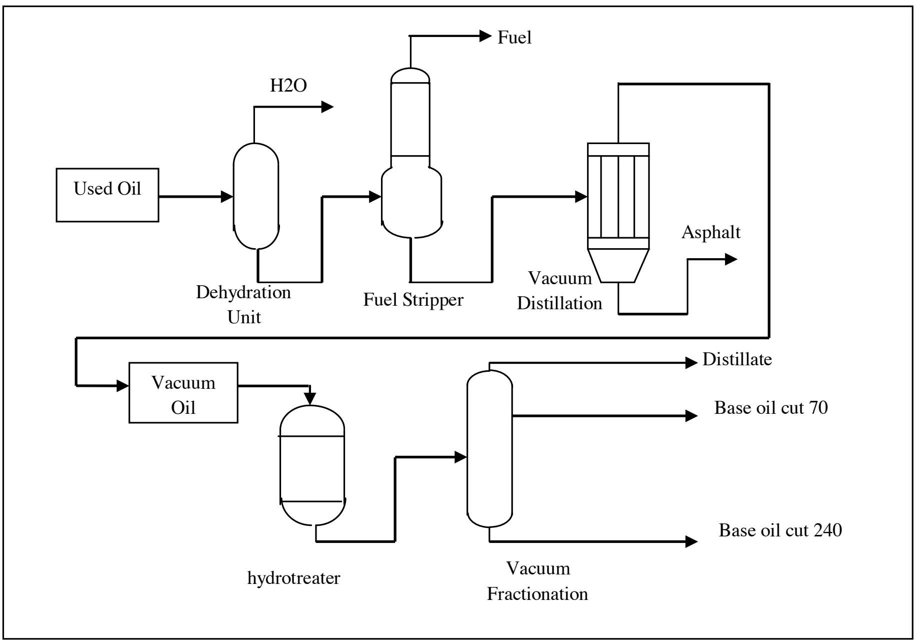

Figure 8 Safety Kleen simplified process flow diagram
Source: Fernatt (2013)

4.2 KTI process

4.2.1 Process description

The KTI (Kinetics Technology International) also known as KTI relube is constituted of the following sequences:

Atmospheric distillation:
In this step, Water and light hydrocarbons are removed.

Vacuum distillation:
Thin film vacuum distillation to produce the lube fraction

Hydrogenation:
The distilled fraction is hydrogenated in order to eliminate contaminants and additives

Fractionation:
The hydrogenated fraction is fractionated into light and heavy oil.
Figure 9 shows a simplified flowsheet of the KTI re-refining process.

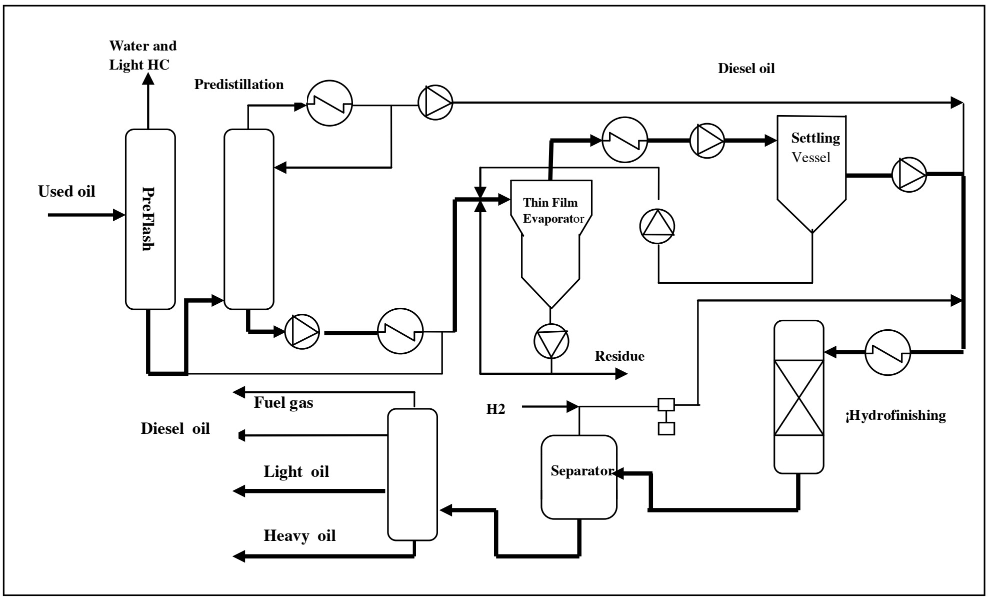

Figure 9 KTI simplified process flow diagram
Source: Audibert as cited UNEP(2012)

البحث الثاني

4.2.1 Process features and drawbacks

The vacuum residue of this process may represent a major environmental problem if not valorized in a commercial operation such as asphalt manufacture (can be used as asphalt extender). Key to the process is the thin-film vacuum distillation. The yield of finished base oil is about 82%.(UNEP, 2014, Walker R, 2013). The first re-refining plant (20000 MTPY) to utilize the KTI Process was completed in 1982 (Fok, 1986).

4.3 The CEP/Mohawk process

The CEP process-also known as CEP-Mohawk process- was introduced in the late 1980s by Chemical Engineering Partners (CEP).

4.3.1 Process description

The process consists of the following steps:

Feedstock analysis:
Due to process consideration the feedstock must analyzed to make sure it is suitable for re-refining.

Chemical treatment:
In order to reduce fouling in the process equipment, the feedstock undergoes a chemical treatment whereby water and light hydrocarbons are removed. Next the contaminants and additives are removed to avoid catalyst poisoning.

Vacuum distillation:
After pre-treatment, the feedstock is sent to a wiped film evaporator operating under vacuum. The vacuum allows the separation of base oil from additives below cracking temperatures.

Hydrotreatment:
Three hydrotreating reactors are used in series to reduce sulfur and increase saturates to produce base oils meeting specifications for API group II.

Fractionation:
The hydrotreated base oil is separated into light and heavy cut.

4.3.2 Process features and drawbacks

The hydrotreating process is claimed to reduce sulfur to less than 300 ppm and increase saturates to over 90%, meeting the key specifications for API Group II base oil.

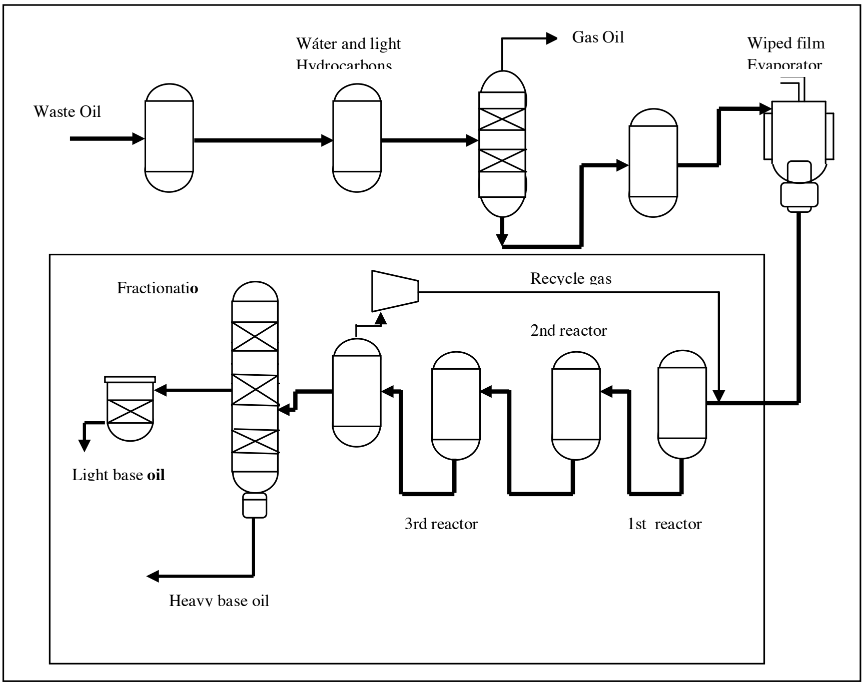

Figure 10 CEP simplfied process flow diagram
source: CEP

4.4 UOP Hylube process

4.4.1 Process description

This technology was designed by UOP in 1995. This process which operates on continuous basis is made up of the following stages:

Pretreatment:
The feedstock is first filtered to remove solids and then mixed with hot hydrogen in a pressurized mixing chamber. The heat mixture is sent to flash separator where the bottoms are routed to a residue stripper.

Hydroprocessing:
In the multi-stage high-pressure system, the gaseous hydrocarbon materials are initially separated from the residual impurities and metal compounds (guard reactor), and then processed through a severe hydofinishing reactor. Using patented hydrogenation catalysts, a deep saturation of olefins and aromatics is achieved (conversion reactor),

which are then hydro finished at adequate high temperatures and pressures. These processes involve intense desulphurization and elimination of other impurities.

Product recovery:
The processed feedstock is converted into a wide boiling range hydrocarbon product, which is subsequently fractionated into neutral oil products of different viscosity to be used for lube oil blending.

4.4.2 Process features and drawbacks

It is claimed that the Hylube process achieve more than 85% of base oils suitable for re-blending into saleable lube oils. It is reported that Lube base stocks quality is equal to virgin base oils (ref.) It is also claimed that no environmentally undesirable by-products are produced. The heavy residue is suitable for asphalt blending. The aqueous effluent has low COD and no organochlorines.

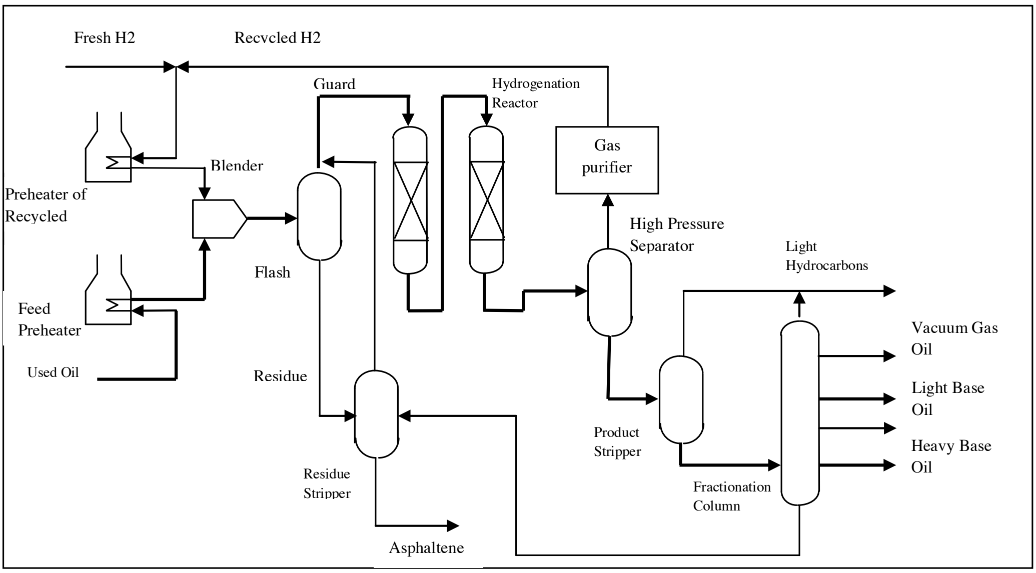

Figure 11 UOP Hylube simplified process flow diagram
Source: UOP

4.5 Axens/Viscolube (Revivoil) process

The Revivoil process was developed jointly by Axens and Viscolube. It combines two technologies: thermal deasphalting and catalytic hydrogenation.

4.5.1 Process description

The process comprises the following steps:

Pre-flash:
The feedstock is heated (140ºC) and distilled in a column where the water and light hydrocarbons are removed.

Thermal De-asphalting:
The dehydrated oil is distilled at 360 ºC in a vacuum de-asphalting column. The asphaltic and bituminous products remain at the bottom.

Hydrofinishing:
The dehydrated oil is treated in the fractionation column(vacuum de-asphalting column) where the asphaltic and bituminous products remain at the bottom and three side cuts of different viscosity are obtained at the same time. Gas oil (VGO) is collected at the top of the column. The base oil fraction is hydrotreated in the catalytic reactor to eliminate unsaturated compounds, sulfur and nitrogen. The effluents from the catalytic reactor are separated into a liquid phase and vapor phase. The liquid phase is stripped with steam to eliminate the most volatile compounds. The re-refined base oil is obtained at the bottom of the stripper.

Figure 12 illustrates the simplified process flow diagram.

4.5.2 Process features and drawbacks

This lubricating base oil has many advantages it is beneficial to health and the environment as well as demonstrating excellent performance on the lubrication circuits where it is used. The final result is clear oil with very low sulphur and aromatics content.

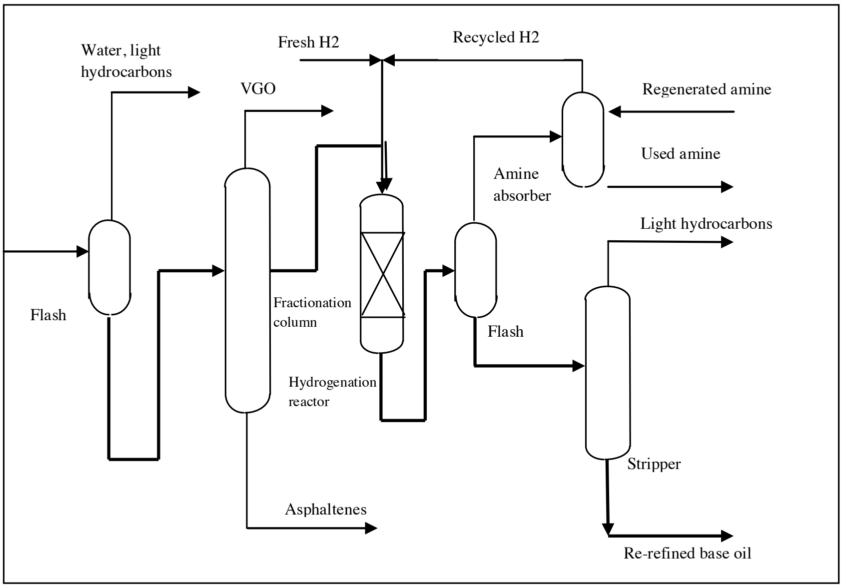

Figure 12 Revivoil simplified process flow diagram
Source: Petder (2012)

4.6 STP Process

STP (Studi Tecnologie y Progetti) is the supplier of this re-refining technology which is based on thin film evaporation and hydrofinishing.

4.6.1 Process description

The basic steps of the process are as follows:

Dehydration and lights removal:
The stocked used oil is pumped through a filter and preheated through heat exchangers which help in recovering heat from finished products. It is then treated with chemical additives. The treated oil is flashed in the flash drum to remove water and light hydrocarbons. Gases are burnt in a thermal oil furnace. Water and hydrocarbons are condensed and separated in a settler.

Gas oil stripping:
The dehydrated oil is sent to the gas oil stripping column working under vacuum. Gas oil from the column overhead is condensed and sent to storage. Incondensable gases from the vacuum system are sent to a thermal oil furnace.

Vacuum distillation:
The oil coming from the gas oil stripping column is introduced into a high vacuum distillation column with thin film evaporator, where the separation of the lubricating fraction and the residue takes place. The lubricating cut is then condensed and sent to finishing while the asphaltic residue is sent to storage.

Finishing:
Finishing is done through chemical treatment for API Group I products or through hydrofinishing in the case of API Group II lubricants production. Finished oil is then sent towards the fractioning column and separated into two regenerated basic oils cuts (150 SN and 500 SN) that are claimed to have the same specifications as their corresponding new base oils. The column bottom is recycled towards the vacuum distillation column.

The simplified process flow sheet is illustrated in Figure 13.

4.6.2 Process features and drawbacks

STP claims that process removes all the contaminants from the used lube oil and recovers a base oil product as VGO or high quality lubricant which is in either API Group I by chemical finishing or API Group II by hydro finishing. STP has implemented several Re-refining Plants worldwide. The advantages of the process are:
High flexibility towards feedstock quality and composition
The lube oil recovery is more than 95% of the lubricant fraction present in the used oil.
The process is claimed to be highly competitive in terms of capital investment and operating cost. It is also environmentally friendly as there is no use of acid and clays.

4.7 Probex process

The Probex (also known as Proterra) waste oil re-refining technology was patented in 1997 by Probex Co. This process is based essentially on vacuum distillation and solvent extraction applied to vacuum distillates.

