



- (51) International Patent Classification:  
C10G 21/00 (2006.01) C10G 73/06 (2006.01)  
C10G 7/00 (2006.01)
- (21) International Application Number:  
PCT/US2018/042323
- (22) International Filing Date:  
16 July 2018 (16.07.2018)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
62/532,935 14 July 2017 (14.07.2017) US  
16/036,120 16 July 2018 (16.07.2018) US
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- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,

(54) Title: PRODUCTION OF HIGH QUALITY BASE OILS

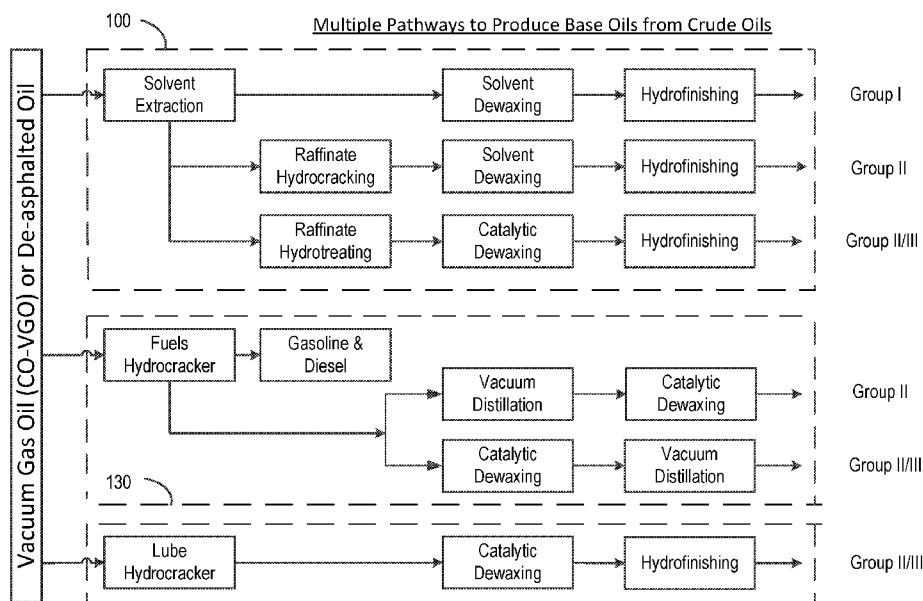


Fig. 1

Source: Solomon Associates  
(as reported in Lubes N' Greases Magazine, March 2016, page 34)

(57) Abstract: A process for creating higher quality and lower quality base oils from used lubricating oils and crude oils, wherein the higher quality base oils may be either Group III or Group II and the lower quality base oils may be either Group II or Group I. Vacuum gas oils produced from used lubricating oils and from crude oils are processed via two or more process steps, including solvent extraction, solvent or catalytic or iso dewaxing, and hydrotreating. Such process enables efficient conversion and operation of refineries formerly capable only of making Group I base oils, even as their ability to make heavier base oils, waxes, and bright stocks is preserved, substantially to the same extent as such products had been made prior to undertaking the conversion.



UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published:**

- *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

**PRODUCTION OF HIGH QUALITY BASE OILS**

**TECHNICAL FIELD**

[0001] The invention relates generally to base oils and, more particularly, to a process for producing high quality and low quality base oils from used lubricating oils and crude oils.

**BACKGROUND**

[0002] Over the course of many years, the vast majority of equipment and machinery (including engines of automobiles and trucks) have been substantially improved, thereby achieving dramatic increases in performance. In the case of internal combustion engines for automobiles using Passenger Car Motor Oils (“PCMOs”) and trucks using Heavy Duty Engine Oils (“HDEOs”), performance improvements have been achieved in higher fuel economy and lower emissions. This increased performance has, in turn, created increased requirements for higher performing finished lubricants. Such improved performance requirements have prompted major advancements in technologies for making base oils, which generally comprise between 70% and 99% of a finished lubricant, the balance being special additives. The result has been dramatic expansion in the production of base oils which are low in sulfur, high in saturates, and achieve a higher viscosity index (“VI”). Viscosity Index is a measure of an oil’s change in viscosity in response to a change in temperature, where a lower change is better, and which corresponds to a higher number. Under the API Classification system, such higher quality base oils are generally described as Group II and Group III base oils, relative to Group I which are the lowest quality base oils. The divisions between Groups I, II and III are based on the levels of sulfur, saturates, and viscosity index, as noted in Table 1 below.

Table 1  
API Base Oil Classification System

Group	Sulfur	Saturates	Viscosity Index
I	> 300 PPM	< 90%	80 - 120
II	≤ 300 PPM	≥ 90%	80 - 120
III	≤ 300 PPM	≥ 90%	≥ 120
IV	PAO Poly Alpha Olefin		
V	Poly Esters (others)		
VI	PIO (Poly Internal Olefins)		Europe Only (ATIEL)

[0003] In the above classification system, informal sub-classifications have evolved in the market where base oils which exceed 90% saturates and have less than 0.03% sulfur and have VIs in the 115 to 119 range, are called Group II+. Base oils which achieve

the same saturates and sulfur levels and have VIs of 130 or more are referred to as Group III+. In comparison to Group I base oils, base oils which fall into Groups II and III generally exhibit improved performance characteristics in volatility, low temperature properties (*e.g.*, pour point, cold cranking viscosity, cloud point and the like), and oxidation stability as well as improved VIs. All of Groups I, II and III are derived from crude (mineral) oils as compared to Groups IV and V which are produced as petrochemicals (ultimately most being made from natural gas, or its derivatives). To make base oils from crude oil (also known as virgin base oils), crude oil is first distilled in an atmospheric column and then the bottoms from the atmospheric column pass to a vacuum column, in which a distillate referred to as Vacuum Gas Oil (“VGO”) is produced. The VGO is then further processed to make base oils. In this application, VGO that is derived from crude oil is referred to as CO-VGO and it typically has VIs that range from 50 to 90.

**[0004]** Viscosity is the single most important characteristic of base oil (and lubricants in general). Viscosities of base oils are closely correlated with their boiling ranges. VGOs suited for making base oils have atmospheric equivalent boiling ranges from 550°F on the low end to 1050°F on the high end, although the majority of all base oils carry an atmospheric equivalent boiling range from 650°F on the low end to 1050°F on the high end (unless noted otherwise, all temperatures referenced herein are atmospheric equivalent boiling points). VGOs may be produced which have boiling points below 550°F but, for making base oils, it is preferred that liquids that boil below 550°F be removed prior to processing, as these lighter viscosity liquids are suited for diesel, kerosene (used in making jet fuel), and gasoline versus base oils, which require thicker viscosities for their applications. Base oils produced from VGO with boiling ranges from 550°F or 650°F up to 1050°F have viscosities generally ranging from about 50 to 70 and up to 700 to 750 Saybolt Universal Seconds (“SUS”) at 100°F, or alternatively measured from about 4 to 14 centistokes at 100°C. Viscosities falling in the ranges from 100 to 120 SUS and from 200 to 240 SUS are commonly used in manufacturing PCMOs and HDEOs, respectively. Heavier viscosities of 300 to 800 are most commonly used in making industrial lubricants.

**[0005]** FIGURE 1 shows the three general pathways by which CO-VGO is processed into Group I, II or III base oils. The first pathway, depicted within dashed outline 100, starts with solvent extraction and then the raffinate produced from solvent extraction is further processed by solvent de-waxing and hydrofinishing to produce Group I base oils (the lowest quality). In the present invention, a Group I plant is thus defined as a facility which primarily processes crude oil and, with respect to the base oils that are produced, produces

primarily Group I base oil. Typically Group I plants utilize process technologies including solvent extraction, dewaxing (which can be any of solvent dewaxing, catalytic dewaxing, and isodewaxing), and hydrofinishing. The addition of hydroprocessing was the first major technology upgrade after solvent extraction was first introduced in the 1930s and this generally began in the 1960s when hydrotreating was first applied to base oils. Exxon-Mobil introduced an innovation to the existing Group I base oil process which inserted hydrocracking or hydrotreating of the raffinate stream produced by solvent extraction (and it was applied before the dewaxing step) and these are the two smaller boxes labeled Raffinate Hydrocracking or Raffinate Hydrotreating which are then followed by the solvent or catalytic dewaxing steps. Exxon's approach enables Group II and Group III base oils to be produced by upgrading the raffinate produced in the initial solvent extraction step (which was applied to the VGO or to the de-asphalted oil ("DAO") feedstock made from crude oil).

[0006] Group I plants typically will produce valuable by-products. For example, many Group I plants also use solvent de-asphalting of vacuum column bottoms produced in processing crude oil (referred to in the present invention as CO-VCB) which produces DAO as well as an asphaltic material (DAO made from crude oil is referred to herein as CO-DAO). DAO is a very thick material that, with further processing, is made into bright stock. Bright stock generally has viscosities of about 2500 SUS at 100°F or, alternatively measured, about 32 centistokes at 100°F. In addition, the solvent de-waxing process shown in FIG. 1 will produce various wax products.

[0007] As many Group I plants have shut down, the supply of bright stock and wax has decreased, which has served to increase the prices of bright stock and wax, and to increase the value of Group I plants still operating. Increased revenues from sale of bright stock and wax products have partially offset a decline in price and volume demanded for Group I base oils. As a result, the useful lives of many Group I plants have been extended longer than if they had been wholly dependent upon selling just Group I base oil. Other de-waxing technologies include catalytic de-waxing and iso-dewaxing, neither of which typically produces wax by-products. Together, solvent de-waxing, catalytic de-waxing, and iso-dewaxing are referred to herein as "dewaxing", a "dewaxing step", or "dewaxing technologies."

