ABSTRACT

A method and apparatus for enabling the computation of a minimum cost blend of lubricating oil base stocks, wherein a viscosity index improver additive is included. System includes measurement of viscosity and related data at two separate concentrations of the additive where such concentrations are in the range from about 1 percent to about 10 percent of the additive with a given base oil. Data obtained are used in non-linear formulae to provide bases for calculating optimum blends to obtain particular specifications with minimum cost.

3 Claims, 9 Drawing Figures
METHOD AND APPARATUS FOR THE OPTIMUM BLENDING OF LUBRICATING BASE OILS AND AN ADDITIVE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation as to all subject matter common to U.S. application, Ser. No. 90,244, now abandoned, filed Nov. 17, 1970 by John M. Leonard et al., and assigned to Texaco Inc., assignee of the present invention, and a continuation-in-part for all additional subject matter.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention concerns lubricating oil blending in general. More particularly, it relates to an improved method of blending lubricating oils where the blend includes a viscosity index improver additive.

2. Description of the Prior Art

Heretofore, in the blending of lubricating oil base stocks, to obtain desired specifications there was no particular difficulty because the blend viscosities were proportional to the percentage amounts of the base stocks by making use of the so-called "H-value" used in determining the viscosity index. However, it was found that where such blends included therein one of more viscosity index improvement-type additives, the resulting blend was not predictable. Thus, it was found that additives of the sort mentioned could not be blended on the basis of a predetermined viscosity index for the additive, since the "H-value" would vary in a non-linear manner with the amount of additive and the particular base oil with which it was blended. Pour points also varied non-linearly with the amount of additive and the base oil used.

Consequently, it is an object of this invention to provide a method and system for predetermining a particular blend of base oils with a viscosity index improver additive, so as to provide predetermining characteristics for the resulting blend.

SUMMARY OF THE INVENTION

A system controls the blending of base oils and an additive to achieve a desired blend oil having predetermined characteristics at minimum cost. The system includes apparatus which controls the quantities of base oils and additive being provided to a blending tank in accordance with control signals. A circuit provides signals corresponding to the predetermined characteristics to a network. The network provides the control signals to the apparatus in accordance with the characteristic signals.

The objects and advantages of the invention will appear hereinafter from a consideration of the detailed description which follows, taken together with the accompanying drawings wherein two embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings are for illustration purposes only and are not to be construed as defining the limits of the invention.

DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a simplified block diagram of a control system, constructed in accordance with the present invention, controlling apparatus shown in schematic form, for the blending of base oils with an additive. FIGS. 2, 3, 4 and 7 are detailed block diagrams of the programmer, the i, signal means, the constraint control means and the blending control means, respectively, shown in FIG. 1.

FIGS. 5 and 6 are detailed block diagrams of the H network and the BV network, respectively.

FIG. 8 shows another embodiment of the present invention in which a general purpose digital computer is used to control the blending of base oils with an additive.

FIG. 9 is a non-linear graph illustrating the non-linear relationship of a base oil mixture and the percentage of additive in the mixture.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Lubricating oils are often blended in order to meet predetermined specifications, e.g., those called for to meet a customer's desires. Heretofore, that could be accomplished in a straightforward manner since the characteristics of the blend varied in proportion with the volume-fraction of the base oils of the blend. However, it was found that the addition of a viscosity index improver additive created conditions such that the linear blending of the base stocks of lubricating oils could no longer be carried out with an expectation of providing a predetermined blend viscosity or viscosity index. It was found that the viscosity index improver additive did not act as a lubricating oil in that its own viscosity H-value was not a constant but varied according to the base oil or oils in the blend. It was also discovered that the pour point depressant effects of the VI improver additive varied according to the base oil or oils in the blend. Thus, a relationship between the viscosity and pour point of a blend of base oils and the viscosity and pour point of that blend with a viscosity index improver additive could not be defined.

It may be noted that the above-mentioned "H-value" is an element in the formula for calculating the viscosity index of any given oil. The formula is given and explained in the "Standard Method for Calculating Viscosity Index from Kinematic Viscosity" of the American Society for Testing and Materials under the fixed designation D2270. Such Standard is published by the Society with an annual issue.