4.7.1 Process description

The basic steps of the process are:

Lights removal:
In this first step the waste oils are treated and light hydrocarbons are separated in flash drum. The residue is sent to a vacuum tower.

Vacuum distillation:
In this step asphalthenes and other impurities are separated from the oil and different viscosity grade oils can be produced. The base oil fraction is delivered to a liquid-liquid extraction column after it is cooled.

Solvent extraction:
The treated base oil fraction is extracted with n-methyl-2-pyrrolidone, where unsaturated, aromatic and heteroatom containing molecules are eliminated. Unsaturated, aromatic and heteroatom containing compounds are in extract phase; the base oil forms the raffinate phase. The solvent is separated from the extract and returned to the process after being reprocessed from both of the abovementioned products with stripping. The extract phase contains up to 10% base oil fraction as a function of process parameters.
The process flow diagram is depicted in Figure 14.

4.7.2 Process features and drawbacks

Probex offers the following advantages: no use of high temperature and pressure, no use of hydrogen, no catalyst handling and replacement. It is claimed that the yields are comparable to hydrofinishing processes.

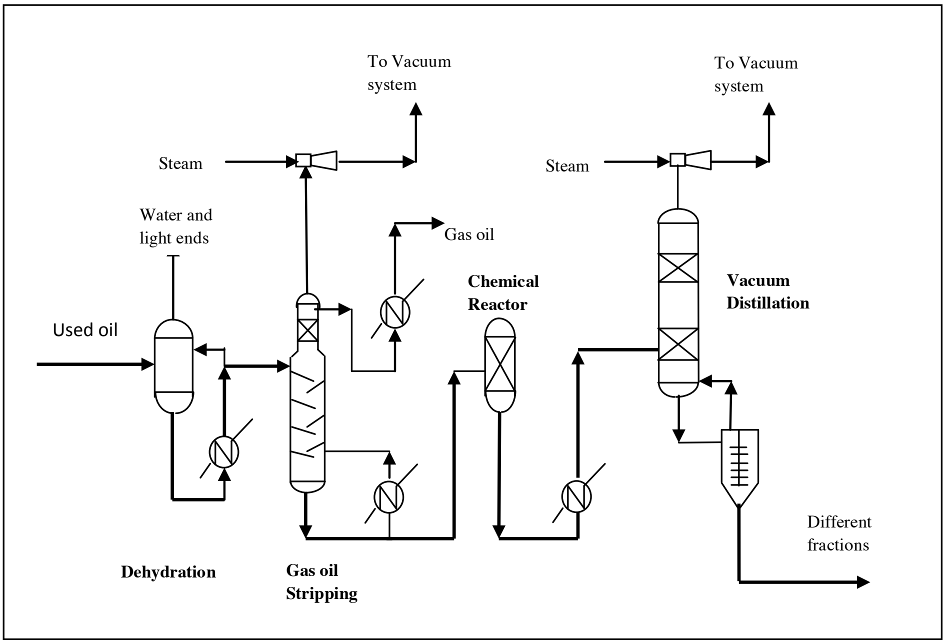

Figure 13 STP simplified process flow diagram
Source STP

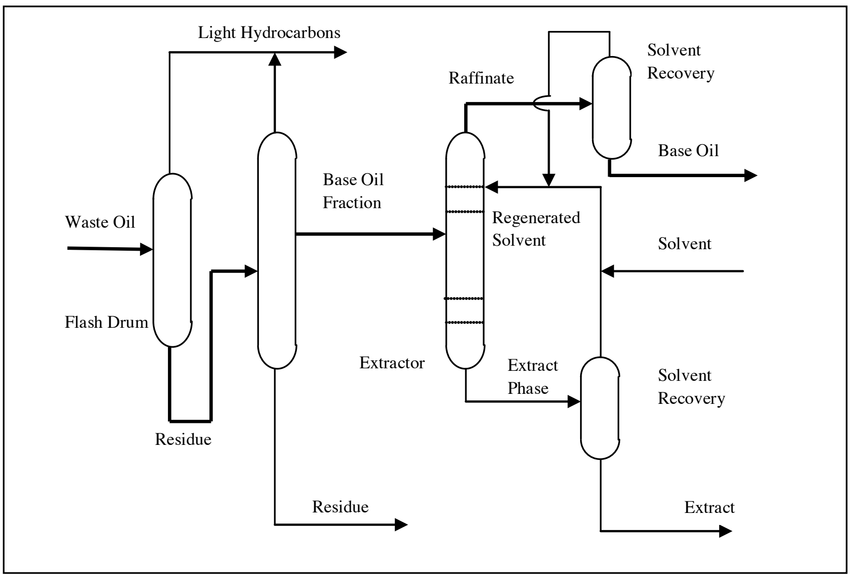

Figure 14 Probex simplified process flow diagram

4.8 PROP technology

The PROP (Phillips Re-refined Oil Process) technology, developed by the Phillips Petroleum Company, combines chemical demetallisation and hydrogenation to remove contaminants from the used lube oil.

4.8.1 Process description

The basic steps of the process are as follows:

Demetallization and contaminants removal:
The process begins by mixing an aqueous solution of diammonium phosphate with heated used lube oil to reduce the metal content of the oil. Chemical reactions lead to formation of metallic phosphates, which are subsequently removed by filtration. The remaining oil is then flashed to remove light hydrocarbons, gasoline, and water.

Hydrogenation:
Next, the oil is mixed with hydrogen and percolated through a bed of clay, and passed over a Ni/Mo catalyst in the hydrogenation reactor. The adsorption step removes the remaining traces of compounds which might poison the catalyst. During the hydrogenation process, sulphur, oxygen, chlorine and nitrogen-containing compounds are removed and the oil's color is thereby improved.

The PROP process flow diagram is depicted in Figure 15.

4.8.2 Process features and drawbacks

The major solid by-product is described as neutral phosphate material with no potential disposal problem. This by-product can be safely disposed of in a landfill. Liquid stream byproducts relate to light ends and heavy gasoline which can be used as fuel. However, the used catalyst is typically treated as hazardous waste. The spent catalyst represents a hazardous waste product.

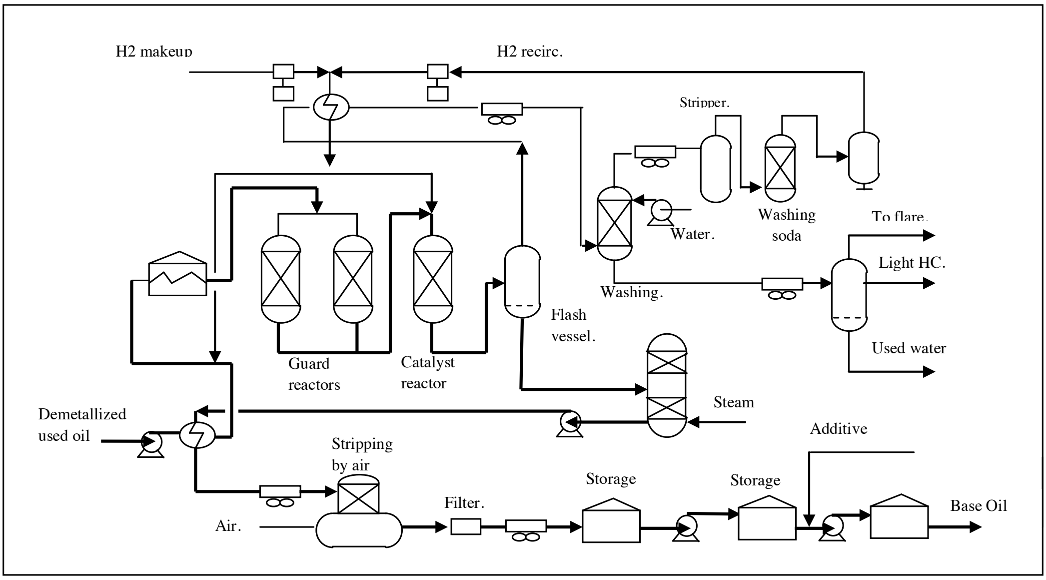

Figure 15 PROP process process flow sheet
Source: Audibert as cited in UNEP (2012)

4.9 IFP technology

IFP technology was developed by the Institut Francais du Pétrole. The principle of this process, also known as Selectopropane process, is based on the use of propane to extract selectively all base oil components from used lubricating oil.

4.9.1 Process description

The process comprises the following steps:

Atmospheric distillation:
First, water and light hydrocarbons are removed in the atmospheric distillation column.

Vacuum distillation:
Then, oil from atmospheric distillation is subjected to extraction with liquid propane at a temperature of between 75 and 95ºC. Light and medium base oils are recovered in this phase.

Hydrogenation:
In this step the vacuum distillates are hydrotreated to produce finished base oils. This is the stage where the propane is separated from the propane-oil mixture. Asphaltic

compounds, oxidized hydrocarbons and solids in suspension are also separated in this stage. The bright stock is recovered from the vacuum residue by propane deasphalting. The final stage is the hydrogenation of the bright stock fraction.
The process is shown schematically in Figure 16.

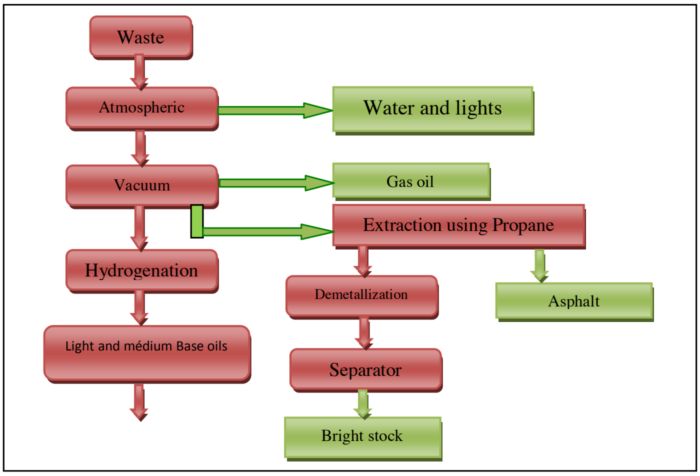

Figure 16 IFP simplified block flow diagram
Source: UNEP (2012)

4.9.2 Process features and drawbacks

Possibility to produce several base oils with various characteristics.

4.10 Snamprogetti process

The Snamprogetti process is similar to the IFP technology in that it uses the same processing steps including propane extraction. Snamprogetti has modified the process by adding a propane extraction step before and after vacuum distillation.

4.10.1 Process description

The process consists of four steps:

Atmospheric distillation:
In this stage, water and light hydrocarbons are eliminated in the extraction column..

Solvent extraction:
Next, waste oil from atmospheric distillation is refined with liquid propane at 75–95 ºC in the propane de-asphalting(PDA)unit. With this step, the majority of the contaminants such as asphalt compounds, oxidized hydrocarbons and suspended solids are separated from the oil.

Vacuum distillation:
In this step base oil is recovered as distillate and sent to hydrogenation unit for further treatment. The vacuum distillation waste is sent through a second extraction, using propane, which is combined together with the vacuum distillate in the hydrogenation unit.

Hydrogenation:
In this final stage, base oils with different properties are produced in the hydrotreatment unit. The bright stock fraction is also recovered from the waste from vacuum distillation.

4.10.2 Process features and drawbacks

There exists the possibility to produce several base oils with various characteristics. The PDA bottoms are used in the asphalt production. The solvent is recycled in the process with minor losses (5~10%).

Figure 17 illustrates the simplified process flow sheet of the SNAMPROGETTI process

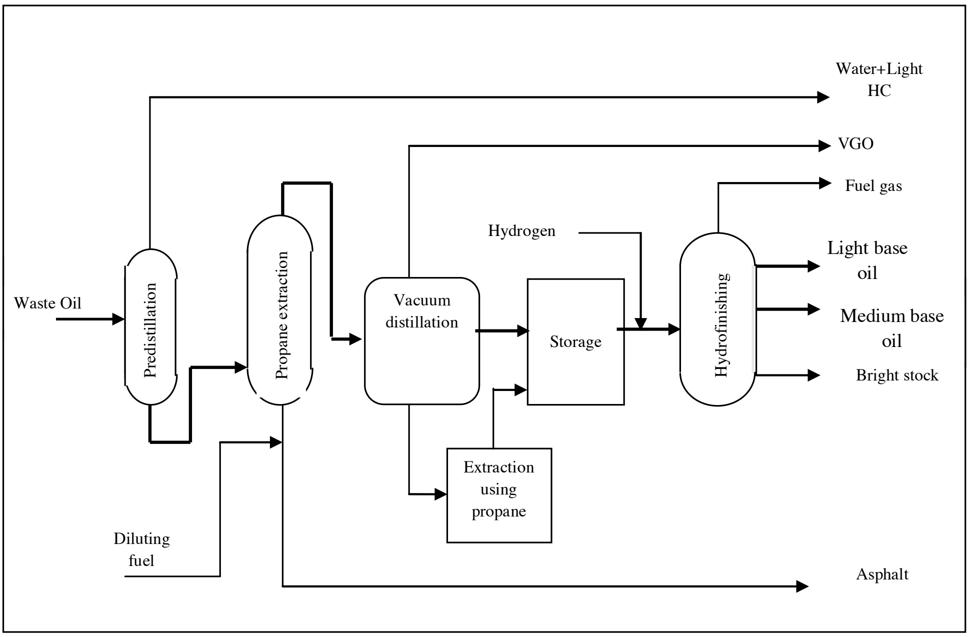

Figure 17 Snamprogetti simplified process flow diagram
Source: Snamprogetti

4.11 Vaxon process

Vaxon technology also known as VCFE (Vacuum Cyclon Flash Evaporator) was developed in Denmark. The advantage of this process is the special vacuum distillation unit detailed below where the cracking of oil is highly decreased.

4.11.1 Process description

The basic steps of this process are as follows:

Fractionated vacuum distillation:
In this initial stage, water, light hydrocarbons, metal compounds and other bituminous elements are separated out. This stage takes place in four modules under different temperature and vacuum conditions, and base oils that are suitable for the following treatments are obtained in the last two modules.

Chemical treatment:
In this step, the base oils from the previous stage are treated with potassium hydroxide, using temperature control and cleaner oil is obtained. Drying of the oil occurs during this stage. The polycyclic aromatic hydrocarbons are separated by solvent refining with polar solvents (dimethyl-formamide, n-methyl-2-pyrrolidone, etc.).

Vacuum distillation:
In this final stage, vacuum distillation is performed to obtain a product that is appropriate for the needs and conditions of the market.

4.11.2 Process features and drawbacks

This technology enables base oils to be obtained that are suitable for the manufacturing of new engine oils and industrial lubricants. It is claimed that these are high quality oils that have been approved according to the strictest regulations that exist at the present time. In environmental terms, this is a clean technology because the waste that is generated in the process is re-circulated in the same process.

Figure 18 shows the Vaxon Process simplified Block Flow Diagram.

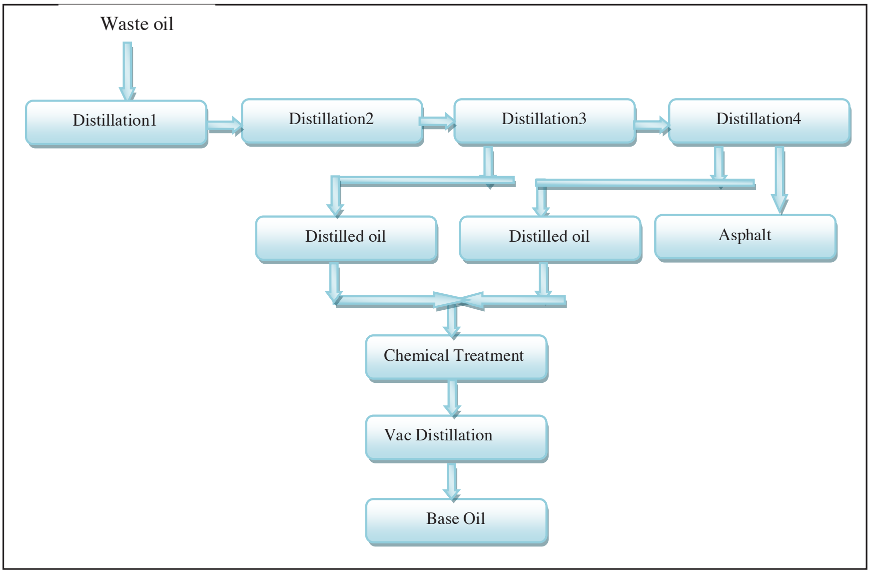

Figure 18 Schematic of the VAXON re-refining process
Source UNEP (2012)

4.12 Interline Technology

This technology was developed by Interline Resources Corporation. It can be applied for production of different oils for vehicles (e.g. motor oils, transmission oils), industrial oils and process oils. The European Environmental Press awarded its 2003 Bronze Medal for Interline Resources Corp.'s re-refining technology (BW, 2004).