[0008] The next major innovation occurred with added hydroprocessing technologies such as various sequences of hydrocracking, hydrotreatment, hydrofinishing, catalytic dewaxing, and iso-dewaxing, and these are shown in dashed boxes 130 and 160 in FIG. 1. As used herein, the term "hydroprocessing" is used to refer to hydrocracking,

hydrotreatment, hydrofinishing, catalytic dewaxing, and iso-dewaxing as well as any associated technologies which apply hydrogen and catalysts under conditions of temperature, pressure, and residence times to achieve improvement in the feedstock. Box 130 in FIG. 1 begins with a Fuels Hydrocracker (*e.g.*, targeted for making gasoline, diesel, jet fuel, and the like) whereas box 160 begins with a Lube Hydrocracker (*e.g.*, targeted for making lube oils). As shown, each of these two pathways will make higher quality Group II and Group III base oils. The advanced hydroprocessing technologies shown in boxes 130 and 160 are now the dominant processes used for making base oils, substantially displacing the traditional solvent extraction, solvent dewaxing, hydrofinishing processing route to Group I base oil production shown in the upper large box. Exxon has continued to produce large volumes of base oils using its raffinate hydroprocessing technologies with some success as well.

**[0009]** The process of creating base oils from used lubricating oils is referred to as re-refining and the produced base oil is referred to as re-refined base oil. The term re-refining is used since the used lubricating oil was refined once previously to make the original lubricant. FIGURE 2 shows the multiple pathways for creating re-refined base oils. Vacuum distillation of used lubricating oils produces an intermediate liquid which is a distillate referred to as vacuum gas oil (“VGO”). When such VGOs have been made substantially from used lubricating oils, these are referred to herein as UO-VGOs. UO-VGOs produced from used lubricating oils that are PCMOs or HDEOs will have higher VIs, whereas UO-VGOs produced from used lubricating oils generated in industrial applications and railroads will have lower VIs. Since used lubricating oils may be derived from industrial uses or from PCMO or HDEO, the VIs of UO-VGO vary widely based on the type of used lubricating oil from which the UO-VGO was produced.

**[0010]** As shown in FIG. 2, as an initial step, re-refining technologies most commonly apply vacuum distillation (200), thermal de-asphalting (230), or solvent de-asphalting (260), which produce one or more intermediate liquids, certain of which are then further upgraded to produce a marketable base oil, most commonly either by clay treatment, solvent extraction, or hydrotreatment. (In the 1960s, acid/clay treating was prevalent, but was discontinued due to extensive by-product solids creation that became ground pollutants, creating many super-fund sites that incurred massive clean-up costs.) Vacuum distillation (which generally occurs after atmospheric distillation) efficiently removes both lighter boiling point liquids and very heavy asphaltene (1050 + °F boiling point) and is the most common initial step in re-refining to make UO-VGO. Thermal de-asphalting will also produce a UO-VGO, but it materially cracks the used lubricating oil which degrades the

quality of the intermediate liquid, thus creating poor yields and lower quality base oils. Solvent de-asphalting of vacuum column bottoms produced from used lubricating oils (referred to in the present invention as UO-VCB) will result in a de-asphalted oil or DAO which is referred to as UO-DAO in the present invention.

[0011] Over time hydrotreating, and to a lesser extent solvent extraction, have become the preferred processing technologies for upgrading UO-VGO into re-refined base oils, as subsequent processing steps following vacuum distillation, thermal de-asphalting or solvent de-asphalting. Hydrotreatment (also referred to herein as “hydrotreating”) is commonly applied in re-refining under processing severities ranging, in temperature from about 500 °F to 700°F, in pressure from about 600 to 1,500 psig, and in space velocities from about 0.5 to 2.0. Hydrotreating of UO-VGO is now capable of producing re-refined base oil with VIs in excess of 110, saturates well in excess of 90%, and sulfur and nitrogen below 200 ppm, thus creating a higher quality Group II base oil.

[0012] To understand the limits of hydrotreatment, it is important to understand the means by which hydrotreatment improves base oil, which in turn requires some knowledge of base oil composition. Base oil may be classified into three groups of compounds: saturates, aromatics, and polars. Thus whether by volume or by mass, Base Oil = Saturates + Aromatics + Polars (olefins are excluded as they are not likely to be material). Aromatics and polar compounds are low VI liquids whereas saturated compounds are higher in a range of VIs. Thus, higher levels of aromatics and polars in base oil will reduce the base oil's VI, whereas increased saturates in base oil will increase VI. Under elevated temperatures and pressures, over a certain residence time, in the presence of hydrogen and catalyst, hydrotreatment converts aromatics and polar compounds to saturated compounds, which may be paraffinic or naphthenic, thereby resulting in an increase in VI. Although both paraffins and naphthenes are saturates, naphthenes have lower VIs than paraffins. Thus, the higher the proportion of paraffinic components to naphthenic components, the higher will be the resultant VI, which is desirable since higher VI lube oils have higher value.

[0013] Conversion of aromatics and polar compounds to saturates in hydrotreatment is primarily dictated by temperature, residence time, and pressure (leaving aside catalyst selection, hydrogen purity, and hydrogen flow rate) with implications for base oil yields and capital cost. For example, there is an upper bound on temperatures above about the 650°F to 700°F range where increased residence time results in increased cracking and thus yield loss and coking of hydrotreating catalysts. Below the cracking temperatures, residence time can be increased (or alternatively stated, space velocity lowered), but there is a

practical limit on results that can be achieved by increased residence time without increasing cracking. Reaction dynamics limit product improvement to temperatures and residence times above which net conversion of aromatics and polars to saturates starts to reverse, thereby actually increasing aromatics and polars.

**[0014]** Although in the aggregate re-refined base oils are produced in far lower quantities than virgin base oils, volumes of re-refined base oils made by hydrotreating UO-VGO have grown dramatically in recent years. This has in part occurred due to the quality of the used motor oil pool increasing with higher lubricant standards, thus resulting in higher quality re-refined base oils. Because of the increased quality of used lubricating oil feedstock, it is now possible to hydrotreat UO-VGO and make Group II+ (with a VI of 115 to 119) and even Group III base oils (with VIs of 120 or more).

**[0015]** While hydrotreatment of UO-VGO alone can achieve high quality base oils, technically it is also possible to apply solvent extraction of UO-VGO alone to make Group III base oils. However, using solvent extraction alone to process UO-VGOs into re-refined base oils suffers from three large challenges. First, the sulfur level of the primary base oil is usually in the range of 200 to 300 ppm or more. Although this falls within the Group II and Group III specifications, this sulfur level is still high compared with typical hydrotreated base oils. Second, the color of the base oil is darker than the almost clear base oils typically produced by hydrotreating. Third, a large amount of extract is produced (up to 50%) and this extract is generally not suitable for sale as base oil, but is typically sold as low value fuel oil.

**[0016]** Over time hydrogen-based technologies such as hydrotreatment, hydrocracking, catalytic dewaxing, and hydro-isomerization, all of which apply hydrogen in the presence of specialized catalysts and specific conditions of pressure, temperature, hydrogen purity and flow rate, and residence time, have come to dominate in making both virgin base oils and re-refined base oils. This has come largely at the expense of Group I plants, and aggregate Group I plant volumes are in a rapid decline as the high sulfur, low saturates, and low viscosity index characteristics of Group I are not suited for the higher volume and higher value PCMO and HDEO market applications. As customers which were formerly using Group I base oils have shifted to purchasing Group II and Group III base oils instead, many Group I base oil plants have shut down. Group I plants are increasingly being relegated to industrial applications where VI, sulfur, and saturates are not key determinants of suitability. For example, applications where Group I base oils still dominate over Group II and Group III base oils include process oils, gear oils, general industrial oils, metalworking

fluids, and the like. Such markets are still substantial and in total equal about 50% of all finished lubricants sold, but a large surplus of Group I production makes it increasingly difficult to sell Group I.

[0017] Various technologies have been developed over the years to further utilize the investment in Group I base oil plants by upgrading them to make more valuable base oils. As mentioned above, Exxon-Mobil has developed a technology called raffinate hydroconversion (U.S. Patent Nos. 6,592,748 and 6,974,535) which applies hydrotreating to the raffinate stream produced in a solvent extraction unit processing vacuum gas oil derived from crude oil. While this does utilize equipment formerly used to make Group I base oil to instead make at least Group II, it does not allow for high yield of Group III base oils since the VIs of CO-VGO fall generally in the range of 50 to 90, which is far below the 120 and above VI level required for Group III base oils. Furthermore, the extract stream is large and has low value since it is hydrogen deficit. Finally when raffinate hydroconversion is applied to make Group III base oils, it generally must utilize hydrocracking which then produces a substantial yield reduction due to the high process severity.

[0018] An additional approach to improving base oils made from crude oil is disclosed in U.S. Patent No. 3,617,476 issued to Woodle in 1971. Woodle '476 discloses a sequence involving first applying mild hydrogenation, followed by solvent refining and dewaxing. The mild hydrogenation conditions include a pressure not greater than 600 psig and the patent notes a highest VI achieved of 111, thus not even achieving Group II+. Furthermore, such mild process hydrogenation conditions are incapable of achieving levels of de-aromatization, de-sulfurization, and de-nitrication demanded by today's higher quality finished lubricant specifications.

[0019] In U.S. Patent No. 4,085,036 issued to Murphy in 1978, a process is disclosed applying hydro-desulfurization to a feedstock (a lubricating oil fraction produced by distillation of crude oil) containing at least 1.5% sulfur, whereupon the residual portion of the distillation is subjected to a de-asphalting step and the de-asphalted oil therefrom is combined with the distillate and then solvent extracted. The raffinate from the solvent extraction step is then subjected to dewaxing, followed by one or more finishing steps such as hydrofinishing and clay treating. The purpose of the Murphy '036 process is to remove sulfur more efficiently, but it does not enable making improvements to VGO, thereby enabling achievement of high quality Group II and III base oils.

[0020] An alternative process for creating a lubricating oil from the residual of vacuum distillation of an asphaltic crude oil by means of solvent treatment is offered in U.S.

Patent No. 3,414,506 issued to Compagne in 1968. A de-asphalted oil is produced by applying a methanol/butanol mixture, which is then further processed by applying hydrotreatment to the de-asphalted oil. A dewaxing step is noted as an option in between the de-asphalting step and the hydrotreating step. The process produces a 44% asphaltic stream and other lower valued streams, and achieves a maximum VI of only 95 in the base oil product with base oil yields ranging from just 15.5% to 28.5%. While this process does recover base oil contained in the vacuum residual (which would otherwise be lost most likely as fuel oil), the patent does not address what happens to the majority stream, which is the distillate from vacuum distillation (the VGO).