Another approach to the problem was to assume a constant H-value for a particular additive over a limited range of viscosity of a base oil blend. However, this was found not to work since it appeared that the effect of the additive on the viscosity of several different base oil blends, each of which blends had the same viscosity, indicated that the assumed or pseudo H-values were not usable.

It was discovered that if the viscosities of a particular lubricating oil base stock at standard temperatures, e.g., 100°F and 210°F, were measured under two separate percentage mixtures with the additive, a predetermined relationship could be expressed for each base oil. Such relationship follows a curve of the general form as illustrated in FIG. 9. This could be represented by the following equation:
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\[ \Delta H_i = H_i - h_i = a_i (1 - e^{-b_i r_i}) \]  

wherein \( H_i \) is the viscosity “H-value” of a given base oil-additive combination; and \( h_i \) is the viscosity H-value of the base oil alone; \( a_i \) and \( h_i \) are constants; and \( x_i \) is the volume-fraction of the additive; and \( e \) is the natural log base.

Since \( h_i \) is known or can be readily determined for each base oil, the H-value of a base oil with any volume-fraction \( x_i \) of a given additive, from 0.0 to somewhat above 0.06, could be predicted by the following equation:

\[ H_i = h_i + a_i (1 - e^{-b_i r_i}) \]  

These base oil-additive combinations can then be treated as separate components in a blend, each with H-value \( H_i \). The viscosity H-value of a blend of \( n \) base oils with a given concentration \( x_i \) of an additive is thus calculated by

\[ H = \sum_{i=2}^{n} \left( h_i + a_i (1 - e^{-b_i r_i}) \right) \frac{x_i}{1 - x_i} \]  

where \( x_i \) \((i = 2, 3, \ldots, n)\) is the volume-fraction of base oil \( i \) in the blend. The blend H-values at 100°F and 210°F may then be used in the Standard formula noted above to calculate a predetermined blend viscosity and viscosity index.

It will be understood that throughout this disclosure the abbreviation “VI” stands for viscosity index.

It was also discovered that the pour point of each base oil mixed with the additive would have a predetermined relationship which follows the general form similar to that for the H-value, as illustrated in FIG. 9, except that the pour point decreases with increasing additive dosage. Consequently, if the pour points of the base oil-additive mixtures using two separate percentages, e.g., with 3 and 6 percent of the additive, was also measured, such data could be converted to form a blending equation comparable to the H-value equation for viscosity.

Thus, using calculations similar to those made for viscosity, the pour blending value (PV) of any blend of base oils with volume-fraction \( x_i \) of the additive could be found by using the following equation:

\[ PV = \sum_{i=2}^{n} \left( (pv) i - c_i (1 - e^{-d_i x_i}) \right) \frac{x_i}{1 - x_i} \]  

where PV is the pour blending value of a blend with volume-fraction \( x_i \) of additive; \((pv) i\) is the pour blending value of base oil \( i \); and where \( c_i \) and \( d_i \) are constants calculated for base oil \( i \).

With respect to other characteristics of a blend of base oils with a VI improver additive included, such as flash point, aniline point, and ASTM color, there was found to be no significant change because of the additive. Consequently, linear blending values previously developed for such property of each base oil could be used to predetermine these characteristics of blends. The characteristic blending value of a blend containing volume-fraction \( x_i \) of base oil \( i \) \((i = 2, 3, \ldots, n)\) could thus be found by the equation:

\[ BV = \sum_{i=2}^{n} (BV) i \frac{x_i}{1 - x_i} \]  

where \( BV \) is the characteristic blending value of a blend; \((BV) i\) is the corresponding property blending value for base oil \( i \); and \( x_i \) is the volume-fraction of the additive in the blend, as above.

The results, expressions, e.g., (3), (4) and (5) above, allow prediction of the viscosities at 100°F and 210°F (and hence VI), plus pour point, flash point, aniline point, and ASTM color of any blend of base oils with a VI improver. It is to be noted that the entire relationship of the constituents of a blend with an additive may be derived from data taken at only two additive levels for each base oil. It will be appreciated that conventional and/or standard equipment (not shown) may be employed in carrying out the measurements of the properties. As pointed out above, the measurements are made using each of two different percentage amounts of an additive in a range from about 1 to about 10 percent mixed with each base oil individually. Actual percentage amounts of an additive that were used in carrying out the invention were 3 and 6 percent.