4.12.1 Process description

The basic steps of this process are as follows:
Solvent extraction:
The used oil feed is mixed with propane and the mixture is then sent to a specific solvent extractor, a proprietary system. Most of the additives, water and other insolubles are separated from the propane/base oil mixture. Then, the solvent/oil mixture is pumped to an oil/solvent separation system. The propane is vaporized at a pressure high enough to allow the propane to be condensed at the cooling water temperatures. The recovered propane is then returned to the solvent extractor to be re-used with incoming used oil.

Flash and Vacuum distillation:
Propane free oil is sent to a light hydrocarbon stripper where the last traces of propane and low-boiling hydrocarbons (gasoline) are removed.

Filtering:

The flash adjusted oil is then directed to a traditional vacuum distillation column. The distilled lubricating oil product is a high quality base oil which, with a clay polishing step, can be blended and marketed as a virgin quality lubricating stock.

4.12.2 Process features and drawbacks

It is claimed that with his process, it is possible to produce 70-75% base oil by separating the water, degraded additives, wear metals and other contaminants in the oil. Propane extraction of the entire used oil stream results in a number of significant technical/economic advantages over traditional re-refining technologies that do not include a hydrogen treatment stage (Kajdas, 2013). The Interline technology eliminates the need for wiped-film distillation (CEP, KTI, Safety Kleen) because the extraction phase removes most of the used oil impurities that cause problems in traditional distillation columns. As the process also eliminates the need for a hydrogen finishing stage, it cannot handle waste oil contaminated with PCBs. The process operates without extensive pressure and temperature (Giovanna et al, 2003). The operating and capital costs are relatively low.

The simplified process flow sheet is illustrated in Figure 19.

4.13 ROSE/Kellog technology

4.13.1 Process description

The ROSE (Residuum Oil Supercritical Extraction) process was developed by Kerr-McGee and sold to Kellog. This technology allows the treatment of used oil mixed with grease. The basic steps of this technology are:

Solvent extraction:

In this step, the used oil is extracted with propane in two stages. In the first stage, asphaltenes are removed by subjecting the oil to a specific temperature and pressure. In the second stage, the de-asphalted solution of oil and solvent is subjected to a supercritical temperature and pressure that facilitates the separating out of the oil and solvent, which can then be recovered and reused in the cycle.

Vacuum distillation:

In this step, the solvents are separated from the lubricants by subjecting the oil – solvent mixture to vacuum conditions (40-200 ºC and 1-100 kPa)

Hydroprocessing:

Finally, the solvent-free extracts go through hydroprocessing to improve the content quality.

The simplified block flow diagram is illustrated in Figure 20.

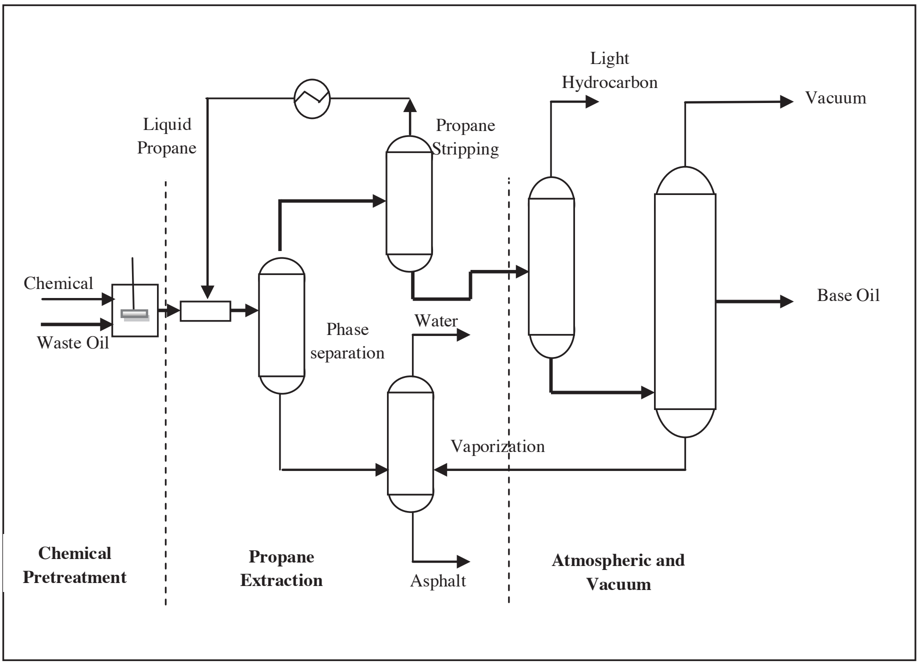

Figure 19 Interline simplified process floe diagram
Source: Audibert (2006)

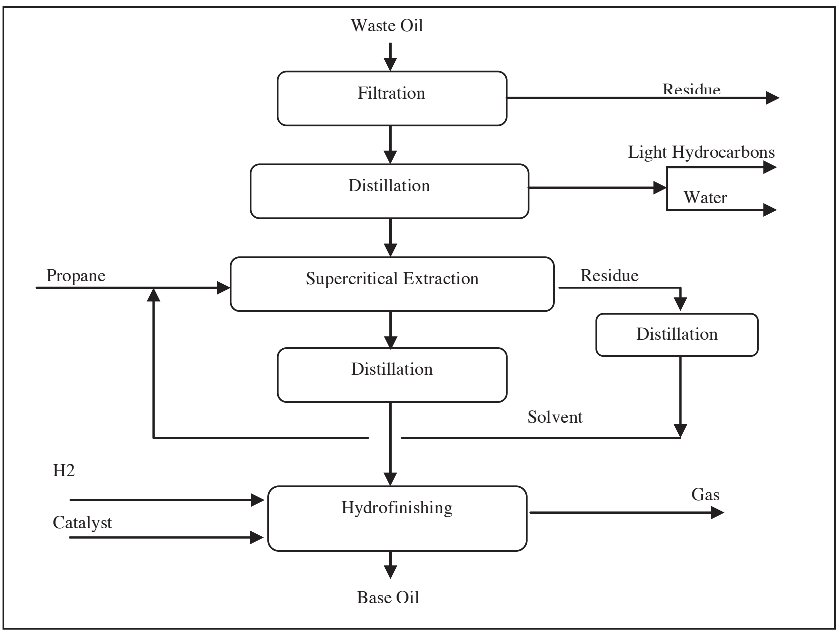

Figure 20 ROSE/Kellog simplified block flow diagram; Source Giovanna et al (2003)

4.13.2 Process features and drawbacks

The process is claimed to enable energy and capital cost savings over other solvent extraction processes. This technology permits the treatment of used engine oils mixed with lubricating grease, provided that the content of the latter does not exceed 5%. Grease is made up of 85% of oil. This technology enables important energy savings to be made, due to the recovery of the solvent in supercritical conditions. As with Interline technology, it also allows the oil content in grease to be recovered.

4.14 Acid/Clay (Meinken) process

Although this technology is phasing out, it is described briefly below and is carried out as follows:

4.14.1 Process description

The process consists of the following steps:

Pretreatment:
The waste oil is filtered to remove any solid impurities. The oil is dewatered in large settling tanks wherein the heavier water settles to the bottom of the tank and the lighter oil floats on top. The water at the bottom is drained off and should normally be treated before disposal. However, this does not remove the water completely and a small quantity still remains.
Figure 21 shows the flowchart of the process.

4.14.2 Process features and drawbacks

For economic reasons and because of environmental pollution inherent to the treatment of acid clay/earth, the technology is no longer in use. The process involves problems of internal corrosion and disposal. The main advantages of this process are the low investment and maintenance costs, the possibility of treating low quality used oil and ease of handling the process itself. The process cannot remove sulphur compounds, polycyclic aromatic hydrocarbons. Final product quality is related to the quality of raw material. There exists modified Meinken process that includes the use of thin film and contact distillation techniques.

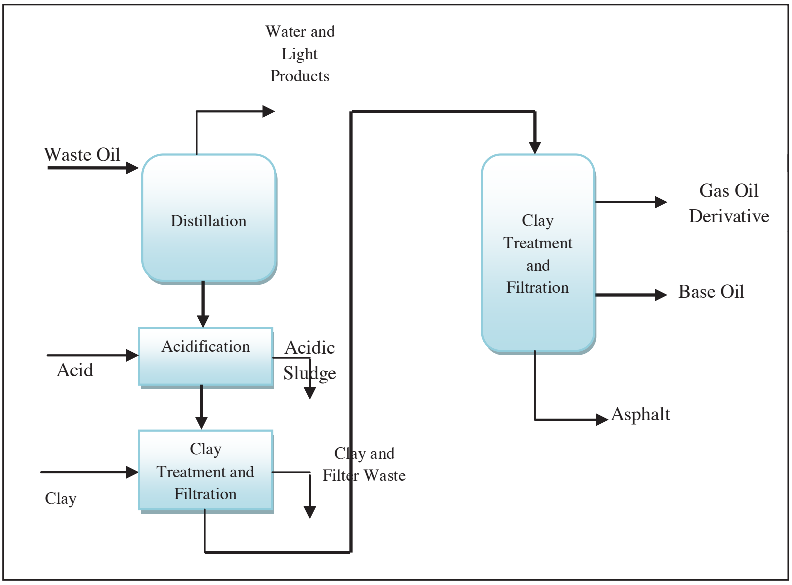

Figure 21 Acid/Clay re-refining process
Source: Giovanna et al (2003)

4.15 ENTRA technology

This technology developed by the ENTRA Company is similar to the distillation/clay treatment approach, being also based on distillation and clay polishing. The difference lies in the fact that the vacuum distillation is carried out in tubular reactors.

4.15.1 Process description

The basic steps of this process are as follows:

Preliminary stage:
A vacuum distillation stage at 130ºC and 100 mm Hg. pressure. The stage involves the separating out of water and light elements.

Cleaning stage:
In the tubular reactor, the used oil gets converted into a vapor due to the rapid increase in temperature. The vapor is then subjected to fractionated condensation. The evaporation process is produced by injection of the oil at a constant speed and at a

temperature of 400ºC. The oil obtained in this stage is free of solid impurities, and metal and other elements.

Discoloration and purification stage:
At this stage, the visual appearance of the base oils is improved. The chlorinated compounds are removed through the addition of Sodium.

The simplified process flow diagram is illustrated in Figure 22

4.15.2 Process features and drawbacks

It is claimed that it is a high performance process in which control of the temperature is highly important for obtaining the required results. The process is considered to be clean technology according to the IACT (International Association for Clean Technology). The TÜV analysis (Technische Überwachungsverein) shows the total elimination of PCBs. The main drawback is the handling of sodium, which is complex and hazardous.

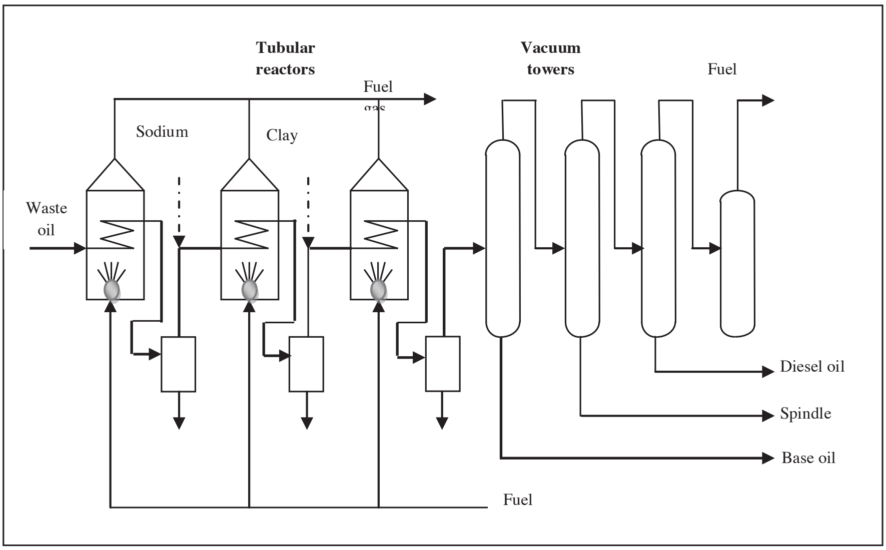

Figure 22 ENTRA simplified process flow diagram
Source: Audibert (2006)

4.16 RTI technology

This technology is based on the Vacuum Cyclone Distillation/Clay Treatment technical principle. This process also enables plants that are based on acid/earth technologies to be transformed to RTI technology.

4.16.1 Process description

The basic steps of the process are as follows:

Separation:
In this step the used oil is dehydrated and heated

Flash/Vacuum distillation:
Water and light hydrocarbons are removed

Earth treatment: In this step, the feed is treated with activated clay to improve the properties.

Vacuum distillation:
In this stage the additives and pollutants that are still in the used oil fraction are separated. Waste oil is dewatered, heated and flashed and then distilled for water and light hydrocarbons removal.

Figure 23 illustrates a simplified block flow diagram.

4.16.2 Process features and drawbacks

It is claimed that cyclonic distillation decreases coke formation and, as a result, reduces fouling of the equipment and increases the stream factor. Oily clay residue is disposed of in landfill while vacuum tower bottoms can be used in asphalt industry.

The quality of the product is not very high, because technology uses clay treatment but not hydrofinishing.

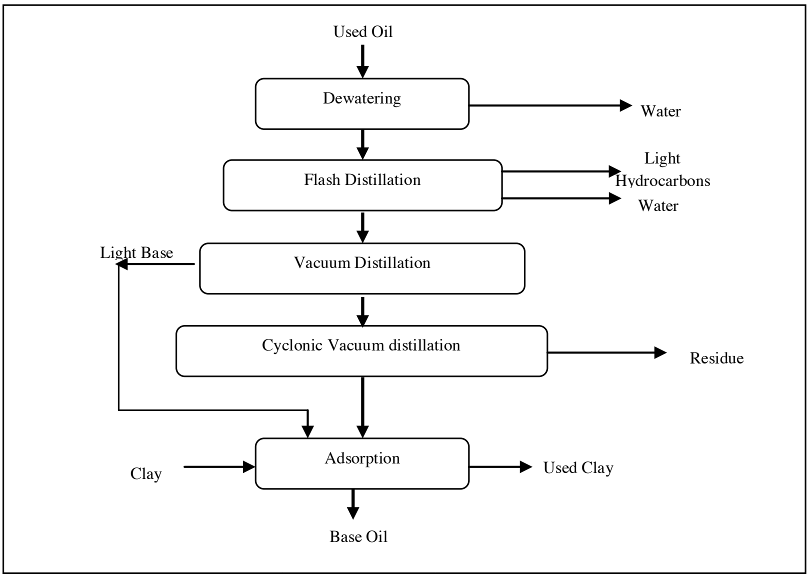

Figure 23 RTI simplified block flow diagram
Source Giovana et al (2003)

4.17 SOTULUB technology

This technology was developed by Societe Tunisienne des Lubrifiants (SOTULUB). It is based on the injection of a strong base at various stage of the process.

4.17.1 Process description

The SOTULUB process consists of the following steps:

Dewatering:
In this section, water and light hydrocarbons present in the used oil are separated by flashing: Used oil entering the process unit is preheated in heat exchangers at about 160°C by recovering the heat of the distillates from the distillation and fractionation columns then mixed with a small ratio of ANTIPOLL. Antipoll, an alkaline product, is injected to the used oil under dosing rate control. The mixture is drawn into a flash drum were water and light hydrocarbons are separated under atmospheric pressure and then treated separately.

Gas oil stripping:
In this section, gas oil present in the dehydrated used oil is separated under vacuum. The dehydrated oil is heated again to approximately 280°C and drawn to a stripper

where gas oil is removed from the oil under vacuum, then condensed and stored for eventual reuse.