**[0021]** Various technologies have been developed over the years to re-refine used lubricating oils into base oils. U.S. Patent No 4,151,072 issued to Nowack et al. in 1979 discloses contacting the used lubricating oil with an aqueous based ammonium salt to produce a precipitate containing the ash forming contaminants, thus leaving a distillate (effectively VGO) to be processed via hydrotreating. This process was effectively employed by Phillips Petroleum (called the Phillips Re-refined Oil Process or PROP) but it did not produce very high quality base oil and the precipitate was a waste stream that, while inert, was nonetheless viewed unfavorably when evaporators were later introduced that instead captured ash forming contaminants in what became an asphalt blend stock (a marketable product). Nowack '072 does not disclose use of solvent extraction or production of products achieving the quality levels of Group II and III base oils.

**[0022]** U.S. Patent No. 6,117,309 issued to Daspit et al. in September 2000 discloses the use of sharp cut distillation of a used lubricating oil feedstock which is achieved in a packed column followed by solvent extraction. Additionally disclosed is that the raffinate produced by such process may be further processed via hydrotreating or clay treating, although the patent notes such treatments are not required. However, Daspit '309 does not disclose creation of products in which the quality levels of Group II and III base oils nor any application of the invention in conjunction with the processing of VGO produced from crude oils.

**[0023]** U.S. Patent Nos. 8,366,912 and 8,936,718 issued to MacDonald in February 2013 and January 2015, respectively, disclose processing used oil through a vacuum distillation followed by solvent extraction wherein the extract produced from the solvent extraction step is combined with a lighter boiling range (likely diesel) for subsequent hydrotreatment. The cited advantages of this approach are creation of higher yields of base oils by upgrading the extract stream to becoming a marketable base oil, ability to source and

process used lubricating oils of varied quality levels and still produce high yields of high quality products, reducing the level of capital expenditure afforded by hydrotreating only the extract stream, and finally, creating a Group III base oil. MacDonald does not explain if the produced Group III base oil was derived from the raffinate (which was not hydrotreated) or the extract stream (which was hydrotreated along with the diesel), nor does MacDonald disclose the high sulfur or poor color of the raffinate stream (which is the majority of the base oil output) which is associated with solvent extraction and which will negatively and materially impact the value and marketability of such base oils.

**[0024]** A further approach that has been applied to produce higher valued products has been blending base oils of varied quality levels together to take advantage of quality disparities. As one example, U.S. Patent No. 8,480,879 issued to Rosenbaum et al. in July 2013 discloses a process for blending a Fischer-Tropsch (gas-to-liquids technology) product with a base oil that does not meet Group I base oil specifications to make a product that achieves a Group I base oil and has a high viscosity index, low pour point, excellent oxidation stability, and potentially low volatility. While this approach does not involve hydrotreating or solvent extraction, it shows that combining two very different streams together can improve the quality of an otherwise off-spec and very low value material. Another example of blending is U.S. Patent No. 7,838,471 issued to Shirazi et al. in November 2010 which exhibits combining a Group II and Group IV base oil together to produce a base oil that meets or exceeds the criteria for SAE Grade 0W multi-grade engine oils, which represent the most challenging specifications to meet and which are currently typically met only by Groups III and IV base oils. While again not involving hydrotreating or solvent extraction, this patent shows how two relatively high end products (Groups II and IV base oils) can be combined to target the market application of a third high end product (Group III) where that third high end product is currently the most commonly used component in meeting the most challenging specification that currently exists in the PCMO lubricant market. Blending of disparate quality products thus has satisfied product specifications that would otherwise typically be addressed by process technologies such as hydro-processing or solvent extraction.

**[0025]** As finished lubricant quality has improved, so too has the quality of used lubricating oils that have been generated by use of the finished lubricants. As a result, an increasingly large portion of the used lubricating oil pool comprises high quality base oils that may be recaptured and reused to make re-refined base oils, which are valued far in excess of burner fuels. However, due to economic challenges associated with re-refineries,

the majority of used lubricating oils today are not utilized to make re-refined base oils, but are instead sold as burner fuel. As of 2017, in the United States alone, over 600 million gallons of used oil are sold as burner fuels, while only about 330 million gallons become re-refined base oils. Since the finished lubricant components that degrade most are additives and not base oils, this is a significant loss of potential value.

[0026] Accordingly there is a simultaneous need for: a) achieving high yields of quality Group II and Group III base oils that are increasingly being required in achieving higher performance levels in lubricants; b) a more efficient process for processing used lubricating oils into Group II and Group III base oils; and c) a process to utilize existing Group I base oil plants more effectively to preserve or enhance their useful life.

#### SUMMARY OF THE INVENTION

[0027] The present invention, accordingly, provides a process for creating high yields of higher quality base oils (*e.g.*, Group III or Group II), as well as low yields of lower quality base oils (*e.g.*, Group II or Group I), from used lubricating oils and crude oils. Vacuum gas oils produced from used lubricating oils and from crude oils are processed via two or more process steps, including solvent extraction, solvent or catalytic or iso-dewaxing, and hydrotreating. Such process enables efficient conversion and operation of refineries formerly capable only of making Group I base oils, even as their ability to make heavier base oils, waxes, and bright stocks is substantially preserved, to the same general extent as such products had been made prior to undertaking the conversion.

[0028] As discussed above, Group I base oil plants are under pressure due to an increase in demand for higher quality Group II and Group III base oils in many finished lubricant applications, including most notably automobile (PCMO) and truck (HDEO) lubricants as two very large applications where engines have been improved markedly in recent years. The existing solvent extraction, solvent de-asphalting, dewaxing, and hydrofinishing technologies which make Group I base oils from crude oils cannot make Group II and III base oils from crude oils. Thus fundamental changes in how a Group I plant is designed, constructed, and operated are needed to upgrade its capabilities to making Group II and III base oils.

[0029] As referenced previously, as the quality of finished lubricants is being upgraded, so too is the quality of a large portion of the used lubricating oil pool improving as a feedstock for making higher quality base oils. However, to optimally benefit from this trend, it is preferable to source gathered used lubricating oils that substantially comprise PCMO and HDEO (*e.g.*, sourcing from quick lube shops, car dealerships, service stations,

fleet operations, and the like) rather than sourcing used lubricating oils from industrial users (e.g., sourcing from machine shops, industrial plants, manufacturing plants, or mining facilities, and the like). By doing this, the UO-VGO produced from the used lubricating oil may achieve a VI of 90 or more (a VI in the range of 90 to 100 is most typical of Group I base oils). To make Group II and Group III base oils as described herein, it is preferable that the UO-VGO feedstock be derived from used oils made from PCMO and HDEO as much as possible. This is preferably measured by measuring the VI of the UO-VGO derived from the gathered used lubricating oil. Thus, disclosed herein is sourcing used lubricating oils whose UO-VGOs achieve VIs of 90 or above. If used oils can be sourced where the VIs of their associated UO-VGOs are 95, 100, 105, 110, or even 115 or more, then this is progressively more preferable.

**[0030]** UO-VGOs generally have lower viscosities (*i.e.*, they are thinner) compared with the average CO-VGO made from crude oils. The reason is that UO-VGOs tend to reflect the lower viscosities common to PCMOs and HDEOs, in the range of 100 to 250 SUS (at 100°F), whereas CO-VGOs on average may have higher viscosities when processing heavier crude oils as are common crude oil sources for many refineries. Notwithstanding the relative viscosities of the average of the UO-VGOs and CO-VGOs, it may be desirable to replace CO-VGOs with UO-VGOs of the same general viscosity range so that the base oils made from the UO-VGO have similar viscosities to those that were made from the CO-VGO which was replaced. This is readily achievable when the vacuum distillation column making CO-VGO produces multiple streams of varied viscosities of CO-VGO, as do most vacuum distillation columns.

**[0031]** Other changes are preferably applied to allow a former Group I base oil plant to make Group II and Group III base oils beyond simply sourcing UO-VGO that achieves VIs of 90 or more. Since UO-VGOs are made from used lubricating oils and the used lubricating oils were substantially dewaxed when they were originally made, when making Groups II and III base oils from UO-VGO, it is generally not necessary to process the stream being made into upgraded base oils through a dewaxing unit. Bypassing the dewaxing unit when processing UO-VGO reduces operating expenses, and where there is very little if no wax contained in the feedstock, bypassing the dewaxing unit is thus a preferred configuration of the present invention when processing UO-VGO. Furthermore, bypassing dewaxing when processing UO-VGO allows for processing CO-VGO through the dewaxer while UO-VGO is being processed by hydrotreating and solvent extraction. On the other hand, if UO-VGO and CO-VGO are blended in proportions where there is a material wax

component in a blend of the two liquids (referred to herein as “blended VGO”), then it may be preferable to process the blended VGO through the dewaxer in addition to the solvent extraction unit and hydrotreater. As noted above, many Group I base oil plants employ solvent deasphalting, and a further element which can be implemented is processing UO-VCB through the solvent deasphalting unit separately, or addition to, processing CO-VCB through the solvent deasphalting unit.

**[0032]** Generally hydrofinishing, as used in Group I base oil plants, applies milder process severities in the range of 600 to 800 psi or even 1,000 psi, and less than 600°F to 700°F. Such pressures and temperatures are typically not able to achieve the levels of hydrodesulfurization (HDS), hydro-denitrication (HDN), and hydro-dearomatization (HDA) as are demanded for applications requiring Group II and Group III base oils, even with UO-VGO VIs of 90 and above. Accordingly, disclosed herein is upgrading the hydrofinishing to hydrotreating wherein selected pressure, temperature, hydrogen purity and flow rates, and catalysts are applied to achieve HDS, HDN, and HDA capabilities which produce:

- a. sulfur levels preferably less than 300 ppm, more preferably less than 150 ppm, and most preferably less than 10 ppm, and,
- b. nitrogen levels preferably less than 300 ppm, more preferably less than 150 ppm, and most preferably less than 10 ppm, and,
- c. saturates levels of preferably greater than 90%, more preferably greater than 95%, and most preferably greater than 99%
- d. viscosity indexes preferably greater than 105, more preferably greater than 110, and most preferably greater than 115.