The entire lube oil blending procedure and systemic lends itself to use with a computer in order to find the minimum cost blend which meets a given set of characteristic specifications. Using a digital computer, a skilled programmer could write a program using non-linear programming so as to minimize the cost function which would be expressed in the form:

\[ C = \sum_{i=2}^{n} C_i x_i \]  

subject to constraints (i.e., specifications) expressed in forms such as the following:

The viscosity constraints \( H_L \) and \( H_U \) would be:

\[ H_L \leq \sum_{i=2}^{n} \left( h_i + a_i (1 - e^{-b_i r_i}) \right) \frac{x_i}{1 - x_i} \leq H_U \]  

The pour constraints \( PBV_L \) and \( PBV_U \) would be:

\[ PBV_L \leq \sum_{i=2}^{n} \left( (pv) i - c_i (1 - e^{-d_i x_i}) \right) \frac{x_i}{1 - x_i} \leq PBV_U \]  

and each additional specification would have constraints \( BV_L \) and \( BV_U \) of the form

\[ BV_L \leq \sum_{i=2}^{n} (BV) i \frac{x_i}{1 - x_i} \leq BV_U \]  

where \( C \) is the total cost of a blend; \( C_i \) is the cost of a constituent base oil \( i \); and \( x_i \) is the volume-fraction of base oil \( i \) in the blend, as in previous expressions; and where \( H \), \( PV \) and \( BV \) are characteristic, and the other terms used in the expressions (7), (8) and (9) are all the same as in previous expressions. Some typical specification characteristics are gravity, flash point, etc.

Referring to FIG. 1, base oils A, B and C from storage facilities (not shown) are provided to a blending tank 1 through lines 2, 3 and 4. For convenience, the following example disclosing the present invention will show the use of three base oils, although there is no restriction on the number of base oils that may be blended in tank 1 to provide a blend oil. The flow rate of a base
oil is directly related to the quantity of that base oil in the final blend oil. The flow rate of the base oil A in line 2 is controlled by a valve 6 receiving a signal from a flow recorder controller 8. Flow recorder controller 8 receives a signal corresponding to the flow rate of base oil A in line 2 from a flow rate sensor 10. The set point of flow rate controller 8 is positioned to a desired flow rate, as hereinafter described, which will provide the desired portion of base oil A for a desired blend oil in blending tank 1. Flow recorder controller 8 provides the signal to valve 6 in accordance with the difference between the flow rate signal from sensor 10 and the position of its set point so that the flow rate in line 2 assumes the desired flow rate.

Similarly the flow rate of base oil B in line 3 is controlled by the cooperation of a valve 6A, a flow rate sensor 10A and a flow recorder controller 8A. The quantity of base oil C entering tank 1 is also controlled in a similar manner by a valve 6B and flow recorder controller 8B and a flow rate sensor 10B. Elements having a number and a suffix are connected and operate in a similar manner to those elements having the identical number without a suffix.

A viscosity improver additive is also provided to tank 1 through line 11. A valve 6C, a flow recorder controller 8C and a sensor 10C cooperate to control the flow rate of the additive in line 11. A direct current voltage V \text{DC} sets the set point in controller 10C to a position corresponding to the predetermined flow rate.

Although, for purposes of illustration, the flow rate of the additive and base oils are shown as being controlled by flow recorder controller cooperating valves and flow sensors, it would be obvious to one skilled in the art that the flow rates can be controlled using meters, valves, differential control counters and digital-to-analog converters. Such a control method is discussed in an article by Mr. J. J. Jiskoot in the Oct., 1968 issue of the Chemical and Process Engineering at page 87.

The set points of flow recorder controllers 8, 8A and 8B are controlled in accordance with equations 6, 7, 8 and 10. In this regard, a programmer 12, which is shown in detail in FIG. 2, provides control pulses E \text{P}, E \text{P}A and E \text{P}B. These pulses correspond to the signals X \text{P}A and X \text{P}B, respectively, which correspond to the quantities of base oils A, B and C, and the additive, respectively, for a particular blend oil.