Vacuum distillation:
In this section the lubricating fractions contained in the used oil are distilled out under high vacuum conditions: The stripped oil is delivered to a distillation column coupled with a thin film evaporator where it is distilled under high vacuum. This operation results in a distillate and a bottom asphaltic residue where heavy metals, chemical additives, polymers and degraded products are concentrated. The residue is stored then reused for other ends. The unflashed oil flows under gravity to the thin film evaporator. The flash vapours generated in the evaporator flow to the distillation column where they are fractionated into light and heavy distillates.

The simplified process flow diagram is shown in figure 24.

4.17.2 Process features and drawbacks

In this process no finishing step is required hence a decrease in the investment cost but a low quality product. The process is based on KTI technology which was modified by Sotulub which operates a 16000 tons/y plant in Tunisia.

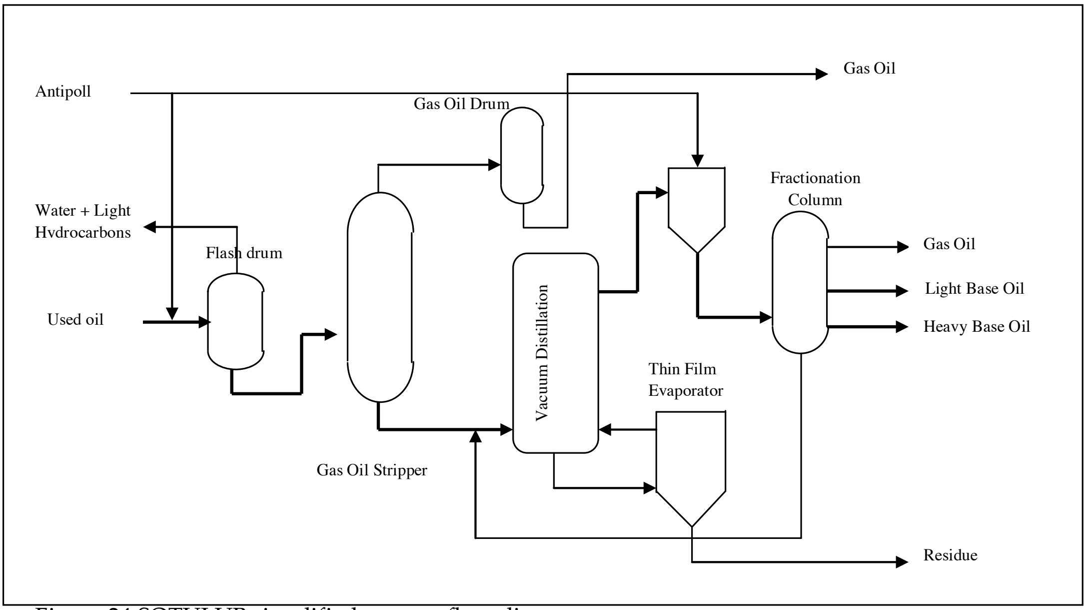

Figure 24 SOTULUB simplified process flow diagram

Source: Sotulub

4.18 MRD Technology

The technology based on liquid-liquid extraction was developed by Mineralol-Raffinerie-Dollbergen (MRD) in the mid-1990s. It is claimed to be one of the latest solvent extraction processes.

4.18.1 Process description

The MRD process consists of the following steps:

Dewatering stage:
Atmospheric distillation is used for separating water and low-boiling fractions

Vacuum distillation and thin film evaporation:
The extract recovery section also consists of a distillation and a stripping column. Pre-treated oil is vacuum-distillated with production of a gas oil fraction. Then it is sent to a special extraction column, where base oil fraction is separated from the extract by specific solvent(N-Methyl Pyrrolidone), which allows quantitative removing of PAH and preservation of the positive impact of low temperature viscosity behavior of these groups of oils.

Solvent Recovery:
The humid solvent separated in the stripping columns of the Raffinate and Extract recovery sections is returned to the solvent drying column, where excess water is removed. The 'dry' solvent is also returned to the solvent tank. From there, the dry solvent can again be used for extraction purposes in the extraction column.

4.18.2 Process features and drawbacks

The MRD solvent extraction process is considered the latest development for refining vacuum distillates from used oils. It is claimed that the novel process developed by MRD completely satisfies the requirements existing for a modern technology for producing from used oils high-quality base oils, the properties of which in some respects are even superior to those of the classical solvent raffinates produced from petroleum.

A plant is operating near Hanover, in Germany. The re-refinery has a capacity allowing it to process 230,000 MTPY of used oil and oil-containing liquids. 120,000 MTPY thereof are used as feedstock for the production of 70,000 MTPY of new base oils.

The simplified process flow diagram is illustrated in Figure 25.

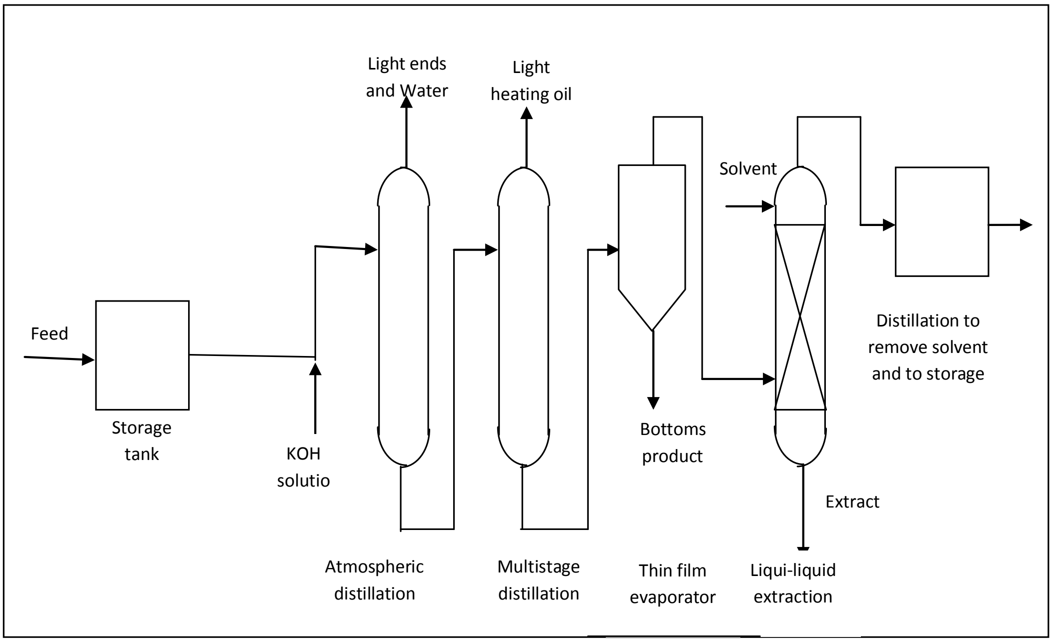

Figure 25 MRD simplified process flow diagram
Source: Speight et al (2014)

5 Comparison of available technologies

In light of the foregoing technology review which covered only some technologies which have found their way into commercial application, it can be seen that these technologies, albeit consisting of different unit operations, are all based on a sequence of steps which can be grouped under three main heading: Primary treatments, secondary treatments and finishing treatments. The process always starts with a primary treatment, followed by a secondary treatment and finally a finishing (tertiary) treatment. Full details of the various treatments are provided in Audibert (2011). A brief overview is given below:

5.1 Treatment steps

i) Primary treatments

Primary treatment is the first stage of any re-refining process. It is all too common for re-refining technologies to start up with a primary treatment which is designed to remove an important part of the used oil contaminants such as water, light hydrocarbons, sludge, coarse particles, etc. For this, each technology uses a particular method, or even a combination of several. Methods may include, but are not limited to, the following: Filtration, settling, decantation, centrifugation, dehydration, heating, thermal treatment, atmospheric distillation, demetallization , chemical treatment, etc.

ii) Secondary (Separation) treatments:

In order to remove additives such as heavy metals, sludge, etc., each technology uses a separation procedure. In the acid/clay technology, an acid is used to settle out the oil followed by an earth (clay) treatment to remove other contaminants. Other technologies use chemical processes such as solvent extraction (Interline, Rose/Kellog), or physical methods such as vacuum distillation (PROP, KTI, IFP). Secondary treatment re-refining technologies include, but are not limited to, the following: physical-chemical treatment, thermal treatment, solvent extraction, vacuum distillation,

iii) Tertiary (Finishing) treatments

While the earlier stages (i.e. primary and separation treatments) allow the re-refining technology to achieve a contaminant-free base oil, a finishing step is necessary in order to obtain a commercially viable base oil that is appropriate for the needs and conditions of the market, especially in terms of odor and color characteristics. As in the previous stages, each system uses a different unit operation to "finish off the look" of the end product. Methods may include, but are not limited to, the following: Bleaching, hydrotreating, fractionation, treatment with zeolites, vacuum distillation.

Table 3 summarizes re-refining technologies where the unit operations corresponding to major steps are sequenced in order of occurrence.

Unit operation[1] \ Technology	Safety kleen	KTI	CEP/Mohawk	Hylube	Revivoil/Viscolube	PROP	Probex	MRD	IFP	Snamprogetti	Vaxon	Interline	ROSE/Kellog	STP	Meinken
	Distillation/Hydrogenation processes						Distillation/Solvent extraction processes								
Atmospheric distillation	1	1	2	2	1		1		1	1		3		2	1
Pretreatment			1	1										1	
Demetallization						1									
Separation				4											
Solvent extraction							3		4	2,5		1	1		
Solvent recovery							4			3		2			
Acid and clay treatment					4										2
Vacuum distillation		2	3		2	2	2		2	4	1	4	2	3,5	
Chemical treatment											2			4	
Hydrogenation	3	3	4	3	3	3			3,5	6			3		
Thin-film distillation	2										3				3
Fractionation		4	5	5		4							4		

1.the number correponds to the order of the operation in relation to each technology.
i.e. 1 corressponds to the first operation, 2 to the second and so on.

Table 3 Applied technologies and their corresponding unit operations
Source: Own elaboration

5.2 Classification by categories

Over the years, the re-refining processes have tended to converge towards three main generic categories which can be described under three broad headings:

5.2.1. Hydroprocessing (vacuum distillation/hydrogenation) processes

Hydroprocessing processes involve a sequence of operations in the order. The hydrotreating process accomplishes this by two main processes: 1) the removal of contaminants and 2) the saturation of aromatics and other unsaturated compounds to meet base oil specifications. In this category can be included such technologies as KTI, CEP, Hylube, PROP.

5.2.2 Solvent extraction processes

In oil refining, solvent extraction is generally applied to vacuum distillates to improve the properties of virgin base oils. The technology has now been successfully used in re-refining. As was discussed earlier, the solvent extraction can be accomplished using various solvents such as propane (IFP, Snamprogetti), N-Methyl-2-Pyrrolidone (Probex, Vaxon)

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5.2.3 Acid/Clay processes

As discussed earlier, an acid (generally sulfuric acid) is used to extract oxygen compounds, asphalt, resin derivatives, other nitrogen and sulphur-based compounds and metal contaminants from the used oil. The active clay removes the color and odor. The acid/clay based processes are obsolete and are no longer in use. Some existing plants have been converted to operate under new technologies such as RTI.

5.3 Which technology to use?

There is no single "right technology" for re-refining. Each technology has both merits and shortcomings. The method employed to re-refine waste oil depends on many factors such as the nature of the base stock, the nature and amount of contaminants, and many other economic factors. Suffice to say that today modern technologies seem to be converging towards a two-step procedure: vacuum distillation of dehydrated used lubricating oil and subsequent hydrotreatment of distilled stocks.

Among these technologies, we can list: Mohawk, Safety Kleen and Revivoil.

Table 3 summarizes the advantages and disadvantages of the various re-refining methods.

Technology	Advantages	Disadvantages
Acid/Clay methods	Low capital investment. Makes it most cost effective for small and tiny scale plants. Requires no advanced instrumentation, no skilled workers. Proven technology that worked for many years worldwide	Hazardous by-products are produced, including acid tar and oil saturated clay. Waste disposal problems and environmental drawbacks. High operation costs, continuous clay consumption, disposal cost of spent clay. The process requires high temperatures. High clay consumption, low yield, inconsistent quality Lower yield due to loss of oil in sludge. Life span of the equipment used in acidic environment is reduced.
Hydroprocessing methods	Product quality and yield are high (API Group II Base Oil), PBC and Chloride can be eliminated efficiently PNA can be eliminated efficiently at high pressure and temperature	The process requires high pressure, high temperature and hydrogen usage It requires high safety standards, H2S and HCl can be generated during the process Investment cost and operational costs are high, operational efficiency is low A separate facility needs to be established on the field in order to provide hydrogen to the process continuously Expensive catalysts are required
Solvent extraction methods	API Group II/II+ Base Oil can be produced based on the quality of the waste oil. Toxic Polyaromatic Hydrocarbons (PAH) and PNA can be completely eliminated. All of the synthetic base oil compounds like PAO / hydrocarbon oils are preserved, The process is carried out under lower pressure and temperature compared to other technologies. The process has high product operational efficiency. Small quantities of waste and comtaminants are generated, waste disposal cost is low	The product quality is dependent upon the waste oil mixture used as feedstock. High quality feedstock is required for high quality Group II, Group II+ base oil. In hydro processing, with hydrogen saturation, the product quality is not dependent on the quality of the feedstock. Based on the waste oil used, the solvent costs can be high

Table 4 Advantages and disadvantages of re-refining technologies
Source: Own elaboration. Data compiled from PETDER

6 Environmental implications of re-refining of used lubricating oils.

Used oils are characterized as hazardous wastes under Basel convention and, therefore, must be handled in accordance with the provisions thereof. Their disposal in the environment is dangerous for the natural systems, be it water, land or air. Initially theses waste oils were either discarded in landfills or burned to recover energy. Both disposal methods were considered, and rightly so, to be harmful to the environment. In the 1970s, growing environmental concerns in industrialized countries have favored the re-refining option over these recycling methods. There have been several studies in recent years to assess the implications of re-refining of used lubricating oils on the environment through a specific process called LCA (Life Cycle Assessment). Briefly, an LCA is a study based on the review of the environmental impacts of a product throughout its life cycle. It is a widely accepted framework that is used to assess the environmental impact of a given product or process. As far as used lubricating oil is concerned, many studies have been conducted to assess its potential impacts on the environment (Vold et Al, 1995; GEIR, 2005; IFEU, 2005; OECD, 2006; CAL, 2013). In these studies, re-refining was compared to the combustion of used oil as fuel with energy recovery. These studies have demonstrated that substantial environmental improvements can be obtained by re-refining used lubricating oil instead of burning it for energy recovery.

Vold et al (1995) have reported that re-refining of used lubricating oil reduces the potential environmental impact in relation to the burning of waste oil, in particular the contribution to acidification and global climate change are reduced.

As illustrated in Figure 26, re-refining used lube oil to lubricants emits less atmospheric pollutants (CO2 emissions are 40% lower) and consumes less energy (66%) than the refining of crude oil into lubricants.

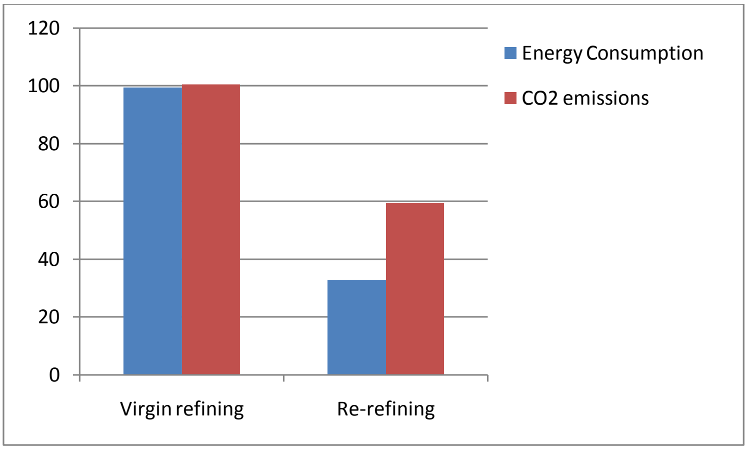

Figure 26 Impacts assessment results of re-refining vs. virgin refining
Source: Own elaboration with data from ICS-UNIDO as cited in Kari-Matti (2013)

In a recent study, Grice et al (2014) showed that the carbon footprint of re-refined base oil is 81% lower than virgin stock-derived base oil that is not re-refined.

A life-cycle analysis of waste oil regeneration versus incineration of waste oils in cement kilns, finds that re-refining is less environmentally damaging (OECD, 2006). In a study undertaken by Broughton and Horvath (2004), it was found that the impact with respect to air and water pollution emissions and generation of solid waste are approximately equal but emissions of heavy metals are much more severe for burning.