**[0033]** Providing enhanced hydrotreating capability does not impair the ability of a plant to operate as a hydrofinisher since the processing severities of hydrofinishing are less severe than hydrotreating. Alternatively stated, while it is feasible to run a hydrotreater as a hydrofinisher, it is not generally feasible to run a hydrofinisher as a hydrotreater.

**[0034]** As discussed above, generally solvent extraction as used in Group I base oil plants is applied to CO-VGO as the first processing step for the removal of aromatics and polar compounds. For targeting any given product quality in processing of any VGO (whether CO-VGO or UO-VGO), if the solvent extraction step is applied to the VGO before hydrotreating, then the solvent-to-oil ratio to achieve such quality must be higher (which will then reduce the overall yield of higher quality product), whereas if the hydrotreating step is applied to the VGO before solvent extraction, then the solvent-to-oil ratio can be lower (which then will increase the overall yield of higher quality product). Processing severities in

processing CO-VGO as measured by the solvent-to-oil ratio generally range from 0.5x up to 5.0x. In general, the levels of aromatics and polar compounds in UO-VGO is lower than in CO-VGO and more particularly when the solvent extraction step is applied to processing a UO-VGO that has first been hydrotreated, the levels of aromatics and polars are even lower still, often being under 5% or even under 1%. Accordingly, in processing UO-VGO that has first been hydrotreated, it is preferable that lower solvent-to-oil ratios ranging from 0.8 to 3.0x be applied, more preferable that solvent-to-oil ratios of 1.0x to 2.0x be applied, and most preferable that solvent-to-oil ratios of 1.3x to 1.8x be applied in order to achieve the optimum combination of yields and product quality. It should thus be evident from the above discussion that balancing processing severities in solvent extraction unit and hydrotreating may be expressly controlled so as to achieve an optimum or desired product quality and yield result, but such a balancing can only occur when the VGO is being processed by means of both hydrotreating *and* solvent extraction (but in either sequence). This capability is particularly important as it can enable hydrotreatment severities to be reduced to take advantage of the positive benefits of solvent extraction, which will then result in less cracking and creation of lower valued by-products (such as fuels and non-condensable gases, which are of low or no value).

**[0035]** As noted above when processing CO-VGO in a traditional Group I plant, the processing sequence generally applied is first solvent extraction followed by dewaxing and then hydrotreating. However, when processing UO-VGO, the processing sequence will preferably not include dewaxing at all. Furthermore, in processing UO-VGO, the sequence is preferably hydrotreating first followed by solvent extraction, but the sequence may be reversed. It is preferable to first hydrotreat and then utilize solvent extraction as this maximizes the product quality that will be passed to the solvent extraction unit with the result that both the raffinate and extract streams from the solvent unit will then preferably become highly marketable base oils. Furthermore, this configuration allows hydrotreatment of only one stream (such as either UO-VGO or CO-VGO) versus two streams (such as raffinate and extract). This also serves to increase total yield of higher quality product since most of the lower quality molecules that are passed to the solvent extraction unit have already been substantially upgraded during hydrotreating.

**[0036]** With respect to yields, the effluent from hydrotreating UO-VGO (before solvent extraction) that falls in the base oil boiling range (that then passes to solvent extraction) is preferably in excess of 80%, more preferably in excess of 85%, and most preferably in excess of 90%. In next applying solvent extraction, the base oils in the raffinate

stream are preferably in excess of 65%, more preferably in excess of 75%, and most preferably in excess of 85%, of the hydrotreated effluent that falls in the base oil boiling range. The vast majority of these raffinate base oils are preferably then processed to become Group III, with only a small minority of these thus becoming Group II (the Group II portions are generally the most low viscosity base oils falling in the range of 50 to 80 SUS). For the extract stream, the majority (if not all) of this preferably becomes a Group II base oil, which itself is of a very high quality. In contrast, the extract stream in Group I base oil plants processing CO-VGO by means of solvent extraction (which occurs before dewaxing and hydrofinishing), will generally not even be Group I (instead typically being a lower valued fuel stream or a hydrogen deficit feed to make gasoline, diesel, and jet fuels), and it can be up to 40% of the CO-VGO.

**[0037]** If alternatively the process sequence for UO-VGO is first to solvent extract and then hydrotreat (again preferably without dewaxing), then it is most economically beneficial for the raffinate stream and the extract stream to each be subsequently hydrotreated. However, since at any given point in time the hydrotreater can only run either the raffinate or the extract stream, the stream not being run must then be sent to intermediate storage (this is referred to as running “blocked out” since each stream is run as a block). Running blocked out produces a need for additional investment in both tankage and inventory, and also requires that a certain portion of the material that is produced during the switchover between the two streams be returned to the feedstock inventory. The portion that is recycled during the switchovers represents a loss in throughput capacity since during this time no product is being made. It is thus viewed as a preferred embodiment of the present invention to process the UO-VGO through the hydrotreater first and then through the solvent extraction unit second, although both sequences are encompassed herein.

**[0038]** The above noted changes in sourcing UO-VGO, upgraded and customized hydrotreating and solvent extraction capabilities and severities, by-passing the dewaxing step, and varied sequences of hydrotreating and solvent extraction, do not impair continued processing of CO-VGO as it had been run prior to the conversions. Instead the upgraded unit capabilities allow for further improvement not only based on the higher quality feedstock of the UO-VGO (in contrast to CO-VGO), but they also allow for more severe treatment of the CO-VGO. For example, the HDS capability that is added may be used to reduce the sulfur content of products produced from the CO-VGO. For this reason, the present invention will improve not only the quality of products made from UO-VGO, but also improve the quality of products made from CO-VGO.

[0039] Making all of the above changes discussed above is relatively simple compared with the addition of a Group III plant as would be shown under the all hydro-processing routes set forth in FIG. 1. Because of this, the changes noted herein are relatively low cost and may be accomplished quickly, in many cases without disrupting production of other areas of a refinery that are making gasoline, diesel, and jet fuel, and, in the case of certain changes, without even disrupting existing current production of base oils.

[0040] As an outgrowth of the current invention, in situations where a portion of the CO-VGO has been replaced by processing of UO-VGO, it is evident that the CO-VGO which has been replaced will then be in surplus (referred to herein as Surplus VGO). That Surplus CO-VGO is then available for use elsewhere, *e.g.*, in another refinery owned by the same party as generated the Surplus VGO, or in swap or sale to third parties, which may have use of such Surplus CO-VGO in making other fuels such as gasoline, diesel, or jet fuels. Making gasoline, diesel, and jet fuel is the most common use for CO-VGO in general and there are many refineries which purchase VGO from other parties as a means to increase their refinery's capacity and increase their sales of gasoline, diesel, or jet fuels. Also as noted above, the CO-VGO that is in surplus may be dewaxed prior to its sale or use in making gasoline, diesel, or jet fuels.

[0041] It should thus be clear that the present invention allows the full range of selection as to the proportions of CO-VGO and UO-VGO processed through the plant at any given point in time. Thus the preferred design for the plant offers the flexibility to run either all CO-VGO, all UO-VGO, or some portions of CO-VGO and UO-VGO blended together (*e.g.*, Blended VGO), as a key element of the present invention. Since processing CO-VGO as before will enable creation of bright stock and wax products, there is thus no impairment of capability to produce these valuable products while the CO-VGO is being run, even after the conversion of the Group I base oil plant as described herein.

[0042] In view of the foregoing, the present invention provides a number of advantages over conventional technology, including the following:

- a. Processing vacuum gas oils made from crude oils (CO-VGO) and used lubricating oils (UO-VGO).
- b. Operating expense savings achieved by not dewaxing when processing UO-VGO.
- c. High yields of Group III base oil using equipment used before in making Group I base oils.
- d. Production of Group II base oils in addition to Group III base oils.

- e. Continued production of valuable co-products such as bright stock, waxes, and heavier base oils.
- f. Minimal upgrades to increase processing severity of hydroprocessing equipment.
- g. Minimal or no upgrading to change processing severity of solvent extraction equipment.
- h. Minimum amount of pipework and tankage needed to alter process flows.
- i. Improved yields of the total Group III and Group II base oils.
- j. Reduced sulfur content, increased saturates content, in all products and improved VIs in most products.
- k. Availability of Surplus CO-VGO to be used internally, or sold to or swapped with third parties.
- l. Dewaxing of CO-VGO while UO-VGO is being processed by hydrotreating and solvent extraction.
- m. Processing UO-VCB in a solvent deasphalting unit that is suitable for processing CO-VCB.
- n. Short timeframe to achieve conversion of process units.
- o. Low creation of by-products and off-gases of lower or no value.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0043] For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0044] FIGURE 1 is a schematic diagram of multiple pathways to produce base oils from crude oils in accordance with the prior art.

[0045] FIGURE 2 is a schematic diagram of multiple pathways to produce base oils from using lubricating oils in accordance with the prior art.

[0046] FIGURE 3 is a schematic diagram exemplifying a preferred embodiment of the invention where CO-VGO is processed in a substantially similar way as per the traditional sequence in making Group I base oils, and UO-VGO is processed in a preferred sequence of hydrotreating before solvent extraction in making Group III base oils.

[0047] FIGURE 4 is a schematic diagram exemplifying a first alternative embodiment of the invention where CO-VGO and UO-VGO may be blended together and processing occurs in which hydrotreating precedes solvent extraction.

[0048] FIGURE 5 is a schematic diagram exemplifying a second alternative embodiment of the invention where CO-VGO and UO-VGO may be blended together and the

processing occurs where solvent extraction precedes hydrotreating, thus necessitating a blocked out configuration which requires storage of intermediate raffinate and extract liquids.

[0049] FIGURES 6A, 6B, and 6C exemplify three distinct modes in which CO-VGO and UO-VGO may be processed either singly, or in blended form as achieved by gate valves, a blending (proportional) valve, or check valves.