The providing of signals E \text{P}A through E \text{P}C may also be done by various types of memory means, in which various combinations of base oils A, B and C have been stored, that would replace programmer 12 and X \text{P} signal means 14 through 14C.

Referring now to FIGS. 1, 2 and 3, signals E \text{P} through E \text{P}C are developed as follows. An operator activates a switch 20 in programmer 12 receiving a direct circuit voltage V \text{DC}. Switch 20 may be a conventional type "momentary on" type of switch. Voltage V \text{DC} passed by switch 20 triggers a flip-flop 24 to a set state. A flip-flop provides a high level direct current output when in a set state and a low level direct current output when in a clear state. The high level output from flip-flop 24 causes an AND gate 26 to pass timing pulses from a clock 27 to a counter 30. Counter 30 counts the timing pulses and its content is decoded by a logic decoder 31 to provide a plurality of outputs to a corresponding plurality of one shot multivibrators 35. One shot multivibrators 35 provide a plurality of control pulses E \text{P} through E \text{P} and a reset pulse E \text{R}. Reset pulse E \text{R} occurs when counter 30 is full. Reset pulse E \text{R} resets flip-flop 24 to a clear state thereby disabling AND gate 26. When disabled AND gate 26 blocks the timing pulses from clock 27 to prevent further counting by counter 30. Reset pulse E \text{R} also resets counter 30 to a zero count. Programmer 12 provides reset pulse E \text{R} to other portions of the control system as hereinafter disclosed.

Each pulse passed by AND gate 26 triggers a time delay one shot multivibrator 36 to provide a time delay pulse. The time delay pulse allows calculating networks to complete the calculation before triggering another one shot multivibrator 37 to provide a pulse. The pulse from multivibrator 37 is inverted by an inverter 38 to provide an inhibiting pulse E \text{E}.

FIG. 3 shows in detail X \text{P} signal means 14 which includes a plurality of conventional type electronic switches 40 through 40D. The number of switches correspond to the number of combinations of base oils A, B and C and additive that is expected to be utilized. For example, if more base oils than base oils A, B and C were desired for blending, then more switches are needed because there would be more possible blend combinations of the various base oils.

Direct current voltages i.e., B through V \text{DC}, provided by a conventional type direct current voltage source not shown, correspond to predetermined quantities of base oil A for different blend oils. For a count of one, electronic switch 40 receiving voltage V \text{DC} is activated by pulse E \text{P}A from programmer 14 to provide voltage V \text{DC} as signal E \text{E}A. Similarly, pulse E \text{P}B causes signal means 14A, 14B, 14C to provide other direct current voltages corresponding to the quantities of base oils B & C standard the additive necessary for that particular blend oil to be provided as signals E \text{E}A, E \text{E}B and E \text{E}C. Similarly, pulses E \text{E}A, E \text{E}B, E \text{E}C through E \text{E}X render switches 40A, 40C and 40D, respectively, conductive in turn to provide direct current voltages V \text{DC} through V \text{DC} respectively as base oil A quantity signal E \text{E}A. In a similar manner signal means 14A, 14B, 14C, 14D are also controlled to provide corresponding direct current voltages so that at any one time signals E \text{E}A through E \text{E}X correspond to quantities of base oil A, B and C and the additive required to make a particular blend oil. In essence, signal means 14, 14A, 14B, and 14C, along with the voltage source, comprise memory means storing signals corresponding to quantities of base oils A, B and C and the additive for different blend oils.

Although a particular blend oil has been defined by signals E \text{E}A, E \text{E}B and E \text{E}C it does not necessarily follow that the particular blend oil is acceptable or that the particular blend oil, if acceptable, is the most economical blend oil obtainable.