IFEU (2005) have reached the same conclusions as regards the environmental impacts of re-refining versus combustion. Their study concludes that the majority of advantages are in favor of re-refining which also causes far less environmental impact than processing base oil from crude oil. Re-refining therefore clearly leads to a decrease in environmental burdens. Figure 27 shows the relative differences between the environmental impacts of re-refining and combustion considering both substitution scenarios. It is evident that for both scenarios the majority of advantages are in favor of re-refining.

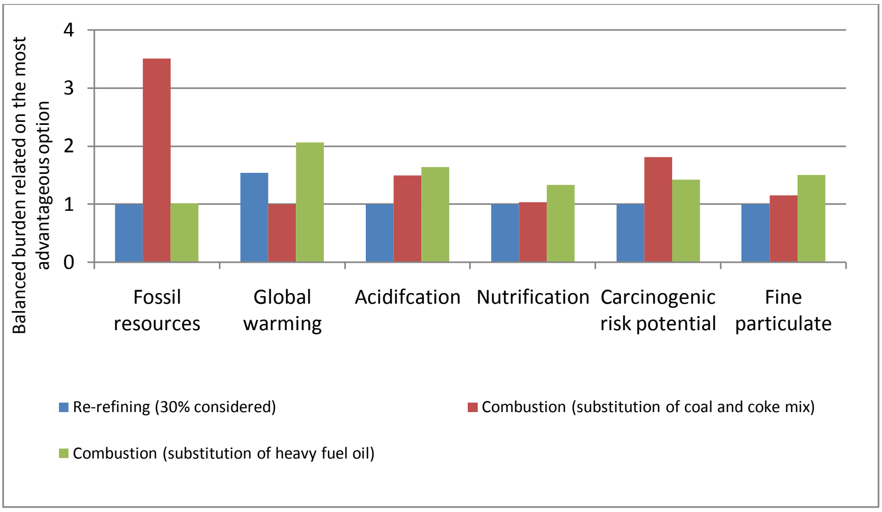

Figure 27 Overview of the impact assessment results (re-refining vs. combustion of used lube oil)
Source: reproduced from IFEU(2005)

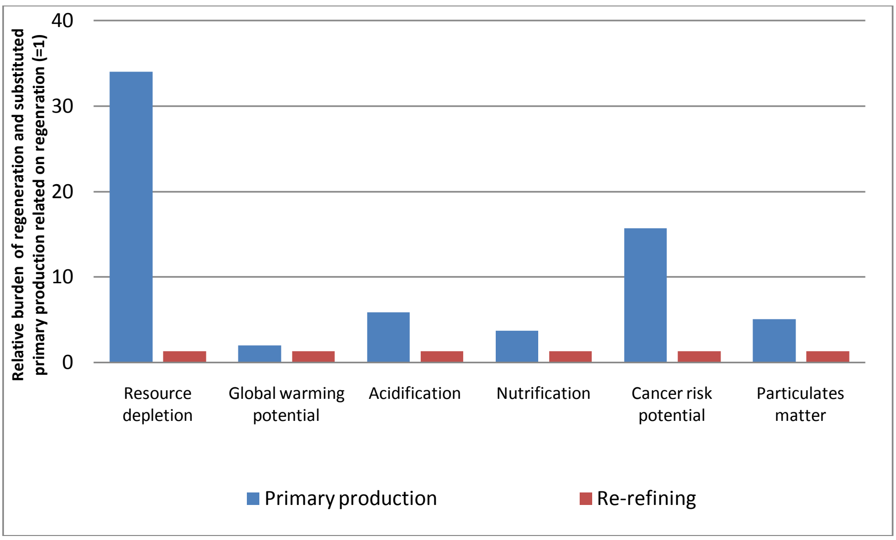

Figure 28 Overview of the impact assessment results (re-refining vs. primary production)
Source: reproduced from IFEU(2005)

Likewise, re-refining represents an environmental benefit over primary production of virgin base oil from crude oil. As illustrated Figure 28, the benefits of re-refining are not limited to displacing atmospheric pollutants but extend to resource conservation. Primary production of lubricants contributes significantly to oil depletion. At least 600 tons of lubricating base oil can be recovered from each 1000 tons of used oil, whereas 6000 tons of crude oil is required to produce this amount of lubricating base oil (Bridjanian et Al, 2006). Moreover, environmental issues such as global warming, acidification, fine particulates emission, etc, are attenuated, but not eliminated, when re-refining is used in lieu of primary production.

6.1 Environmental implications of used oil burning

When used lubricating oil is burned as a fuel for energy recovery, the benefits are limited. In a controlled combustion process such as in steel mills or cement kilns, used lubricating oil can be burned in order to recover its heating value. According to EPA (1996), one gallon of used oil processed for fuel contains about 140,000 BTUs of energy. The heat recovery option certainly provides valuable energy, but the product is destroyed and cannot be recycled again as in re-refining. This alternative, however, is not without problems for burning of used oils generate toxic emissions and non degradable products. According to US EPA, potential pollutants include carbon monoxide, sulfur oxides, nitrogen oxides, particulate matter, toxic metals, organic compounds, hydrogen chloride and global warming gases (carbon dioxide, methane). Moreover, if burned at low temperatures, it releases a range of toxic compounds directly into the atmosphere. Thus, for each ton of used oil burned, 2.9 tons of CO2 are released into the environment. What´s more, the used lube oil which is burned produces a carbon footprint eight times greater than re-refining (Gray, 2014). It is estimated that every one hundred million gallons of re-refined used oil consumed avoids over 650 million metric tons of greenhouse gas emissions- that´s equal to the carbon sequestrated by growing over 19 million trees for 10 years in an urban area (Knapp, 2013). In short, uncontrolled burning results in significant levels of hazardous emissions to the atmosphere.

6.2 Unsafe disposal of used oil

When used oil cannot be re-refined or recycled as fuel, it is often disposed of in landfills or burned without heat recovery. In both cases, the heating value is lost. If improperly disposed of (i.e. illegal dumping), used lube oils can pollute the environment to a point of no return. It is estimated that each volume of used oil can pollute at least 250000 volumes of water (Bridjanian et Al, 2006), hence its disposal in landfills can pose serious environmental problems. Studies have shown that it takes up to 20 years for a

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contaminated spot to return to a healthy condition (Avadhut, 2011). What´s more, harmful impacts include toxic contamination, destruction of food resources and habitats and impaired reproductive capability.

In view of the foregoing, although re-refining of used lubricating oils is an expensive option and requires skill and expertise, on the question of environmental impacts it is by far the most viable option. The choice between re-refining and the energy recovery method (i.e. burning) depends upon the environmental legislation and the market conditions prevailing in the concerned country. GEIR (2005) advises to give priority to re-refining "insofar as there is no indication by life cycle assessment that there are options which deliver better overall environmental outcome". The waste management hierarchy is illustrated in Figure 29. Re-refining of used lubricating oil is ranked as the best option in the waste hierarchy by the European Waste Framework Directive 2008/98/EC.

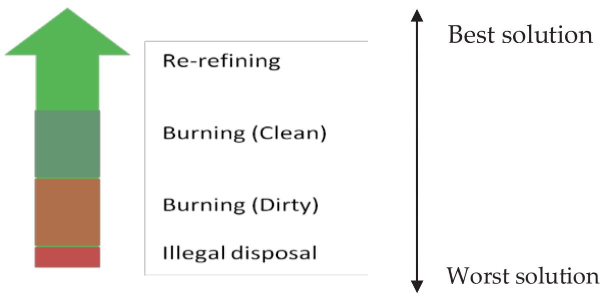

Figure 29 Used oil disposal hierarchy

7 Economic viability of the re-refining process and its role in improving the added value of oil industry and natural resources conservation.

7.1 Economic viability of the re-refining process

From the environmental perspective, re-refining is certainly the most preferred recycling option. However, its economic viability depends, at the project level, on the scale and the economics of the operation. On a broader level, the re-refining process is impacted by the price of crude oil, the country regulations concerning the handling of used lube oil and the tax policy on recycled lubricating oils. The re-refining industry has quite often experienced business cycle upturns and downturns as a direct consequence of being subjected to fluctuations in the crude oil prices. The 1973 OPEC oil embargo led to a tripling of crude oil prices, stimulating interest in used oil recycling (Ray, 2014). OPEC oversupply in 1986 led to crude oil prices collapse with a correspondingly marked decline in the selling price of re-refined base oils (Fuchs, 2010). Currently the oil prices have reached record lows and if the past is any indication of the future, clearly the re-refining industry will be in very challenging times. This being said, in this section we will discuss key parameters which we feel to be important to take into account in assessing the economic viability of a re-refining process.

7.1.1 Operating costs

Operating costs are comprised of variable costs and fixed costs. The variable costs depend mainly on feedstock cost, utility costs, and catalysts & consumable costs. It can be seen from Figure 30 that the fixed costs represent more than 50 % of total operating costs, regardless of the technology. Should the production drop, the operating cost per ton will increase. As a result, the re-refiner experiences a period of increasing costs and at the same time stable or decreasing base oil prices. This is the so-called cost-price squeeze. In order to limit the effect of the cost-price squeeze, it is important for the re-refiner to operate at or near full capacity. This explains why it is so important to secure feedstock availability. When the feedstock is made available at sufficient quantities and at a reasonable cost, the economic viability of re-refining can be achieved.

7.1.1.1 Feedstock cost and availability

Control over the used oil supply chain is a key success factor to economic viability of the operation depending itself not only on the availability of the waste oil in substantial amounts but on the existence of an efficient collecting system. Ultimately, the collecting system will influence the cost of used oil because this latter is practically equal to the cost of collection and transportation to the site. Economically, the feedstock cost depends on alternative applications. In other words, the value at which the feedstock is valued depends on the opportunity cost depending itself, in the case of used lube oils, on the cost offered by the used oil burners. By securing the feedstock, the re-refiner can afford to operate at or near capacity. This is not something self-evident as, in many countries, the quantity of used lube oil that can be made available for re-refining may be a limiting factor. According to OECD (2005) and Audibert (2011), the breakeven point for a re-refinery corresponds to a minimum capacity of 60000 MTPY. CEP, a technology licensor, claims that a minimum annual capacity of 20000 metric tons of feed is necessary in order to generate a reasonable profit (Park, 2012). The only way for re-refiners to guarantee a constant feedstock supply and to keep the feedstock cost sufficient low, is to develop their own used oil collecting service. Integrating vertically with used lube oil collectors is an option seriously envisaged. As a matter of fact, some re-refiners are planning vertical integration through the acquisition of used oil collection companies (Choi, 2013).

Even when the feedstock constraint is relieved, other constraints are likely to be more binding on the economic viability of the operation which could be affected by such parameters as the base oil selling price.

7.1.1.2 Base oil selling price

Even when the operating costs, and more specifically the feedstock cost, are under control, other constraints such as the selling price are likely to impact the profit margin. The selling price of the re-refined base oil is beyond control of the re-refiner as it is linked to the selling price of the virgin base oil depending itself on the crude oil price fluctuations. Due to low crude oil prices, the base oil market today is quite different to that which existed in the early 2010s. The market conditions are going to be difficult with the virgin base stocks prices facing downward pressure as a result of falling oil prices. Major lubricant producers have announced a general decrease in lubricant prices (Glenn, 2015). The price decrease is not going to be without impact on the price of re-refined lube oils and subsequently on the economic viability of the re-refining operation.

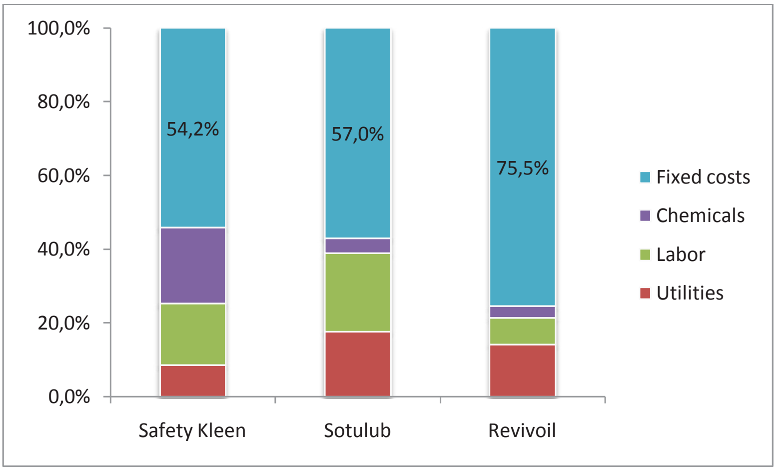

Figure 30 Operating costs for different re-refining technologies
Source: Own elaboration with data from (Audibert, 2006)

7.1.3 Capital costs

Graziano and Daniels (1995) have concluded in their study that the capital costs associated with re-refining have long been identified as an obstacle to the expansion of the re-refining industry. For the specific case of Middle East/North Africa region, the capital costs structure is a mixture of the costs of imported equipment and material together with local costs such as feedstock, utility and labor. These costs are in general site specific and usually location factors are used to convert them to local conditions. The fact that the most important cost factors such as engineering, equipment, skilled labor, erection, etc., have to be outsourced aggravate the investment cost which is a strong function of the technology employed. Contrary to what one might think, the relation between the investment costs and the production capacity is not linear. Increasing the capacity ensures the economies of scale and costs savings. Figure 31 shows the variation of capital costs versus capacity for a grassroots re-refinery based on CEP/Mohawk technology described earlier. It also highlights the fact that the relation between the investment costs and the production capacity is not linear. The higher the capacity of the plant, the less the capital cost is required per metric ton of used oil processed. For a 50000 MTPY capacity, the capital costs amount to US$ 40 million. Doubling the capacity to 100000 MTPY increases the capital costs by only 55%. Just like in crude oil refining, the economies of scale are an important factor to consider in re-refining profitability.

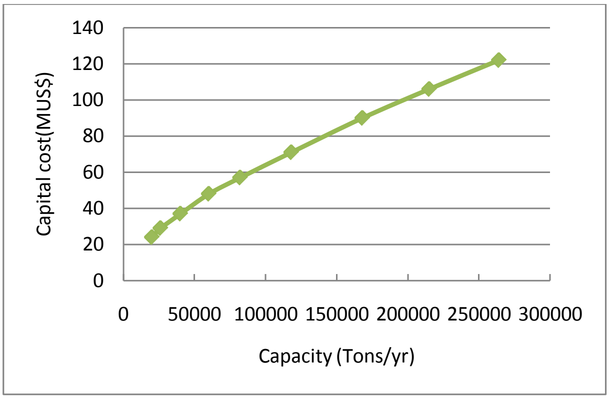

Figure 31 Capital costs versus capacity for a grassroots re-refinery
Source: Reproduced from (Park, 2012)

7.1.4 Profitability

In order to compete, the re-refined lube oil must be sold at a lower price than virgin oil base stocks. Actually, re-refined base oils have always been linked to virgin base stocks depending themselves on the price of crude oil. Historical re-refining margins were in the range of $1.0 per gallon and $2.5 per gallon during the 2010-2014 period. Up till now, this spread has provided re-refiners with substantial revenues. But this boom period may be over as the industry's specific cycle is declining and falling oil prices are starting to have an effect on the re-refining industry. Kline´s November 2015 report (Globenewswire, 2015) showed a steady decline in re-refinery margins and Kline went on to predict that prospects for a short term rebound in re-refinery cash margins are limited.

The re-refining industry is constrained both by feedstock cost and product prices which are dictated by oil product prices. While a high feedstock cost will put pressure on profits margin, a low base oil selling price will make it difficult to maintain these profits. The re-refiner has no control over the base oil market, and is usually forced to accept the market price if he wants to sell its products.