#### DETAILED DESCRIPTION OF THE INVENTION

[0050] Refer now to the drawings wherein depicted elements are, for the sake of clarity, not necessarily shown to scale and wherein like or similar elements are designated by the same reference numeral through the several views. In the interest of conciseness, well-known elements may be illustrated in schematic or block diagram form in order not to obscure the present invention in unnecessary detail, and details concerning various other components known to the art, such as solvent extraction extraction units, hydrotreaters, and the like necessary for the operation of many oil and gas processes, have not been shown or discussed in detail inasmuch as such details are not considered necessary to obtain a complete understanding of the present invention, and are considered to be within the skills of persons of ordinary skill in the relevant art. Additionally, as used herein, the term “substantially” is to be construed as a term of approximation.

[0051] FIGURE 3 presents a preferred configuration in which CO-VGO is processed using the traditional solvent extraction, solvent dewaxing (which could be catalytic dewaxing), and hydrofinishing sequence. When UO-VGO is being run, the assumption in FIG. 3 is that the hydrofinishing has preferably been upgraded to hydrotreating, if and as needed the solvent extraction unit has also been upgraded, and that an additional fractionation capability may optionally be added so as to provide continuous fractionation of both the higher valued (primarily Group III) stream and the lower valued Group II stream. FIG. 3 thus assumes that CO-VGO and UO-VGO will each be run separately through the plant at different times (*i.e.*, blocked out). In FIG. 3, the solid lines represent processing of CO-VGO and the dotted lines represent processing of UO-VGO. An explanation of processing for each of the CO-VGO and UO-VGO streams follows next below.

[0052] In FIG. 3, CO-VGO 300 is charged first to solvent extraction unit 311, and the extract (which is a low value stream) is then generated as stream 313. Also charged to solvent extraction unit 311 is CO-DAO 307 generated by solvent de-asphalting unit 305, which has been generated from the vacuum column bottoms CO-VCB 303. The separate or blended processing of UO-VCB 304 is presented as a further option from which is then generated UO-DAO 308 which is passed to solvent extraction unit 311. Also generated in

solvent de-asphalting unit 305 are one or more asphalt-like products shown as CO-Asphalt 309 and UO-Asphalt 310.

**[0053]** The raffinate from solvent unit 311 is then passed to solvent dewaxing step 316 (which could instead be catalytic dewaxing or iso-dewaxing) whereupon wax products 317 are produced by removal of these wax compounds from the raffinate (or converted by catalytic dewaxing or iso-dewaxing). Thereafter the raffinate after removal (or conversion) of the waxy compounds becomes dewaxed oil which is passed to hydrotreating unit 319. In hydrotreating 319, a small volume of naphtha, kerosene, and diesel (along with sulfur in the form of H<sub>2</sub>S) is generated. However, the majority of the product is passed to fractionation unit 323 where the stream is fractionated in the proper viscosities which are denoted as stream Group II 325. Included in Group II 325 will thus be base oils of different viscosities along with bright stock which has primarily been recovered through the stream called CO-DAO 307 (and prospectively UO-DAO 308), generated by solvent de-asphalting unit 305.

**[0054]** Turning to FIG. 3 where processing of the UO-VGO is undertaken (versus processing of CO-VGO), UO-VGO is first passed to hydrotreater 319 (upgraded from hydrofinishing). The hydrotreated UO-VGO is then passed as stream 359 to solvent extraction unit 311, thus bypassing solvent dewaxing step 316. (The dewaxing step is preferably not applied because the UO-VGO has been made from used lubricating oils which have already been dewaxed). During a period of time when solvent dewaxing unit 516 is not processing UO-VGO (and thus dewaxing is not otherwise being utilized), an alternative embodiment (not shown) is processing CO-VGO in solvent dewaxing unit 516 and generating wax products and dewaxed oil, with such dewaxed oil being available for processing in other units as have available capacity. Solvent extraction unit 311 then produces two streams, the first of which is unfractionated Groups III and II 367 generated from the raffinate and the second of which is unfractionated Group II 363 generated from the extract. In hydrotreating 319, a small volume of naphtha, kerosene, and diesel (along with sulfur in the form of H<sub>2</sub>S) is also generated as stream 370. Each of the two unfractionated base oil streams 367 and 363 are then passed to their respective fractionation columns 323 and 373. When processing UO-VGO, fractionation column 323 leads to creation of Group III and Group II base oils labeled as stream 376 and fractionation column 373 leads to creation of Group II base oils 379.

**[0055]** In the processing mode noted in FIG. 3 above, for a given viscosity, Group II products in stream 367 will most likely be higher VI than Group II products in stream 363, as processed in fractionation columns 323 and 373, respectively. Fractionation columns 323

and 373 may be one and the same units but if so, then these must be run blocked out so that each of the Groups III and II products in raffinate stream 367 and Group II products in extract stream 363 are not commingled during processing. It is thus a preferred mode of operating the invention to disclose a separate fractionation capability for processing the products in streams 367 and 363 simultaneously in separate fractionation columns.

**[0056]** FIGURE 4 presents an alternate configuration in which CO-VGO and UO-VGO may either be run separately or blended in varied proportions (e.g. Blended VGO) and then processed together under a hydrotreating, solvent dewaxing (which could instead be catalytic dewaxing or iso-dewaxing), solvent extraction processing sequence. Running a Blended VGO is depicted by means of a proportional valve (425 in FIG. 4). The function of a proportional valve is to allow either of two alternative feedstocks to be run through the plant individually and exclusively, or to allow for any proportions of the two alternative feedstocks to be combined together and then run through the plant as a blend.

**[0057]** The assumptions in FIG. 4 are that hydrofinishing is preferably upgraded to hydrotreating, if and as needed the solvent extraction unit has also been upgraded, and an additional fractionation capability may optionally be added so as to provide continuous fractionation of both the higher valued (primarily Group III) stream and the lower valued (Group II) stream. FIG. 4 thus assumes that CO-VGO and UO-VGO will be run through the plant at the same time, but in varied proportions as desired. In FIG. 4, the solid lines represent processing of CO-VGO and the dotted lines represent additional processing associated with the addition of UO-VGO. Unlike in FIG. 3, where UO-VGO is not processed through the dewaxing unit, FIG. 4 depicts processing each of the CO-VGO and UO-VGO, or Blended VGO, through the dewaxing unit. An explanation of processing for the CO-VGO and UO-VGO streams follows next below.

**[0058]** In FIG. 4, CO-VGO 400 and UO-VGO 450 are charged via proportional valve 425 to hydrotreating unit 419. Also charged to hydrotreating unit 419 is CO-DAO 407 generated by solvent de-asphalting unit 405, which has been generated from vacuum column bottoms CO-VCB 403. Presented as a further option is the separate or blended processing of UO-VCB 404 from which is then generated UO-DAO 408 which is passed to solvent extraction unit 411. Also generated in solvent de-asphalting unit 405 are one or more asphalt-like products shown as CO-Asphalt 409 and UO-Asphalt 410. In hydrotreating 419, a small volume of naphtha, kerosene, and diesel (along with sulfur in the form of H<sub>2</sub>S) is also generated as stream 470. Because most CO-VGOs contain waxy compounds, after hydrotreating in hydrotreating unit 419, the hydrotreated oil is then passed to solvent

dewaxing (which may instead be catalytic dewaxing or iso-dewaxing), whereupon wax products 417 are produced by removal of these wax compounds from the hydrotreated oil (or converted by catalytic dewaxing or iso-dewaxing).

[0059] Following dewaxing in dewaxing unit 416, the dewaxed (and already hydrotreated oil) is then passed to solvent extraction unit 411. The raffinate stream 467 from solvent unit 411 is then passed to fractionation unit 423 where raffinate stream 467 is fractionated in the proper viscosities which are denoted as Groups III and II base oils 476. The extract stream 463 from solvent extraction unit 411 is then passed to fractionation unit 473 where extract stream 463 is fractionated in the proper viscosities which are denoted as Group II base oils 479. Included in either of the heavier streams produced by fractionation units 423 and 473 will be the bright stock which has primarily been recovered through the stream called CO-DAO 407, generated by solvent de-asphalting unit 405. Also included in products produced by fractionation units 423 and 473 will be heavier viscosity base oils which are inherent within CO-VGO which tend to be higher viscosity than the base oils found in most UO-VGOs.

[0060] In the processing mode noted in FIG. 4 above, for a given viscosity, the Group II products in stream 467 will most likely be higher VI than the Group II products in stream 463, as processed in fractionation columns 423 and 473, respectively. Fractionation columns 423 and 473 may be one and the same units but if so, then these must be run blocked out so that each of the Groups III and II products in raffinate stream 467 and Group II products in extract stream 463 are not commingled in processing. It is a preferred mode of operating the invention to disclose a separate fractionation capability for processing the products in streams 467 and 463 simultaneously in separate fractionation columns.

[0061] FIGURE 5 presents an alternate configuration in which CO-VGO and UO-VGO may either be run separately, or blended in varied proportions and run as Blended VGO processed together under a solvent extraction, solvent dewaxing (which could instead be catalytic dewaxing or iso-dewaxing), hydrotreating processing sequence. The assumptions in FIG. 5 are that hydrofinishing is preferably upgraded to hydrotreating, and, if and as needed, the solvent extraction unit has also been upgraded. Because each of the CO-VGO and the raffinate and extract streams may be run blocked out, additional fractionation capability may not be required (and FIG. 5 does not show any additional fractionation). The configuration in FIG. 5 allows for Blended VGO to be run through the plant at the same time, but in varied proportions as desired. In FIG. 5, the solid lines represent processing of CO-VGO and the dotted lines represent additional processing associated with the addition of UO-VGO.

**[0062]** An explanation of processing for the CO-VGO and UO-VGO streams as shown in FIG. 5 follows under three different scenarios. The first scenario is where only CO-VGO is processed. The second scenario is where only UO-VGO is processed. The third scenario is where both CO-VGO and UO-VGO are blended and then processed in some proportions (referred to herein as “blended VGO”). As noted previously, such flexibility is presented in the present invention by means of a proportional valve. Whenever CO-VGO is run (whether alone or blended), it is assumed that there will be waxy components included in the feedstock and therefore that the process configuration shall preferably include solvent dewaxing (which could instead be catalytic dewaxing or iso-dewaxing).