Referring to FIGS. 1, 4 and 5, control means 42 determines if a particular blend oil, as defined by signals E \text{E}A, E \text{E}B and E \text{E}C meets the various constraints imposed on a blend oil and more particularly the characteristics defined by equations 3, 4 and 5. Constraint control means 42 includes an H constraint circuit 44, a pour constraint circuit 45, a flash point constraint circuit 46, an aniline constraint circuit 47 and an ASTM color constraint circuit 48. Constraint circuits 44 through 48 provide a plurality of direct current outputs to an AND gate 50. Each constraint circuit will provide a high level output when a parameter, being monitored by the constraint circuit, is within upper and lower con-
straint limits and a low level output when the monitored parameter is not within the constraint limits. When all parameters are within their constraint limits, AND gate 50 provides an output $E_5$ at a high level output as signal $E_5$ and a low level output as signal $E_5$ when any or all of the constraint circuits outputs are at a low level.

Signals $E_{24}, E_{25}, E_{26}, E_{27}$ are applied to $H_1$ networks $55, 55A$ and $55B$, respectively, providing signals $E_{24}, E_{25}$ and $E_{26}, E_{27}$ respectively, corresponding to the $H$ values for blend oils $A, B$ and $C$, respectively. In network $55, A$ multiplier $56$ multiplies direct current voltage $V_{ci}$ corresponding to the term $b_2 X_3$ with signal $E_{27}$ from signal means $14A$ to provide a signal corresponding to the term $b_2 X_3$. The signal from multiplier $56$ is applied to a unity gain inverting amplifier $57$. A logarithmic amplifier $58$ provides an output corresponding to the logarithm of a direct current voltage $V_{ci}$ which corresponds to the term $e$ in equation 3. A multiplier $63$ multiplies the output from amplifiers $57, 58$ to provide a signal corresponding to the term $-b_2 X_3 \log e$ to an antilog circuit comprising an operational amplifier $64$ having a function generator $65$ as a feedback network. Function generator $65$ may be of the type manufactured by Electronic Associates under their Part Number PC12. Thus, the output from amplifier $64$ corresponds to the term $e^{b_2 X_3}$.

The output from amplifier $64$ is subtracted from a direct current voltage $V_{ci}$ corresponding to the term in equation 3, by subtracting means $70$. A multiplier $71$ multiplies the output from subtracting means $70$ with a direct current voltage $V_{ci}$ corresponding to the term $a_0$. Summing means $72$ sums the output from multiplier $71$ with a direct current voltage $V_{ci}$ corresponding to the term $b_2 X_3$ in equation 3, to provide a signal to another multiplier $73$. A divider $74$ divides signal $E_5$ with a signal from subtracting means $75$ corresponding to the term $1 - X_3$, to provide an output to multiplier $73$. Subtracting means $75$ subtracts signal $E_{24}$ from voltage $V_{ci}$. Multiplier $73$ multiplies the output from summing means $72$ and divider $74$ to provide signal $E_5$.

Similarly networks $55A$ and $55B$ operate on signals $E_{24}, E_{25}, E_{26}, E_{27}$, respectively, to provide signals $E_{4A}$ and $E_{4B}$.

In circuit $44$, summing means $80$ sums signals $E_{4A}, E_{4B}$ and $E_{4C}$ to provide a signal $E_5$ corresponding to the $H$ value for base oil $A$ with direct current voltages $V_{ci}$ and $V_{10}$ corresponding to predetermined upper and lower constraint limits, respectively. Comparator $81$ provides a high level output when voltage $V_{ci}$ is more positive than signal $E_5$ and a low level output when $V_{ci}$ is not more positive than signal $E_5$. Comparator $81A$ provides a high level output when signal $E_5$ is more positive than voltage $V_{ci}$ and a low level output when signal $E_5$ is not more positive than voltage $V_{ci}$ so that when $H$ is within the constraint limits, comparators $81, 81A$ provide high level outputs which cause an AND gate $82$ to provide a high level output to AND gate $50$. When the $H$ value exceeds the upper constraint limit, signal $E_5$ is more positive than voltage $V_{ci}$ causing comparator $81$ to provide a low level output which disables AND gate $52$ causing it to provide a low level output to AND gate $50$. Similarly, when the $H$ value is less than the lower constraint limit signal $E_5$ is not more positive than voltage $V_{10}$ which causes comparator $81A$ to provide a low level output which has the same effect as when comparator $81$ provided a low level output.