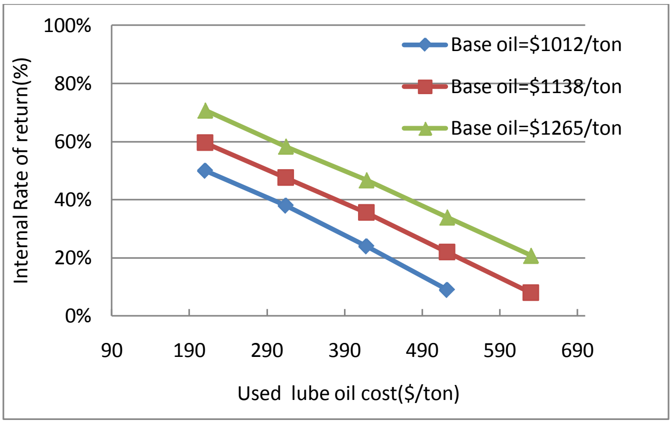

Figure 32 IRR at various feedstock and base oil prices (Base: 40000 metric tons re-refinery)
Source: own elaboration with data from Park (2012)

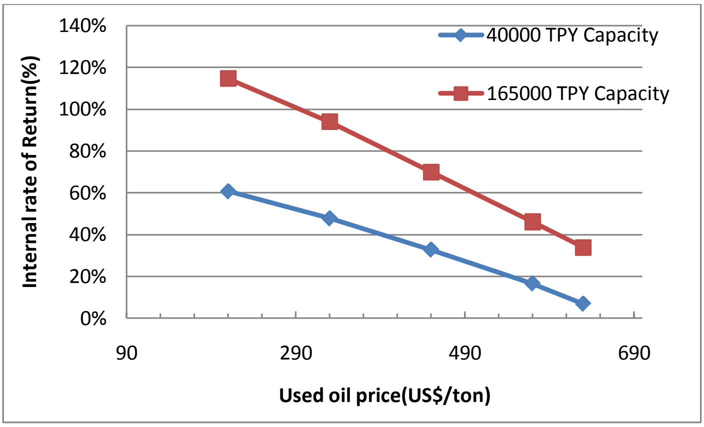

Figure 33 IRR at various feedstock prices and operating capacities at constant base oil price (US$ 1138 per metric ton)
Source: own elaboration with data from (Park, 2012)

Recently published data on the economics of re-refining lubricating oils has been reported by Park (2012). The data which is illustrated in Figure 32 shows that the IRR (Internal Rate of Return) for production of re-refined base oils increases with increasing base oil price at a fixed used oil price. Conversely, the IRR decreases with increasing feedstock cost at a fixed base oil price.

Also, the IRR increases with increasing capacity, at a given base oil price. This is illustrated in Figure 33 where the internal rate of return is better for a bigger plant. The return for a 165,000 MTPY plant at $450 feedstock cost and $1138 base oil price is about 70% while it is about 33% for the 40,000 MTPY plant for the same used oil and the base oil prices.

The results presented here are relative and only indicative of trends based on the CEP/Mohawk technology. The case study shows that the internal rate of return is dependent on the feedstock cost, the base oil selling price and the operating capacity.

In light of the present day situation, the economic viability of re-refining appears to be critical and much will depend on the will of authorities to provide subsidies or tax advantages, which will enable existing re-refiners and potential investors to survive the oil industry ups and downs. According to Audibert (2006), all the economic evaluations have shown that the re-refining industry can only survive with financial support. This support which can take many forms, is offered in many countries including, Germany, Italy and England (Oakdene, 2005). Brazil and Indonesia, have established tariffs or restrictions on lube oil imports that have provided support for local re-refining firms (Challener, 2012). In Italy, re-refined base oil benefits from a tax reduction compared to virgin base oil. Re-refining projects requires support across many of the key parameters critical to their success, such as financing, feedstock management, and legislation.

7.2 Role of re-refining in improving the added value of oil industry and natural resources conservation

The crude oil industry gross added value is derived mainly from the refining activities. In general, the value added can be improved by increasing sales, reducing operating costs, adopting new technologies or upgrading of a low value (waste) stream. In that regard, re-refining of used lubricating oil represents an opportunity to add more value to oil industry. Lubricating oil is one of the most valuable components of crude oil and costs 52% to 68% more than conventional petroleum products such as gasoline and heating oil (DOE, 2006), notwithstanding the fact that the proportion of crude oil that is refined into lubricant base oil is only 1% of the total. The high price reflects the higher manufacturing costs, including energy costs, of the base oils compared to standard petroleum products. Even though the economic contribution of the re-refining industry to the overall petroleum industry is often low, largely due to the small quantities being recycled, a substantial energy savings can be realized by choosing this recycling option. It has been previously pointed out in section 7 that re-refining consumes less energy (50% to 85% less) than the refining of virgin oil into lubricants. The energy savings can be translated into reductions in crude oil consumption. As previously indicated in section 1, used lubricating oil contains about 70% base oil which can be recovered through re-refining. According to GEIR, re-refining one barrel of used lube oil saves about 70 barrels of crude oil. Estimates indicate that recycling used oils can save millions of barrels of crude oil annually. By recycling used lubricating oil, a crude oil importing country would save an enormous amount of money in its energy bill. As an illustration of the savings that can be made by re-refining used lubricating oil, we take the specific case of Egypt, the largest oil consumer in Africa, where 240000 tons are available for collection (cf. Table 1). If we assume only 50% recovery of this amount of used lube oil as base oil, 84000 metric tons (based on 70% recovery) of base lubricant oil would be recovered every year. Based on the selling price of $1200 per ton, $100 million could be generated annually as revenue. Furthermore, re-refining 120000 tons (50% of collectable amount) of used lubricating oil could preserve 4.7 million tons of crude oil.

8 Used lubricating oil re-refining projects: A case study

The following is a case study of a re-refining project implemented in France in early 2010s. The OSILUB plant is part of a dynamic policy recycling encouraged by the European directive on waste 2008/98 / EC, which states that countries must give priority to the regeneration of waste oils at the expense of incineration, which is discouraged.

8.1 Project presentation

The 120000 ton per year re-refining project is located in Gonfreville, France. The owner is OSILUB. The French regional government granted financial contribution to the project. In France, regeneration became the norm in 2011 compared to incineration (52%), reaching 63% in 2012. This figure is partly explained by the start of the new OSILUB factory, which now has a capacity of 120 000 MTPY. The plant was designed by STP and completed in 21 months. Raw material is collected from France and from North Western Europe (England, Benelux).

The STP technology has been described earlier in section 4.6. The simplified process flow diagram is illustrated in Figure 13.

8.2 Feedstock and product analyses

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Table 5 shows process figures, including used oil composition, product´s characteristics and utilities consumption. It is claimed that 95% of the oil fraction present in the used lube oil feedstock is recovered. These data have obtained from CEP website.

Process figures			
Used lube oil composition			
Composition, wt%	Normal	Min-Max	
Water	5.0	2.0-10.0	
Light ends	2.0	1.0-4.0	
Gas oil	3.0	1.0-4.0	
Oil fraction	78.0	65.0-18.0	
Asphaltic Residue	12.0	10.0-18.0	
Product characteristics			
Characteristic	ASTM	Light fraction	Heavy fraction
Color	D1500	2.0	2.3
Density	D1298	860	868
Viscosity, cst @40ºC	D445	15-20	30-50
Flash point, ºC	D 92	205	220
Sulfur content	D4294	0.30	0.35
Metal content, ppm	D6595	<10	<10
Utilities Consumption			
MP Steam, Kg/h	3400		
Thermal oil, Kcal/h x 10^6	3.60		
Cooling Water, m^3/h	490		
Electric power, Kwh/h	320		

Table 5 Process figures of the STP project
Source: STP

8.3 Process economics

For the purpose of the economic evaluation, the following assumptions have been made:

Plant capacity: 120000 metric tons per year
Plant location: Gonfreville, France
Cost basis: 2012/2013
Stream factor: 8000 hours
Depreciation: 10 years

Used lubricating oil cost: US$ 330 per ton. In France, the used oil cost was about $330/t in 2011 (Ballerini, 2011).

Utilities costs:

Electric power:	$0.067/KWh
Steam:	$ 30.61/ton
Thermal oil:	$ 283.5/ton
Cooling water:	$ 0.256/m^3

The utilities costs for cooling water, electric power, steam and thermal oil have been obtained from INSEE (2013).

The estimated fixed capital cost is US$55 million (Infineum, 2013). The total investment cost includes the fixed capital, interests on loan and start-up cost. This adds up to US$ 74 million.

Labor costs: An average of $20 per ton of feed are assumed (Audibert, 2011):
Supervision and Operators: $300000 per year; 3 operators per shift
Depreciation: Based on 10 years straight line depreciation method, has been estimated at 46 $ per ton of feed.

Revenues: Sales of products and residue
The selling price of re-refined base oil was assumed to about $1000/t (roughly 10% to 20% less than the price of virgin base oil), in 2013 (year of production start).

Table 6 summarizes the project´s costs including feedstock, operating and investment costs.

For this case example, the total production cost per ton of feed is US$ 474. The pay-out time is anticipated to be nearly 2 years, which is acceptable. The investment has averaged an annual ROI of 25%. This economic evaluation indicates that re-refining of used lubricating oil can be profitable provided that the feedstock costs are subsidized by the government, which was the case in this example.

	Investment cost (k$)		
Fixed capital cost			55000
Intercalary interests(9% of Fixed capital)			4950
Start up costs(3 months of operating costs)			14200
Redeemable Capital			74150
	Operating cost ($/t of feed)		
Variable costs			$/ton of feed
Raw material			330
Cost of utilities			
MP Steam			8
Thermal oil			2
Cooling Water			8
Electric power			2
Total variable cost			**350**
Labor			
Operators and Personnel			25
Total variable cost + Labor			**375**
Fixed cost			
Depreciation (10 years)			46
Maintenance (5% investment)			23
Laboratory expenses			5
Insurance, Licensing fee			25
Total fixed costs			**99**
Total operating costs			**474**
Product revenues (total yield of base oil=95%)	Price ($/t)	Production (kg/t)	
Water	0	50	0
Light ends	250	20	5
Gas oil	330	30	10
Base oil	800	741	741
Asphaltic residue	125	120	15
Total sales			771
Annual total sales(k$)			92508
Annual operating cost(k$)			56911
Profit before tax			35597
Cash flow(profits + depreciation)			41093
ROI (%)			25
Pay-out (years)			1.8

Table 6 Evaluation of STP project process economics

9 Future outlook for the re-refining industry in light of decreasing oil prices

Despite the attractiveness of re-refining, if it is to survive in the open market it must be able to compete not only with virgin lube oil operations but with used oil burners as well. It is well known that there is a competition for feedstock between re-refiners and used oil burners. The market price of virgin lube oils and fuels impacts to some extent the availability of the used lube oils. Already in the early seventies, it has been observed that higher virgin fuels prices in relation to those for virgin lube oils will direct used oils to fuels market (Cukor et Al, 1973). Conversely, used oils will be directed to re-refiners in case where virgin fuels prices are lower.

Re-refining has long existed ever since the scarcity for crude oil supplies encouraged the recycling of all types of products including lubricating oils. Overtime, used lubricating oils have evolved from an environmental liability into an economic asset, thanks to technological breakthroughs in re-refining. With increasing stringent environmental regulations it may become a business necessity rather than an option. The continuing change in reformulation of automotive lubricants has had a corresponding effect on the global base oil consumption. It was observed that, amid the new trends in the lubricating oil industry, there is a tendency to reformulate the lubricants towards tougher specifications, thereby excluding group I base oils out of the newer automotive lubricants (Moncrieff, 2013). This is corroborated by the decline of the demand in group I lubricants (Figure 34). The proportion of Group I stocks in global base oil consumption has fallen from around 70% in 2000 to 54% in 2012. As a result, group I plant closures have been observed in Europe and North America (Infineum, 2014). At the same time, the capacities of group II and III are expanding, at the expense of group I. The acid/clay technology is declining and its share in the production of lube oil also. In the 1970 nearly 90% of the re-refined base oil was produced by acid/clay technology; by 1974 it declined to less than 80% and 1977 to less 77% (Liroff, 1977). As of 2012, Group I base oils with 54% is still the dominant in the global consumption but and it is expected to continue declining to around 30% by 2030.

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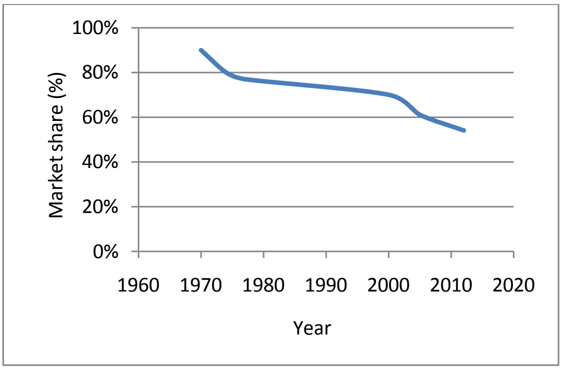

Figure 34 Group I base oil market share evolution over the years
Source: own elaboration

On the other hand, it has been observed that in engine oil formulations, the conventional mineral-based auto lubricants are being displaced by synthetic products which have better performance characteristics (Moncrieff, 2005). However, it seems that some of these mixed-composition lubricants would not be suitable for later re-refining (Fiedler, 2005). This trend will certainly have implications on the re-refining industry and it can be expected that it will not be favorable to technologies geared towards producing group I lubricants. These market trends, i.e. the group I being displaced and the ever increasing part of synthetic lubricants, along with a number of factors including technology, crude oil prices, environmental legislation and market uncertainties, will shape the future of the re-refining industry.

10 Conclusions and recommendations

In this section of the report, an attempt is made to draw the appropriate conclusions and make the useful recommendations that could be used to promote the re-refining industry in the Arab countries and elsewhere:

10.1 Conclusions

Within the scope of Arab countries legal frameworks for the management of used lubricating oil vary from country to country. In some countries, legislation is simply inexistent.

In Arab countries, only a small quantity is re-refined into base oil. Most of the collected is either burned or improperly disposed of.

Used Lubricating Oils if not appropriately treated represent a serious environmental problem. The direct burning of used oils in conventional combustion devices can create serious pollution problems.

The re-refined base oils have the same performance characteristics as virgin base oils made from crude oil.

As far as re-refining technology selection is concerned, a number of criteria need to be considered before deciding on which recycling technology to adopt.

Re-refining of used lubricating oil is an economically attractive recycling method from the standpoint of environmental protection and resources conservation.

An efficient used oil collection system is key to successful used oil management programme.

For many Arab countries, data are not available for the final destination of used lubricating oil.

10.2 Recommendations

It is advisable to promote public awareness of the improper disposal of used oil and educate public about the energy and environmental benefits of recycling used oil.

Where legislation does exist, the local authorities should be responsible to enforce the policies and to implement the regulations set forth.

As demonstrated by Life Cycle Analysis of used lubricating oil, priority must be given to re-refining of used oil as opposed to its use as fuel oil.

It is recommended to assess the economic viability of any re-refining project taking into account such parameters as project location, feedstock availability, operating costs and product pricing.

For a successful re-refining project appropriate measures are necessary, including an efficient collecting system, state financial support through taxes and levies and regulations to encourage investment in re-refining.

References

Actu-Maroc (2012). in Industrie : Les déchets devenus matières premières. *Actu-Maroc 03/02/2012*. Retrieved from http://www.actu-maroc.com/industrie-les-dechets-devenus-matieres-premieres/

Al-Haya (2013). Lube oil recycling available at http://www.alhayaqatar.com/lube_oil_recycling.asp.

Anged (n.d), in Filière de gestion des huiles lubrifiantes usagées: Eco-Zit. retrieved from http://www.anged.nat.tn/index.php?option=com_content&view=article&id=108&Itemid=238

Audibert, F. (2011), "Leading industrial and non-industrial processes." Waste Engine Oils. Amsterdam, Elsevier, 2011, p.195

Audibert, F. (2011), "Oil Composition and the Required Treatment Steps." Waste Engine Oils. Amsterdam: Elsevier, 2011. 37-40. Print.

Audibert, F. (2006). Waste engine oils (First ed.). Amsterdam, Netherlands: Elsevier. P.36. Available at http://store.elsevier.com/Waste-Engine-Oils/Francois-Audibert/isbn-9780444522023/

AOG (2014) http://www.arabianoilandgas.com/article-12342-the-future-of-waste-oil-refining-in-the-uae

Archontaki, G. (2015). GEIR-"Green Planet Association Annual Conference Waste Lube Oil Management in Europe". Retrieved from http://www.mentineromaniacurata.ro/images/mrc/evenimente/confintl2015/glyka_geir.pdf

Avaduth, 2011 re-refining of used lubricating oil available at http://fr.slideshare.net/palekaravadhut/presentation-on-re-refining-of-lubricating-oil-by-avadhut-pravin-manoj

Ballerini, D. (2011), *Les Biocarburants*. Paris: Editions Technip, 2011. 184. Print.