**[0063]** In FIG. 5, under the first scenario (CO-VGO only as feedstock), CO-VGO 500 is charged via proportional valve 525 to solvent extraction unit 511, and the extract (which is a low value stream) is then generated as stream 513. Also charged to solvent extraction unit 511 is CO-DAO 507 generated by solvent de-asphalting unit 505, which has been generated from vacuum column bottoms CO-VCB 503. The separate or blended processing of UO-VCB 504 is presented as a further option from which is then generated UO-DAO 508 which is passed to solvent extraction unit 511. One or more asphalt-like products are also generated in solvent de-asphalting unit 505 shown as CO-Asphalt 509 and UO-Asphalt 510. The raffinate from solvent unit 511 is then passed to solvent dewaxing step 516 (which could instead be catalytic dewaxing or iso-dewaxing) whereupon wax products 517 are produced by removal of these wax compounds from the raffinate (or converted by catalytic dewaxing or iso-dewaxing). Thereafter the raffinate after removal (or conversion) of the waxy compounds becomes dewaxed oil which is passed to hydrotreating unit 519. In hydrotreating 519, a small volume of naphtha, kerosene, and diesel (along with sulfur in the form of H<sub>2</sub>S) is generated. However, the majority of the product is passed to fractionation unit 523 where the stream is fractionated in the proper viscosities which are denoted as stream Group II 579. Included in Group II 579 will thus be base oils of different viscosities along with bright stock which has primarily been recovered through the stream called CO-DAO 507 (and prospectively UO-DAO 508), generated by solvent de-asphalting unit 505.

**[0064]** In FIG. 5, under the second scenario (UO-VGO only as feedstock), UO-VGO 550 is charged via proportional valve 525 to solvent extraction unit 511, and the extract is then generated as either stream 551 where it is either passed directly to hydrotreating 519, or passed to Intermediate Extract Storage 555 via stream 553. Because the hydrotreater 519 can only run one quality of oil at a time, under the configuration where solvent extraction precedes hydrotreating, only one of the raffinate stream or the extract stream coming from

solvent extraction unit 511 can be processed in hydrotreater 519 at once. Thus when either of the raffinate or extract streams is being processed in hydrotreater 519, the other stream must be passed into storage. So, at the same time as the extract is being generated from solvent extraction unit 511, so too is raffinate being generated and this either becomes stream 541 where it is passed directly to hydrotreating 519 or is passed to Intermediate Raffinate Storage 545 via stream 543.

**[0065]** After raffinate stream 541 is passed directly from solvent extraction unit 511 (or raffinate is passed from Intermediate Raffinate Storage 545), it is then processed in hydrotreater 519 whereupon it becomes Unfractionated Groups III and II 567. Unfractionated Groups III and II 567 is then passed to fractionation unit 523 whereupon it is fractionated into its products by viscosity and becomes Groups III and II Products 576. After extract stream 553 is passed directly from solvent extraction unit 511 (or extract is passed from Intermediate Extract Storage 555), it is then processed in hydrotreater 519 whereupon it becomes Unfractionated Group II 563. Unfractionated Group II 563 is then passed to fractionation unit 523 whereupon it is fractionated into its products by viscosity and becomes Group II Products 579. In each case as the raffinate and extract streams are being processed in hydrotreating 519, a small volume of naphtha, kerosene, and diesel (along with sulfur in the form of H<sub>2</sub>S) is also generated as stream 570. In the processing mode in FIG. 5 under the second scenario of running UO-VGO only, for a given viscosity, the Group II products in stream 576 will most likely be higher VI than the Group II products in stream 579, even though each will be processed in fractionation column 523 (preferably run blocked out so as not to commingle the higher VI and lower VI base oils together). During a period of time when solvent dewaxing unit 516 is not processing UO-VGO (and thus the dewaxing unit is not otherwise being utilized), in an alternative embodiment (not shown) solvent dewaxing unit 516 processes CO-VGO and generates wax products and dewaxed oil, with such dewaxed oil being available for processing in other units as have available capacity.

**[0066]** The presentation of scenario 3 in FIG. 5 (Blended VGO) is illustrated by assuming the starting feedstock mix is 100% UO-VGO, but that CO-VGO is increased as a % of the feedstock, and then viewing the preferred mode of operating the invention. As discussed above, when running UO-VGO, the sequence of the solvent extraction unit 511 prior to hydrotreater 519 necessitates the utilization of intermediate storage 545 and 555 as the raffinate and extract must be processed in separate blocks. Also previously noted is how, to save operating expenses, it is preferable to bypass dewaxing unit 516 when processing only UO-VGO. In processing blended VGO by increasing the mix of CO-VGO in UO-VGO,

there will reach some point where the waxy compounds included in the CO-VGO will preferably be removed (or converted by catalytic dewaxing or iso-dewaxing) to achieve a targeted low temperature property (such as pour point for example) in the final base oil products. When that point is reached, then the blocked out return lines 547 and 557 will need to connect to dewaxing unit 516 (they are currently depicted as passing to hydrotreater 519). So in running Blended VGO, the unit will again be running blocked out but instead of bypassing the dewaxing unit (as was preferable when running only UO-VGO), processing will still occur blocked out but processing will occur through dewaxing unit 516.

**[0067]** As the portion of the CO-VGO in the Blended VGO is increased, the ultimate product quality of most of the products produced downstream from hydrotreater 519 and fractionation 523 will degrade, or the yields of the higher product quality will drop, or some combination of the two will occur since the quality of the CO-VGO is less than the quality of the UO-VGO. Because the product quality will drop and/or yields of the higher quality product will drop as the CO-VGO portion of the Blended VGO is increased, and this is a continuum versus a bright line change, running the unit in this mode will require careful balancing of product quality and yield considerations. Achieving variations in the proportions of CO-VGO and UO-VGO has been depicted by means of a proportional valve as presented in FIGS. 4 and 5, but as noted in FIGURES 6A, 6B, and 6C, alternative means of varying proportions may be applied.

**[0068]** FIGURES 6A, 6B, and 6C depict several means of valve assemblies which enable the two feedstocks to be processed individually or in blended mode through a blending valve (FIG. 6A), gate valves (FIG. 6B), or check valves (FIG. 6C). With the blending valve 605 (FIG. 6A), either of the CO-VGO 600 or UO-VGO 601, or some blend of the two, may be processed passing through to gate valve assembly manifold 607 in which the material may then be passed along any of three different pathways. With reference to FIG. 6B, gate valves 625 and 610 allow either of the CO-VGO 620 or UO-VGO 621, respectively, or some blend of the two, to be processed passing through to gate valve assembly manifold 627 in which the material may then be passed along any of three different pathways. With reference to FIG. 6C, centrifugal pumps 635 and 645 allow either of the CO-VGO 630 or UO-VGO 631, respectively, or some blend of the two, to be processed passing through check valves 640 and 650, respectively, to gate valve assembly manifold 637 in which the material may then be passed along any of three different pathways. Check valves will allow flow in one direction but will prevent backflow so that none of the material which is being pumped by either centrifugal pump 635 or 645 will be passed through to the other pump. Many other

configurations for controlling the pathways of the streams may be utilized as may be well understood by one of ordinary expertise in the art.

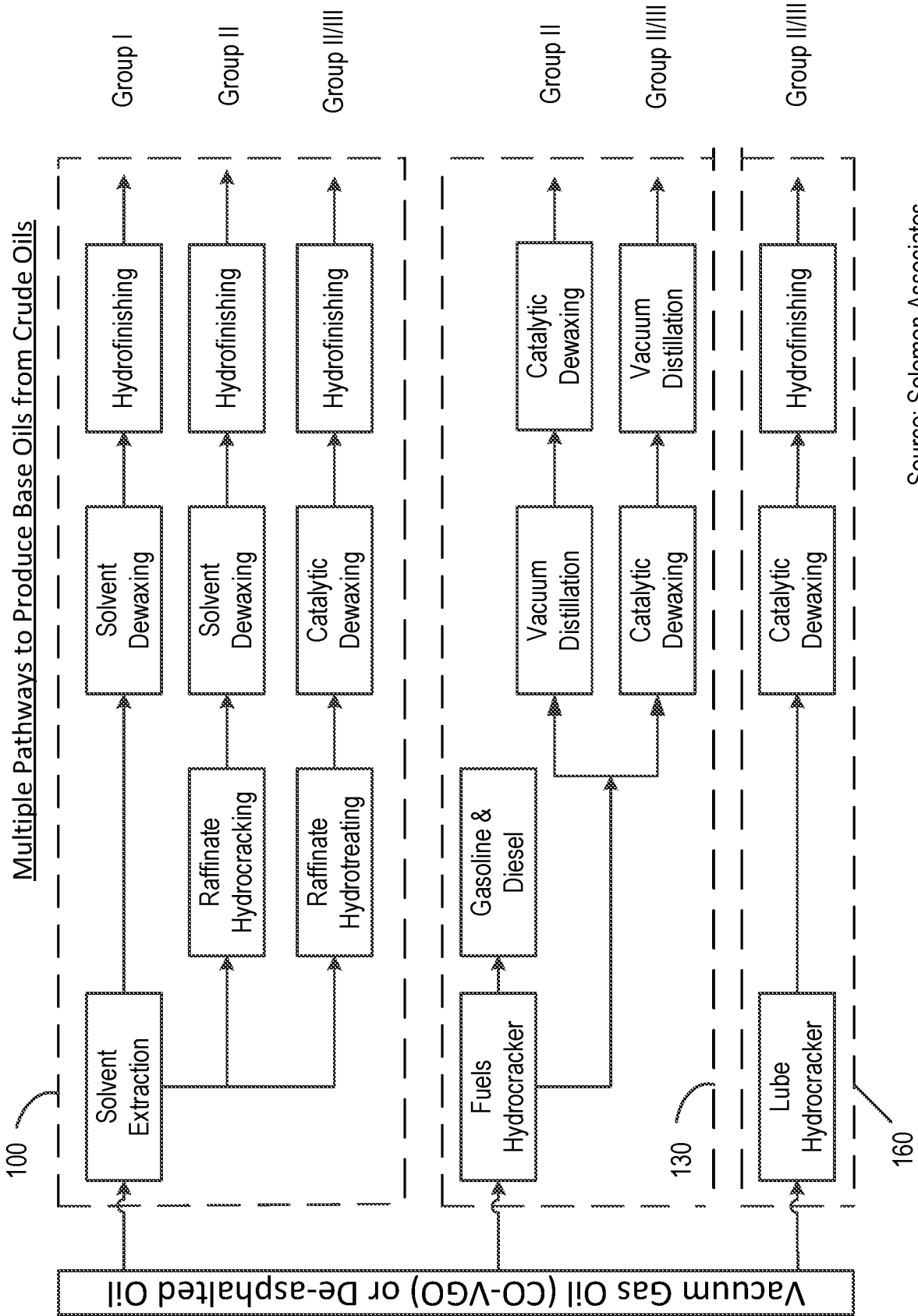
[0069] In general, a preferred mode of the present invention may be to run CO-VGO and UO-VGO separately and further to run processing of each in the sequence of hydrotreating and then solvent extraction, followed by fractionation, using dewaxing when CO-VGO is being processed in sufficient quantities to generate material amounts of wax products. It is thus also a preferred mode of the current invention that when most or all feedstock being processed is UO-VGO, or CO-VGO which has minimal wax compounds, that the dewaxing unit is bypassed as this will save operating cost and is not expected to result in a material loss of wax product creation. In such times, the dewaxing unit can alternatively be used for processing CO-VGO. It is also possible that processing CO-VGO through the hydrotreater 519 first before dewaxing and solvent extraction may produce benefits in product quality or yield (or reduced operating) cost. In any event, this configuration where hydrotreating precedes solvent extraction, along with the addition of a fractionation column, avoids block treating the raffinate and extract streams separately. In this instance, then, a combination of FIGS. 3 and 4 would then be the preferred mode for processing CO-VGO (but this is not depicted). Many such variations may be considered obvious and desirable by those skilled in the art based upon a review of the foregoing description of the preferred embodiments that are described in this specification.