Pour constraint circuit $45$ is similar to constraint circuit $44$. Pour constraint circuit $45$ utilizes $PBV$, networks in place of the $H_1$ networks $55$ through $55D$ in constraint circuit $45$. The $PBV$ circuits are similar to the $H_1$ networks with the difference being that the direct current voltages received correspond to the constants $c$ and $d$ instead of a and b and the $PBV$ network has summing means instead of having subtracting means $70$ which sums the output from the operational amplifier with a direct current voltage corresponding to $PBV$.

Constraint circuits $46, 47$ and $48$ are identical with each other and are similar to constraint circuit $44$. The difference between constraint circuits $46, 47$ and $48$ are constraint circuits $44$ is that constraint circuit $44$ uses $H_1$ networks $55$ through $55B$ while constraint circuits $46, 47, 48$ use $PBV$ networks in lieu of networks $55$ through $55B$. Referring to FIG. 6, there is shown a $BV_1$ network. A divider $88$ divides signal $E_5$ from subtracting means $90$. Means $90$ subtracts signal $E_5$ from voltage $V_5$. A multiplier $89$ multiplies the signal from divider $88$ with a direct current voltage $V_{10}$ which corresponds to the blend value of a particular characteristic, which by way of example may be the ASTM color, for base oil $A$ to provide a signal corresponding to a particular $BV_1$ value.

Referring now to FIGS. 1 and 7, programmer $12$ provides reset pulse $E_5$ to blending control means $90$ which also receives signals $E_{24}, E_{25}$ and $E_{26}$ from X1 signal means $14A, 14A$ and $14B$, respectively, and signal $E_5$ from constraint control means $42$. Blending control means $90$ provides signals $E_{10}, E_{16}A$, and $E_{16}B$ corresponding to desired set point positions for flow recorders controllers $8$, $8A$ and $8B$, respectively, to set their set points to control the blending of base oils $A, B$ and $C$ with the additive in tank 1. Multipliers $93, 93A$ and $93C$ in blending control means $90$ provides signals corresponding to the cost for the different component portions of a particular blend oil. Multiplier $93$ multiplies direct current voltages $V_{11}$ and $V_{12}$ corresponding to $X_1$ and $C_1$, the cost of the additive, to provide a cost signal. Similarly, direct current voltages $V_{16}, V_{16}A$ and $V_{16}B$ corresponding to economic values of base oils $A, B$ and $C$, respectively, are multiplied with signals $E_5, E_{24}$ and $E_{25}$, respectively, by multipliers $93A, 93B$ and $93C$, respectively, to provide cost signals. Summing means $94$ sums the cost signals from multipliers $93$ through $93C$ to provide a blend oil cost signal $E_{12}$ corresponding to $C$ in equation 6.

Signal $E_{12}$ is applied to a conventional type analog-to-digital converter $98$ which provides digital signals, corresponding to signal $E_{12}$, to a plurality of AND gate $99$. Signal $E_5$ is also provided to AND gates $99$ to partially enable those gates. When AND gates $99$ receive a transfer pulse as hereinafter explained, the digital signals from converter $98$ are transferred to a storage register $100$.

Storage register $100$ effectively stores the minimum cost signal. This is accomplished by applying outputs from storage register $100$ to a conventional type digital-to-analog converter $101$ which provides an analog signal $E_{14}$ corresponding to the content of register $100$. Signal $E_{14}$ is applied to an electronic switch $107$ and to a comparator $108$. Electronic switch $107$ is in effect a single pole double throw switch receiving a direct current voltage $V_{16}$. Voltage $V_{16}$ has an amplitude larger than the amplitude of a typical cost signal $E_{12}$. Compar-
switch 114 to provide voltage $V_{15}$ to comparator 112. Since voltage $V_{15}$ is greater than signal $E_{14}$, comparator 112 output goes to a high level. Now, when the next successive cost is lower than the next preceding cost, comparator 112 output will change from a high level to a low level triggering one shot multivibrator 118.

Where the present cost is greater than the minimum cost, comparator 112 output remains at a high level and does not trigger one shot multivibrator 118. Since one shot multivibrator 118 is not triggered, the minimum cost remains stored in register 100. When all the costs for different blend oils have been computed, storage register 100 will contain the minimum cost.