Bambridge, J. (2015). ENOC Lubricants expands to Jebel Ali facility. Retrieved from (http://www.constructionweekonline.com/article-33982-enoc-lubricants-expands-to-jebel-ali-facility.

BW(20004), " *Interline Resources' Re-Refining Process Awarded 2003 Bronze Medal by European Environmental Press*. Businesswire, 18 Feb. 2004. http://www.businesswire.com/news/home/20040218005950/en/Interline-Resources-Re-Refining-Process-Awarded-2003

Cukor,P.; Keaton,M.J.; Wilcox,J. (1973), A Technical and Economic Study of Waste Oil Recovery: Part III - Economic, Technical and Institutional Barrier to Waste Oil Recovery. Downloaded from http://www2.epa.gov/nscep

Casanova (2003), Margarita Montes Casanova, Trabajo de tratamiento de residuos re-refinado de aceites usados avaialble at http://www.miliarium.com/PremiosMiliarium/2003/RefinadoAceites/RefinadoAceites.pdf

EC(2006) Integrated Pollution Prevention and Control-Waste treatments industries p.22 http://www.prtr-es.es/data/images/BREF%20Tratamiento%20de%20Residuos-21891D712A33A259.pdf

Eldridge T, Rudd M., 2009, The environmental and renewables regime in Oman. http://www.lexology.com/library/detail.aspx?g=fb2e1c42-65ee-4195-9e4c-9a42f6925c19

Egypt (2010). *Country report on the solid waste management* (July 2010). Retrieved http://www.sweep-net.org/sites/default/files/EGYPT20RAANG 14_1.pdf

Fernatt, J. (2013). Bringing used oil back to life. Tribology and Lubrication Technology. August 2013, issue, p.20-25. Retrieved from http://www.ecopoweroil.com/files/Rerefining_used_oils_article_Aug_13_sm.pdf

FINCORP.(2009). Investment research (Rep.). Retrieved http://up.m-e-c.biz/up/Mohcine/Report/FINCORP_SHELL_230309.pdf

Giovanna, D., Khlebinskaia, O., and A. Lodolo, S. Miertus. *Compendium of Used Oil Regeneration Technologies*. Rep. UNIDO, 2003. Web. <https://institute.unido.org/wp-content/uploads/2014/11/95.-Compendium-of-Used-Oil-Regeneration-Technologies.pdf>.

Glenn, Thomas F. "The Flipside to the Downslide in Lubricant Prices." N.p., n.d. Web. 3 Feb. 2015. http://jobbersworld.net/

Grice L.N; Nobel C.E; Longshore L.; Huntley R; DeVierno A.L , 2014 "Life Cycle Carbon Footprint of Re-Refined versus Base Oil That Is Not Re-Refined" *ACS Sustainable Chem. Eng*., 2014, 2 (2), pp 158–164 available at http://pubs.acs.org/doi/pdf/10.1021/sc400182k

Infineum (2013), Greener oil, available at http://www.infineuminsight.com/insight/sep-2013/greener-oil.

البحث الثاني

INSEE (2013), “Consommation d´énergie dans l´industrie manufacturière”. Available at (http://www.insee.fr/fr/ffc/docs_ffc/ENTFRA13j_FTLo5energie.pdf)

Jordan (2014). *Country report on the solid waste management* (April,2014). Retrieved http://www.sweep-net.org/sites/default/files/JORDAN20RAANG 14_1.pdf

Kari-Matti, E. (2013),”Re-refined base oil quality today: Myth vs. reality”, LAB/VSN Seminar, June13, 2013 available at http://slidegur.com/doc/1867520/slide-1)

Kerneis, H. (2013). (http://www.veolia.com/fr/groupe/medias/actualites/osilub-nouvelle-vie-pour-les-huiles-noires.

Kline (2015), The Need for Fuel Economy and Stringent Emission Norms is Increasing Demand for Low-viscosity Grade Basestocks. Available at http://www.klinegroup.com/blogs/index.php/tag/base-oils/

Kline(2010), Global Used Oil Markets and Re-refining Industry-On the cusp of growth? Available at http://gail.federchimica.it/docs/default-source/congresso-ueil-2010/Phadke.pdf?sfvrsn=0

Knapp, C.(2013) Greener oil- Feedstock challenges (September, 2013). Retrieved from http://www.infineuminsight.com/insight/sep-2013/greener-oil#heading-5

KOC (2005) Kuwait Oil Company, Waste Management System, retrieved from *mcsetender.kockw.com/.../KOC%20Waste%20Management*

Kupareva, A.; Arvela, P.M; Murzin, D.Y. (2013) "Technology for Rerefining Used Lube Oils Applied in Europe: A Review." *Journal of Chemical Technology and Biotechnology*. , Oct. 2013. Web. <http://onlinelibrary.wiley.com/doi/10.1002/jctb.4137/references>.

Palestine (2014). *Country report on the solid waste management* (April,2014). Retrieved http://www.sweep-net.org/sites/default/files/PALESTINE%20RA%20ANG%20WEB.pdf

Marcopolis (2015). Lubricants in Saudi Arabia: Lubricants Market to Grow. Retrieved from http://www.marcopolis.net/lubricants-in-saudi-arabia-industrial-lubricants-market-to-grow.htm

Morocco (2014). *Country report on the solid waste management* (April, 2014).Chapter 9. Retrieved http://www.sweep-net.org/sites/default/files/MAROC%20RA%20ANG%20WEB.pdf

Petder (2012), Selection of the Most Appropriate Technology for Waste Mineral Oil RefiningProject Technical Research Report 2012, available at http://www.petder.org.tr/uploads/2013/06/c381fed2524f47e7cc5b1061f6a035e5.pdf

Henderson, H. (n.d.). Re-refining of used oils. In R. Rudnick (Comp.), *Synthetics, Mineral Oils, and Bio-Based Lubricants* (Second edition ed., p. 369). Leslie R. Rudnick.

Infineum (2014), Infineum International Limited, Change and challenges, downloaded from http://www.infineuminsight.com/insight/jun-2014/changes-and-challenges

Isaac, J., (2015). Khaleej Times dated June 03/2015- Enoc boosts lubricants capacity with new plant. Retrieved from http://www.khaleejtimes.com/business/markets/enoc-boosts-lubricants-capacity-with-new-plant.

Durrani, H.A., Panhwar, M.I., Kazi, R.A., (2011),"Re-Refining of waste lubricating oil by solvent extraction", Mehran University Research Journal of Eng. & Tech., [ISSN 0254-7821], 30 (2) 237-246.

ECONEWS (2015) downloaded from (http://www.leconews.com/fr/actualites/nationale/energie/naftal-compte-creer-une-raffinerie-15-01-2015-173042_289.php).

Speight, James G., and Douglas I. Exall.,2014 "Refining Processes for Used Oils." *Refining Used Lubricating Oils*. CRC Press, 2014.

UNEP ((2006), Basel convention technical guidelines on used oil re-refining or other re-uses of previously used oil. p.9, Retrieved from http://www.basel.int/Portals/4/Basel Convention/docs/meetings/sbc/workdoc/old docs/tech-r9.pdf

UNEP (2012) . *Compendium of Recycling and Destruction Technologies for Waste Oils*. p.*33* United Nations Environment Programme Division of Technology, Industry and Economics International Environmental Technology Centre Osaka, Japan

Fok, J. (1986), re-refining case study: Evergreen oil refinery. Downloaded from http://infohouse.p2ric.org/ref/30/29100.pdf

Krishnan, G.(2013). Re-refining of base oils-Go for it. *Lube Magazine*, issue *113*, pp.6-10. retrieved from http://www.geir-rerefining.org/documents/Pg06withoutcropmarks.pdf

Globenewswire (2015), available at https://globenewswire.com/news-release/2015/11/16/787581/10156402/en/Kline-s-November-Index-of-Base-Stock-Production-and-Re-refining-Cash-Margins-Shows-Second-Straight-Month-of-Declines.html

Liroff, S.(1979), NBS special publication 556- A limited assessment of the waste oil re-refining industry-Proceedings of a workshop on measurements and standards for recycled oils held at NBS-Gaithesburg, Maryland November 29 and 30, 1977.- p.15-19.

OECD (2006) *Improving Recycling Markets*, OECD Publishing, Paris.-improving markets for waste oils. DOI, p.52: http://dx.doi.org/10.1787/9789264029583-en).

Wolfe P. (1992), Economics of used oil recycling still slippery. Available at http://infohouse.p2ric.org/ref/06/05467.pdf

DOE (2006). Used Oil Re-refining Study to Address Energy Policy Act of 2005 Section 1838. Retrieved from http://fossil.energy.gov/epact/used_oil_report.pdf

Randles et al, a review of the potential human and environmental health impacts of synthetic motor oils. P4 http://oehha.ca.gov/risk/pdf/SyntheticsFINAL-040607.pdf

Vold, M., Moller, H., Moller, J.(1995), Burning or re-refining used lube oils-life cycle assessment of environmental impacts. Oestfold Research Foundation-November, 1995 . ISBN 82-7520-225-6
http://ostfoldforskning.no/uploads/dokumenter/publikasjoner/331.pdf

Gray, Y. (2014). Recycling at its best. *QMIsolutions*, pp.10-13.Retrieved from http://www.sor.com.au/QMI Magazine-Queensland's first waste oil refinery shows the power of recycling.pdf.

Statista (2015), Distribution of global demand for lubricants by region 2014, available at http://www.statista.com/statistics/411627/lubricants-demand-worldwide-share-by-region/

Bibliograply

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The bibliography presents a subject compilation of books, serials, documents, and periodical articles newly acquired by OAPEC's library. The entries are classified under the following subject headings.

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- POLLUTION & ENVIRONMENTAL PROTECTION
- TECHNOLOGY TRANSFER
- MISCELLANEOUS

I- COMMERCE & INTERNATIONAL ECONOMIC RELATIONS

Christen, Elisabeth. **Time zones matter: The impact of distance and time zones on services trade**.-- The World Economy.-- Vol. 40, no. 3 (3/2017).-- p. 612-650.

Egger, Peter H. (et al). **The role of goods-trade networks for services-trade volume**.-- The World Economy.-- Vol. 40, no. 3 (3/2017).-- p. 532-543.

Egger, Peter; Merlo, Valeria and Wamser, G.. **Cross-country services versus manufacturing activity of multinational firms in response to services versus goods policy**.-- The World Economy.-- Vol. 40, no. 3 (3/2017).-- p. 490-498.

EIU. **Good neighbor gone bad: Policy risks for Mexico and Latin America under Trump**.-- London: Economist Intelligence Unit, 2017.--V.p.

Garcia-Duran, Patricia & Eliasson, Leif Johan. **The public debate over transatlantic trade and investment partnership and its underlying assumptions**.-- Journal of World Trade.-- Vol. 51, no. 1 (2/2017).-- p. 23-42.

Hoekman, Bernard and Shepherd, Ben. **Services productivity, trade policy and manufacturing exports.**-- The World Economy.-- Vol. 40, no. 3 (3/2017).-- p. 499-516.

Ismail, Faizel. **The changing global trade architecture: Implications for Africa's regional integration and development**.-- Journal of World Trade.-- Vol. 51, no. 1 (2/2017).-- p. 1-22.

Mayer, Joerg. **How could the South respond to secular stagnation in the North?**.-- The World Economy.-- Vol. 40, no. 2 (2/2017).-- p. 314-335.

Moons, Selwyn J. V. and Bergeijk, Peter. **Does economic diplomacy work? A meta-analysis of its impact on trade and investment**.-- The World Economy.-- Vol. 40, no. 2 (2/2017).-- p. 336-368.

Tian, Wei and Yu, Miaojie. **Firm R&D, processing trade and input trade liberalization: Evidence from Chinese firms**.-- The World Economy.-- Vol. 40, no. 2 (2/2017).-- p. 297-313.

II- ECONOMICS & DEVELOPMENT

Brunello, Giorgio; Weber, Guglielmo and Weiss, Christoph. **Books are forever: Early life conditions, education and lifetime earnings in Europe**.-- The Economic Journal.-- Vol. 127, no. 600 (3/2017).-- p. 271-296.

EIU. **Worldwide cost of living 2017**.-- London: Economist Intelligence Unit, 2017.--14 p.

Iran: Land of rising opportunities.-- Technical Review Middle East.-- Vol. 33, no. 1 (2017).-- p. 14-18.

Market focus: Opposition's return puts projects at risk.-- MEED.-- Vol. 2, no. 1 (1/2017).-- p. 54-69.

OECD. **Main economic indicators**.-- Paris: OECD/IEA, 2017.--253 p.

Top 100 projects: Projects markets to recover slowly.-- MEED.-- Vol. 2, no. 1 (1/2017).-- p. 37-47.

III- ENERGY

BMI. **The year ahead: Global industries outlook 2017**.-- London: BMI, 2017.--118 p.

The Economist. **The role of coal in Europe's power mix**.-- London: The Economist, 2017.--27 p.

UAE powers ahead on Middle.-- Technical Review Middle East.-- Vol. 33, no. 1 (2017).-- p. 29-32.

ENERGY – CONSERVATION

Bhati, Abhishek; Hansen, Michael and Chan, Ching Man. **Energy conservation through smart homes in a smart city: A lesson for Singapore households**.-- Energy Policy.-- Vol. 104 (5/2017).-- p. 230-239.

ENERGY - ECONOMIC ASPECTS

Cornot-Gandolphe, Syvie. **Indonesia's electricity demand and the coal sector: Export or meet domestic demand?**.-- Oxford: Oxford Institute for Energy Studies, 2017.--29 p.

Petitet, Marie; Finon, Dominique and Janssen, Tanguy. **Capacity adequacy in power markets facing energy transition: A comparison of scarcity pricing and capacity mechanism**.-- Energy Policy.-- Vol. 103 (4/2017).-- p. 30-46.

Trade-offs in energy and environmental policy.-- Energy Policy.-- Vol. 104 (5/2017).-- p. 415-418.

ENERGY - POLICY

Griffiths, Steven. **A review and assessment of energy policy in the Middle East and North Africa region**.-- Energy Policy.-- Vol. 102 (3/2017).-- p. 249-269.

Malen, Joel and Marcus, Alfred A. **Promoting clean energy technology entrepreneurship: The role of external context**.-- Energy Policy.-- Vol. 102 (3/2017).-- p. 7-15.

Bibliograply

ENERGY – RESOURCES

Farrell, Niall (et al). **Specifying an efficient renewable energy feed-in tariff**.-- The Energy Journal.-- Vol. 38, no. 2 (3/2017).-- p. 53-75.

Ford, Neil. **Renewables: A generational shift in sentiment**.-- Energy Economist.-- No. 426 (4/2017).-- p. 26-29.

Narula, Kapil (et al). **Sustainable energy security for India: An assessment of the energy supply sub-system**.-- Energy Policy.-- Vol. 103 (4/2017).-- p. 127-144.

Samarah, Ahmad. **Going small with nuclear power**.—MEED .-- Vol. 2, no. 1 (1/2017).-- p. 50-52.

Vitelli, A**.. Report: Renewables**.-- Petroleum Economist.-- Vol. 84, no. 2 (3/2017).-- p. 12-15.

ENERGY- SOLAR

Closas, Alvar and Rap, Edwin. **Solar-based groundwater pumping for irrigation: Sustainability, policies, and limitations**.-- Energy Policy.-- Vol. 104 (5/2017).-- p. 33-37.

KOC utilizes solar technology in North Kuwait.-- The Kuwaiti Digest.-- (1-3/2017).-- p. 27-29.

Labordena, Merce (et al). **Impact of political and economic barriers for concentrating solar power in sub-saharan Africa** .-- Energy Policy.-- Vol. 102 (3/2017).-- p. 52-72.

MENA solar power reaches key milestones.-- Technical Review Middle East.-- Vol. 33, no. 1 (2017).-- p. 20-22.

IV- FINANCE & PUBLIC FINANCE

BMI. **Global country risk: Track record, 2016**.-- London: BMI, 2016.--15 p.

Brunello, Giorgio; Weber, Guglielmo and Weiss, Christoph. **Identifying the elasticity of taxable income**.-- The Economic Journal.-- Vol. 127, no. 600 (3/2017).-- p. 297-329.

Christodoulakis, Nicos and Sarantides, Vassilis. **External asymmetries in the Euro area and the role of foreign direct investment**.-- The World Economy.-- Vol. 40, no. 2 (2/2017).-- p. 393-423.