[0070] While the present invention has been described by reference to certain of its preferred embodiments, the embodiments presented here are intended to be illustrative rather than limiting in nature and many variations, modifications, changes, and substitutions are contemplated in the foregoing disclosure and, in some instances, some features of the present invention may be employed without a corresponding use of the other features. Many such variations and modifications may be considered obvious and desirable by those skilled in the art based upon a review of the foregoing description of preferred embodiments. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

## CLAIMS

1. A method for making base oil, the method comprising steps of:  
blending together (a) vacuum gas oil made from crude oil (“CO-VGO”) and (b) vacuum gas oil made from used lubricating oil (“UO-VGO”) to form a blended VGO (“Blended VGO”); and  
processing the Blended VGO by means of at least two of solvent extraction, dewaxing, and hydrotreating to make a base oil.
2. A method for making base oil by solvent extraction, de-waxing, and hydrotreating, the method comprising steps of:  
processing vacuum gas oil made from crude oil (“CO-VGO”) during a first period of time by at least two of solvent extraction, dewaxing, and hydrotreating to make at least one first base oil; and  
processing vacuum gas oil made from used lubricating oil (“UO-VGO”) during a second period of time by at least two of solvent extraction, dewaxing, and hydrotreating to make at least one second base oil.
3. The method of claim 2 wherein the UO-VGO is processed by hydrotreating prior to processing by solvent extraction.
4. The method of claim 2 wherein the UO-VGO is processed by solvent extraction prior to processing by hydrotreating.
5. The method of claim 3 wherein at least a portion of the effluent produced after processing the UO-VGO by hydrotreating is then processed by solvent extraction.
6. The method of claim 4 wherein at least a portion of the effluent produced after processing the UO-VGO by solvent extraction is then directly processed by hydrotreating.
7. The method of claim 2 wherein at least a portion of the at least one second base oil produced from processing UO-VGO is a Group III base oil.
8. The method of claim 2 wherein at least a portion of the at least one second base oil produced from processing the UO-VGO is a Group II base oil.
9. The method of claim 2 wherein at least a portion of the at least one first base oil produced from processing the CO-VGO is a Group II base oil.
10. The method of claim 2 wherein UO-VGO has a viscosity index in excess of 100.
11. The method of claim 2 wherein UO-VGO has a viscosity index in excess of 105.
12. The method of claim 2 wherein UO-VGO has a viscosity index in excess of 110.
13. The method of claim 2 wherein UO-VGO has a viscosity index in excess of 115.

14. A method for making at least one of a first base oil and a second base oil, the method comprising the steps of processing a vacuum gas oil that is made from used lubricating oil (“UO-VGO”) that has a viscosity index (“VI”) of 90 or more by means of at least two of solvent extraction, dewaxing, and hydrotreating.
15. The method of claim 14 wherein the UO-VGO has a VI in excess of 105.
16. The method of claim 14 wherein the UO-VGO has a VI in excess of 110.
17. The method of claim 14 wherein the UO-VGO has a VI in excess of 115.
18. The method of claim 14 wherein solvent extraction precedes hydrotreating.
19. The method of claim 14 wherein hydrotreating precedes solvent extraction.
20. The method of claim 14 where at least a portion of the UO-VGO is processed into a Group III base oil.
21. The method of claim 14 wherein at least a portion of the UO-VGO is processed into a Group II base oil.
22. A method of processing at least one of CO-VCB and UO-VCB by means of solvent deasphalting wherein the deasphalted oil produced by solvent deasphalting the at least one of CO-VCB and UO-VCB is then further processed into bright stock.
23. The method of claim 22 wherein the deasphalted oil is then blended into at least one of CO-VGO and UO-VGO.



Source: Solomon Associates  
(as reported in Lubes N' Greases Magazine, March 2016, page 34)