V- GAS

Bela, F. **Put acid gas hydrocarbons in their place with staged regeneration**.-- Hydrocarbon Processing.-- Vol. 96, no. 2 (2/2017).-- p. 39-42.

BMI. **LNG: Global industry trends, Sept. 2017**.-- London: BMI, 2017.-- 49 p.

Burns, Sarah K and Ziliak, James P.. **Air pollution and infant mortality: Evidence from the expansion of natural gas infrastructure**.-- The Economic Journal.-- Vol. 127, no. 600 (3/2017).-- p. 330-362.

Curtis, Toisha. **Unravelling the US shale productivity gains**.-- Oxford: Oxford Institute for Energy Studies, 2016.--15 p.

Horlick, Gary N. **Spain's winter scramble for gas**.-- Energy Economist.-- No. 426 (4/2017).-- p. 14-17.

Khalifa, F. **LPG plant revamp to increase capacity, produce commercial-grade propane**.-- Gas Processing.-- (1-2/2017) .-- p. 27-31.

Knudsen, Brage R and Foss, Bjarne. **Shale-gas wells as virtual storage for supporting intermittent renewables** .-- Energy Policy.-- Vol. 102 (3/2017).-- p. 142-144.

Lee, Yusin. **Interdependence, issue importance, and the 2009 Russia - Ukraine gas conflict**.-- Energy Policy.-- Vol. 102 (3/2017).-- p. 199-209.

Martin Daniel. **Japanese market liberalization to impact LNG trade**.-- Energy Economist.-- No. 426 (4/2017).-- p. 10-13.

Mokhatab, S; Cleveland, T and Santos, S.P. Dos. **Standardize compressor station design to reduce project costs and time line**.-- Gas Processing.-- (1-2/2017).-- p. 15-18.

Nuclear pain, gas gain.-- World Gas Intelligence.-- Vol. 28, no. 11(15/3/2017).-- p. 1.

Prague, NJ Watson. **Evergreen gas problem**.-- Petroleum Economist.-- Vol. 84, no. 2 (3/2017).-- p. 20-23.

Put acid gas hydrocarbons in their place with staged regeneration.-- Hydrocarbon Processing.-- Vol. 96, no. 2 (2/2017).-- p. 39-42.

Qatar restarts gas expansion plans as Iranian output of shared field soars.-- MEES.-- Vol. 60, no. 14 (7/4/2017).-- p. 2-3.

Renewable gas to play bigger role as energy transition gathers pace.-- World Gas Intelligence.-- Vol. 28, no. 11(15/3/2017) .-- p. 9-10.

Sahajpal, S and Sircar, A. **Improve gas distribution networks with innovative pipeline monitoring and repair**.-- Gas Processing.-- (1-2/2017).-- p. 23-26.

Sutcliffe, G. **Advancing the role of gas and LNG in the global energy mix**.-- Gas Processing.--(1-2/2017).--p. 33-34.

Xunpeng, Shi (et al). **Global impact of uncertainties in China's gas market**.-- Energy Policy.-- Vol. 104 (5/2017).-- p. 382-394.

VI- PETROCHEMICALS

Al-Sadoun, Abdulwahab. **Molecules, mind and matter: How the Arabian Gulf became a global petrochemical hub**.-- London: Medina Publishing, 2015.--154 p.

VII- PETROLEUM

Butt, Gerald. **Petroleum: Middle East**.-- Petroleum Economist .-- Vol. 84, no. 2 (3/2017).-- p. 44-47.

Butt, Gerald. **Report: Oman**.-- Petroleum Economist.-- Vol. 84, no. 2 (3/2017).-- p. 16-19.

CERAWeek 2017: Encouragement & engagement.-- OPEC Bulletin.-- (3-4/2017).-- p. 13-18.

Elkins, Mark. **Offshore facilities**.-- JPT.-- Vol. 69, no. 2 (2/2017).-- p. 54-62.

Industry at a glance.-- World Oil.-- Vol. 238, no. 2 (2/2017).—p. 29-30.

KOC participates in world heavy oil congress.-- The Kuwaiti Digest.-- (1-3/2017).-- p. 21-23

McCracken, Ross .. **Making India work**.-- Energy Economist .-- No. 426 (4/2017).-- p. 3-6.

Prague, W.. **Petroleum: Africa**.-- Petroleum Economist.-- Vol. 84, no. 2 (3/2017).-- p. 48-51.

Rassenfoss, Stephen. **Petroleum engineering schools begin to see enrollment declines**.-- JPT.-- Vol. 69, no. 2 (2/2017).-- p. 22-23.

SPE international heavy oil conference & exhibition.-- The Kuwaiti Digest.-- (1-3/2017).-- p. 8-10.

Su, Chi-Wei. **When will occur the crude oil bubbles**.-- Energy Policy.-- Vol. 102 (3/2017).-- p. 1-6.

PETROLEUM - MARKETING

Ford, Neil. **Nigeria: oil market reform and Delta politics**.-- Energy Economist.-- No. 426 (4/2017).-- p. 7-10.

Barkindo, Mohammad Sanusi. **OPEC stresses importance of structured partnership for global oil producers**.-- OPEC Bulletin.-- (3-4/2017).-- p. 35-38.

Return of Iranian crude makes big splash in Europe.-- MEES.-- Vol. 60, no. 14 (7/4/2017).-- p. 9-10.

Egypt receivables: A glass half full or half empty?.--MEES .-- Vol. 60, no. 14 (7/4/2017).-- p. 11-13.

Saudi Arabia is back.-- World Oil.-- Vol. 238, no. 2 (2/2017) .-- p. 23.

Stability through cooperation-it works!.-- OPEC Bulletin.-- (3- 4/2017).-- p. 1.

Diesel fumes.-- Energy Economist.-- No. 426 (4/2017).-- p. 2

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Ghandi, Abbas and Lawell, CY Cynthia Lin. **On the rate of return and risk factors to international oil companies in Iran's buy-back service contracts**.-- Energy Policy.-- Vol. 103 (4/2017).-- p. 16-29.

How Aramco can become a $2 trillion firm.-- Petroleum Intelligence Weekly.-- Vol. 56, no. 10 (13/3/2017).-- p. 1-2.

Meidan, Michal. **China's loans for oil: Asset or liability?**.-- Oxford: Oxford Institute for Energy Studies, 2016.--16 p.

Meineke, Michelle. **Report: The Aramco IPO**.-- Petroleum Economist.-- Vol. 84, no. 2 (3/2017).-- p. 10-11.

What's next for Sonatrach sales deals?.-- MEES.-- Vol. 60, no. 14 (7/4/2017).-- p. 4-6.

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Barkindo, Mohammad Sanusi. **Oil sector cannot afford another year of lost investment**.-- OPEC Bulletin.-- (3-4/2017).-- p. 26-28.

The inauguration of the Ahmad Al-Jaber oil & gas exhibition.-- The Kuwaiti Digest.-- (1-3/2017).-- p. 3-7.

Petroleum Economist (et al). **Oil and oil product pipelines map of European and Asian markets**.-- London: Petroleum Economist, 2017.

Special focus: 2017 forecast US reserves.-- World Oil.-- Vol. 238, no. 2 (2/2017).-- p. 51-52.

Speight, James. **An introduction to petroleum technology, economics, and politics**.-- Hoboken, New Jersey: John Wiley & Sons, 2011.--320 p.

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BMI. **Oil & Gas global capex outlook 2017**.-- London: BMI, 2017.--36 p.

BMI. **Top 7 oil & Gas exploration hotspots for 2017**.-- London: BMI, 2017.--34 p.

Gerden, E. **PNG provides investment opportunities to global oil and gas majors**.-- Gas Processing.-- (1-2/2017) .-- p. 9-10.

Jacobs, Trent. **US shale productivity will offset rising service costs**.-- JPT.-- Vol. 69, no. 2 (2/2017).-- p. 32-34.

Shale and stocks overshadow OPEC discipline.-- Petroleum Intelligence Weekly.-- Vol. 56, no. 10 (13/3/2017).-- p. 2-3.

Tallett, Dunbar M (et al). **Anticipated market and pricing impacts from new marine fuel regulations**.-- Hydrocarbon Processing.-- Vol. 96, no. 2 (2/2017).-- p. 9-10.

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Members report high level of conformity to oil production adjustments in February.-- OPEC Bulletin.-- (3-4/2017).-- p. 4-11.

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PETROLEUM - REFINING

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Mars, Tommy. **Europe's refineries: Walking dead or happy valley?**.-- Hydrocarbon Processing.-- Vol. 96, no. 2 (2/2017) .-- p. 23-24.

New method to measure TAN of crude oil and refinery distillation fractions.-- Hydrocarbon Processing.-- Vol. 96, no. 3 (3/2017).-- p. 27-34.

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Africa: Will increase demand spark downstream capacity builds?.-- Hydrocarbon Processing.-- Vol. 96, no. 3 (3/2017).-- p. 9-13.

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SSY Consultancy & Research Ltd. **World oil tanker trends, 2017**.-- London: SSY Consultancy & Research, 2017.--78 p.

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Rudolph, Kurt W and Goulding, Frank J. **Benchmarking exploration predictions and performance using 20+yr of drilling results: One company's experience**.-- AAPG Bulletin.-- Vol. 101, no. 2 (2/2017).-- p. 161-176.

Special focus: 2017 forecast US drilling.-- World Oil.-- Vol. 238, no. 2 (2/2017).-- p. 41-47.

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Bridger, D. and Meredith, Emily. **Trump climate order leaves (some) negotiating room**.-- New Energy.-- Vol. 6, no. 13 (30/3/2017).-- p. 5.

Davi-Arderius, Daniel (et al). **CO2 content of electricity losses**.-- Energy Policy.-- Vol. 104 (5/2017).-- p. 439-445.

Exploration: If cost cuts will last.-- JPT.-- Vol. 69, no. 2 (2/2017).-- p. 35-41.

Fan, Ying (et al). **What policy adjustments in the EU ETS truly affected the carbon prices?**.-- Energy Policy.-- Vol. 103 (4/2017).-- p. 145-164.

Moore, Michael O. **Carbon safeguard? Managing the friction between trade rules and climate policy**.-- Journal of World Trade.-- Vol. 51, no. 1 (2/2017).-- p. 43-66.

S. J, Richard. **The structure of the climate debate**.-- Energy Policy.-- Vol. 104 (5/2017).-- p. 431-438.

Schleich, Joachim and Faure, Corinne. **Explaining citizens perceptions of international climate-policy relevance**.-- Energy Policy.-- Vol. 103 (4/2017).-- p. 62-71.

Trump to steer new climate course.-- World Gas Intelligence .-- Vol. 28, no. 11 (15/3/2017).-- p. 2.

Tulloch, Daniel J (et al). **The impact of liberalization and environmental policy on the financial returns of European energy utilities.**-- The Energy Journal.-- Vol. 38, no. 2 (3/2017).-- p. 77-106.

Washer, Jim. **BP takes centrist approach on climate**.-- New Energy.-- Vol. 6, no. 13 (30/3/2017).-- p. 1-2.

Weatherl, Michael. **Drilling technology and rigs**.-- JPT.-- Vol. 69, no. 2 (2/2017).-- p. 45-53.

Young, G.C. **Mitigate CO2 emissions from industrial plants by conversion to fuels**.-- Hydrocarbon Processing.-- Vol. 96, no. 2 (2/2017).-- p. 47-52.

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Momani, Bessma. **Barriers persist for Arab women**.-- MEED.-- Vol. 2, no. 1 (1/2017).-- p. 18-19.

Professional women network holds second summit.-- The Kuwaiti Digest.-- (1-3/2017).-- p. 24-26.

Re-Refining of Used Lubricating Oils and its Economic and Environmental Implications

Jamal Al Harbey

More than a hundred years have elapsed since the fossil fuel energy has become the preeminent cornerstone of the civilized human society.

Such a position has continuously evolved so that fossil fuel is currently meeting the lion's share of the global energy demand. As the twentieth century was themed with environmental changes- considerations, global warming was linked -by some institutes- to increasing consumption of fossil fuel, Policies were established and pledges were made as to address the phenomena. However, extrapolating the current demand to the foreseen future shows that fossil fuel will remain the major source with 75% share of the energy mix, energy demand in general is forecasted to increase by 40% within the next two decades.

Conventional fossil fuel resources are abundant, but many factors need to be considered before simple- figure resources could be classified as reserves that could spin the wheel of development after passing through the world energy markets.

The increase of conventional oil prices has participated in re-evaluating the resources that once were economically unavailing. Advanced technologies enabled the utilization of some reservoirs that used to be regarded as cap rocks or source rocks.

Following the success of some countries in the exploitation of their shale oil resources, the world began to reconsider the possibility of developing this type of hydrocarbons, some have even argued that the extracted oil might contribute to changing the shape of the world energy markets by impacting producers of conventional oil, especially those in the Middle East and North Africa.

Within the last few years, much attention was drawn towards the so called Shale Revolution in USA, numerous research centers rushed to preach a new petroleum era that could pause what the consumers accept as the producers' cartel to which oil production and prices are attributed. The media in turn enlarged the image as if shale oil and gas were going to reshape the petroleum industry for good, and provide energy for pennies.

This study sheds light on shale oil resources and production, and investigates the obstacles that faces its effective utilization. The study also outlooks current and future real reflection of shale oil production on the energy market.

The study concluded that there is a remarkable contrast in estimating shale oil resources and its future potential production around the world. It also noted the main reasons behind the success of USA in utilizing shale oil and gas of which are the availability of human resources, considerable investments, governmental incentives, abundance of water resources, and the vast number of rigs. Kuwait, 2014.

Chapter 3 deals with virgin and used oil processing where virgin production steps are discussed briefly as an entrance to the main processing of used oils. Various processes are discussed in details to demonstrate their relevance to the modern requirements of lubricants. Processes to treat used oil for fuel purposes are also discussed.

Chapter 4 deals with burning used oil for fuel and energy recovery, a great competitor to used oil re-refining. The quantities are discussed on regional basis to discover the trends and the potential for further re-refining of used oil.

Chapter 5 deals with the economics of re-refining in discussing what affects this important aspect including supply and demand for lubricants, the impact of oil prices and the process selection and so on. An important economic model is also presented which can be used by others in further studies.

Chapter 6 deals with the lubricating oil industry in the Arab countries including the production and consumption of lubricants. The re-refining plants and plans in the Arab countries are also discussed. It was difficult to obtain accurate data here as is the case in other world regions.

Examples of countries experience are imbedded in the relevant chapters where the experience of Italy is included in chapter 5 and the experience of Saudi Arabia and the UAE is included in chapter 6.

Conclusions and recommendations are cited in chapter 7 with special emphasis on what is to be done in Arab countries.

Upfront, the executive summary is a condensation of the most important aspects of the report which also shows the direction followed in the research.

Needless to say that the lack of expensive consultant's reports made reliance on the Internet and public sources paramount. This is sometimes followed by discussion with private sources in the industry.

I hope this research serves the purpose of OAPEC and that the Organization would go ahead to promote the collection, controlled utilization and processing of used oils for the benefit of the economy, environment and the wellbeing of the Arab people in their different countries.

Abstract

Re-Refining of Used Lubricating Oils and its Economic and Environmental Implications

Saadallah Al Fathi

The Organization of Arab Petroleum Exporting Countries (OAPEC) is indeed fortunate in selecting the theme of this year's resea rch titled "Re-Refining of Used Lubricating Oils and its Economic & Environmental Implications".

Used lubricating oils affect the environment adversely for the pollutants that they accumulate as a result of deterioration throughout the service life under the conditions of heat and friction.

At the same time, used oils are still a hydrocarbon resource that should be conserved as much as practicable to lessen the needs for crude oil and its products.

While the collection of used oil and its utilization for fuel or in re-refining industry in the Arab countries is small and limited to few countries, increasing interest is seen forthcoming and will pick up momentum once the governments make it a policy to support the industry by laws and regulations and financial compensation.

The breakdown of the requested research as outlined in (OAPEC) announcement has been covered here with the variation that was found necessary to cover the intended purpose especially with respect to burning used oil for energy recovery and the relationship with virgin lubes supply and demand. It was found that the used oils question is not isolated and must be viewed in relation to the overall industry of lubricants and to fuel users as well.

Chapter 1 deals with the history of lubrication and re-refining to see how the re-refining industry evolved from the consumption of virgin base oils and to take note of the similarity in processing steps of both.

In chapter 2 the environmental impact and resource conservation of used oils disposition is discussed with respect to dumping, burning for energy recovery or processing for base oil production.

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