Fig. 1 Prior Art

Multiple Pathways to  
Produce Base Oils  
from Used  
Lubricating Oils

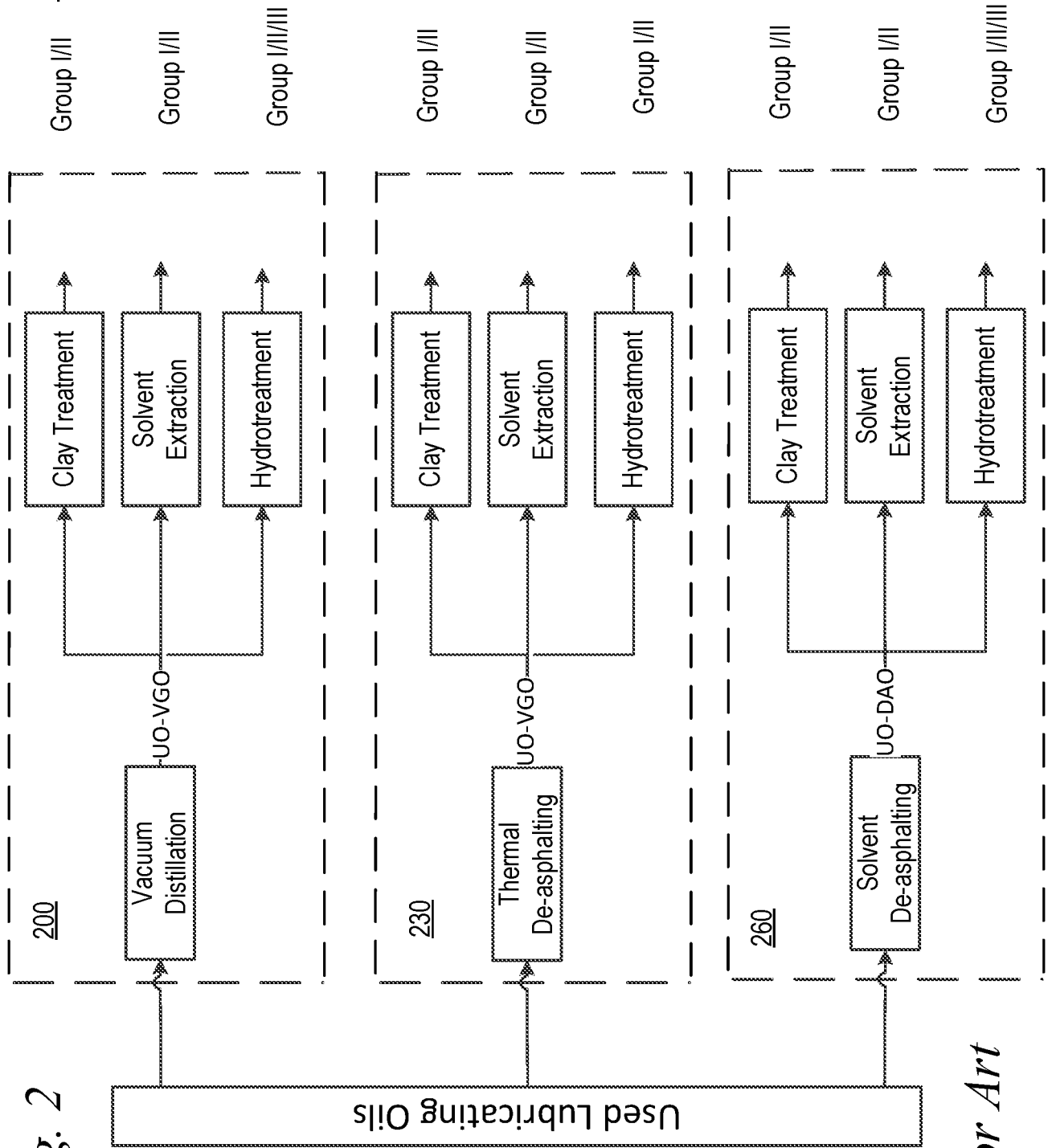


Fig. 2

*Prior Art*



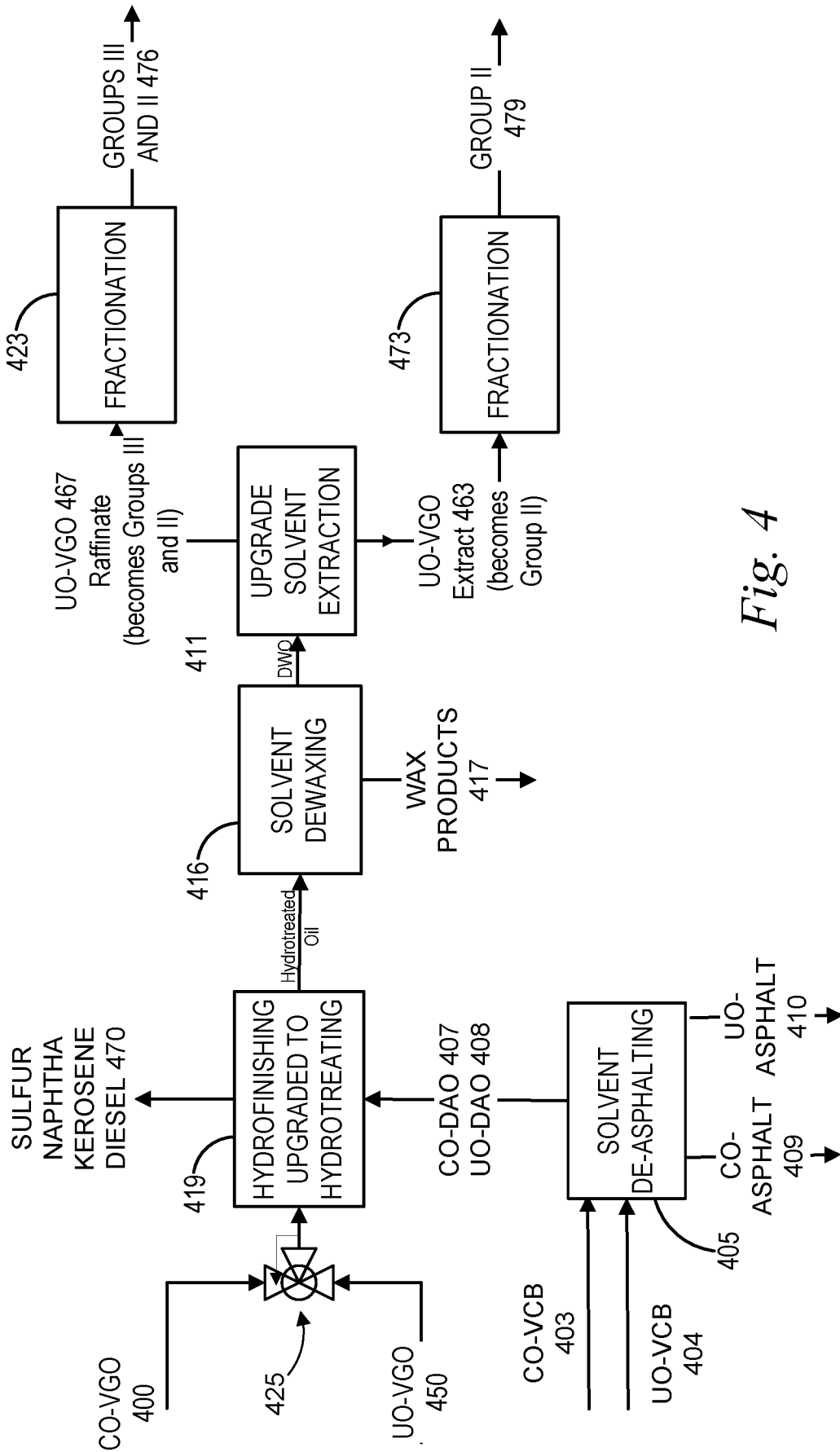


Fig. 4

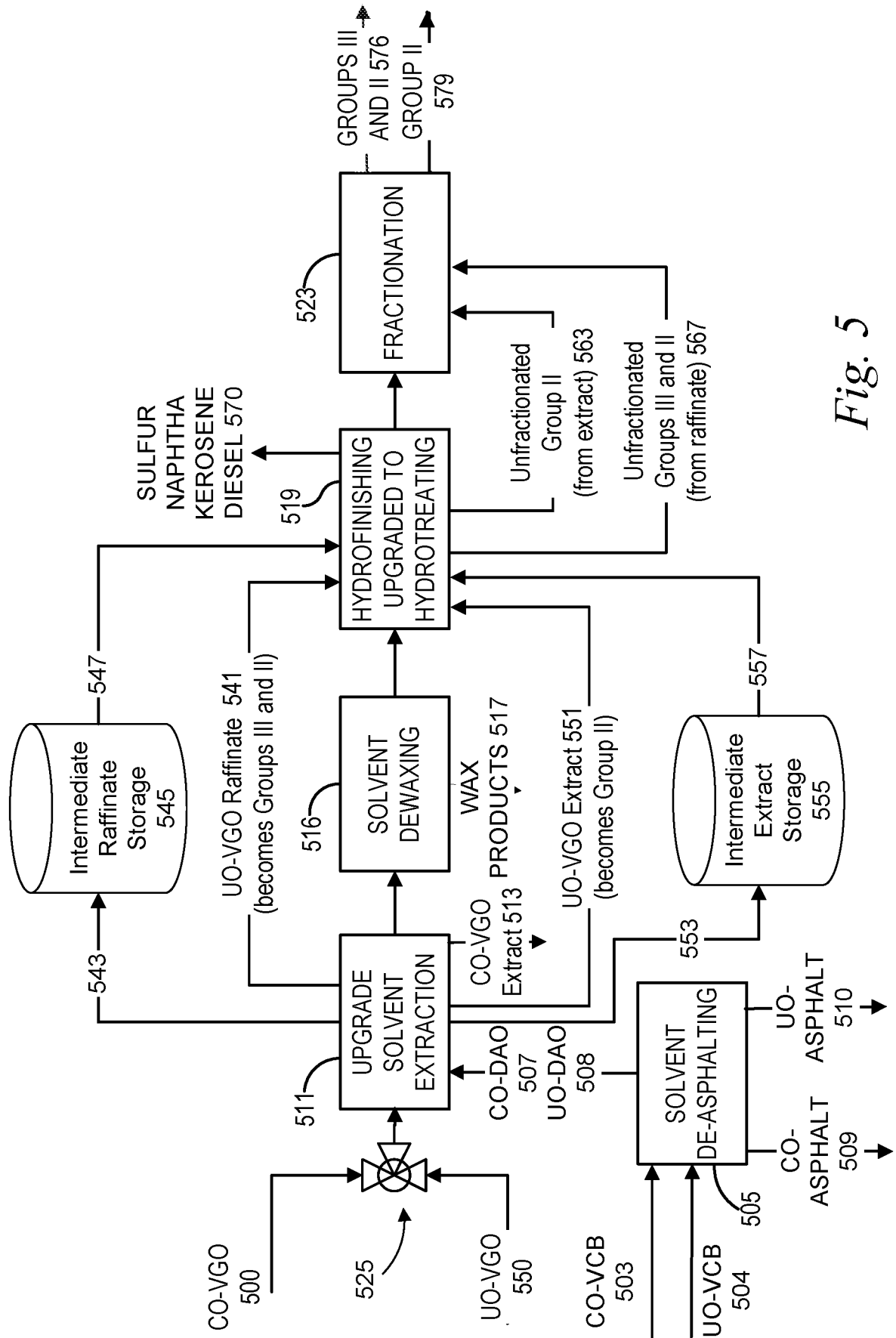
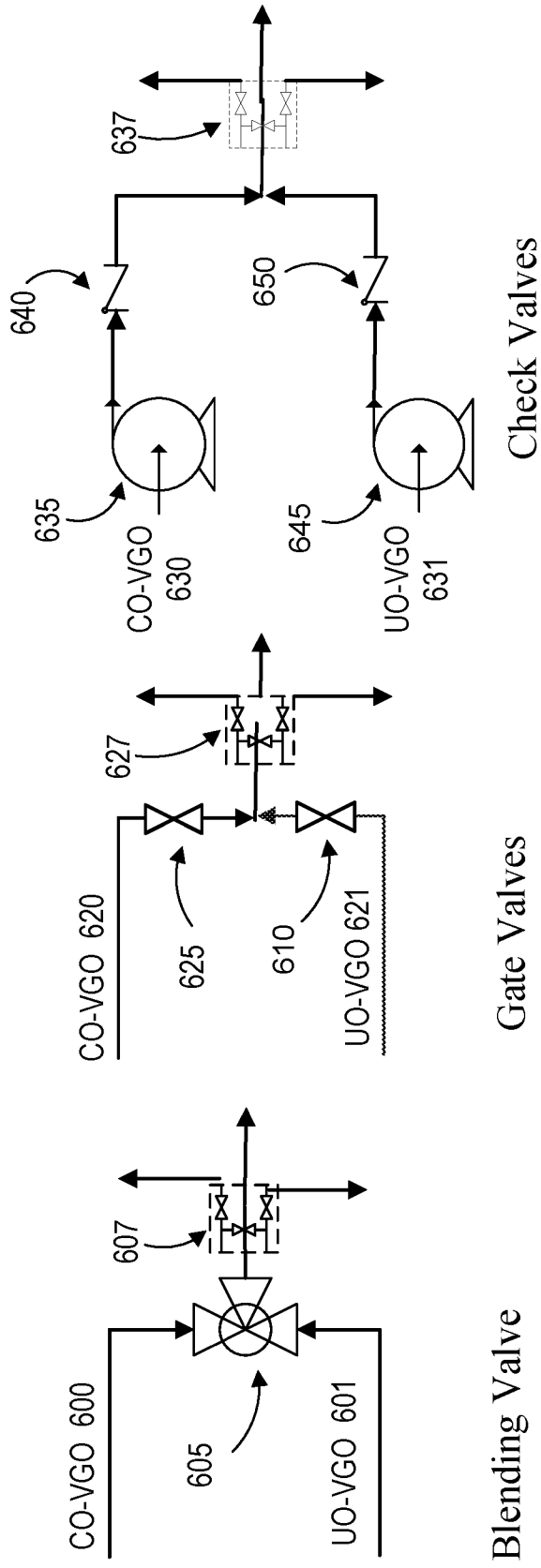


Fig. 5



Blending Valve

Gate Valves

Check Valves

Fig. 6A

Fig. 6B

Fig. 6C