Concurrent with storing of the minimum cost in register 100, it is necessary that the quantities of base oils $A$, $B$ & $C$ and the additive comprising the blend oil having the minimum cost be stored in registers. The pulse from one shot multivibrator 118, passed by AND gate 121 resets a storage register 128 in set point signal means 130. Signal $E_6$ is applied to a conventional type analog-to-digital converter 131 which provides corresponding digital signals to a plurality of transfer AND gates 135. AND gates 135 are fully enabled by the pulse provided by one shot multivibrator 119 so that when a particular cost signal is transferred to storage register 100, signal $E_6$ corresponding to the quantity of base oil $A$ contributing to that particular cost is also transferred to storage register 128. Thus, at any time the content in register 128 corresponds to the quantity of base oil $A$ in the blend oil that has the minimum cost.

Register 128 provides a plurality of outputs to transfer AND gates 140, which are connected to storage register 141. Reset pulse $E_1$ from programmer 12 resets registers 100 and register 141. Pulse $E_1$, also triggers a one shot multivibrator 142 causing it to provide an enabling pulse to AND gates 140 causing them to transfer the content of registers 128 to 141. Register 141 holds the content corresponding to the quantity of base oil $A$ in the minimum cost blend oil until the operation is repeated.

The signals stored in register 141 correspond to a quantity and must be converted to a flow rate control signal. A conventional digital-to-analog converter 150 converts the outputs from register 141 to an analog signal. A multiplier 151 multiplies the signal from converter 150 with a conversion signal $E_{60}$ to provide signal $E_{60}$. Summing means 152 sums $x_1$ through $x_4$ signals from signal means 130-130C, respectively, to provide a sum signal to a divider 153. Divider 153 divides a direct current voltage $V_{25}$ with the sum signal to provide signal $E_{60}$.

Set point signal means 130A, 130B, 130C provides signal $E_{15}$ and $E_{14}$, respectively, in a similar manner to that of the set point signal means 130 so that valves 6 through 6C are controlled to allow the proper rates of the base oils & additive to achieve a minimum cost blend oil.

Although an analog computer has been used to describe the present invention, it would be obvious to one skilled in the art to use a general purpose digital computer in its stead provided that the hardware is not restricted to an analog computer but also encompasses digital computer control as well as hybrid digital and analog control systems. Referring to FIG. 8, a general purpose digital computer 140 provides digital outputs to digital-to-analog converters 141-141C which converts the digital
outputs to signals $E_1$ through $E_{10}$, respectively. Computer 140 is programmed in a conventional manner to provide the digital outputs as follows:

1. Store in the computer memory values for different quantities of base oils A, B and C & the additive.
2. Store in the computer memory, equations 3 through 6.
3. Store in the computer memory, predetermined values for $a$, $b$, $c$, $d$, $h$, $p$, $v$, $b$, ASTM color $b$, flash point $b$, and aniline point $b$ for each base oil.
4. Store predetermined limits for $H$, PBV, ASTM color $b$, flash point $b$ and aniline point $b$.
5. Store the costs $c_1$, $c_2$, and $c_3$ of base oils A, B and C, respectively, in the memory.
6. Select a first combination of base oil and additive quantities.
7. Calculate $H$ using equation 3, PBV using equation 4 and the ASTM color $b$, flash point $b$ and aniline point $b$ using equation 6 in accordance with the selected base oils quantities and the stored values of $a$, $b$, $c$, $d$, $h$, $p$, ASTM color $b$, flash point $b$ and aniline point $b$.
8. Compare the calculated values of $H$, PBV, ASTM color $b$, flash point $b$ and aniline point $b$ with their respective limits stored in the memory.
9. If any of the calculated values are not within the limits, repeat steps 6 through 8 and 9 or 10, whichever is applicable, for the next blend combination of base oil quantities.
10. If all of the calculated values are within the limits, calculate the cost of the blend combination.
11. If there is no minimum cost, store the present cost and blend combination quantities values and select a next combination of blend oil quantities values and repeat steps 7 through 11.
12. If there is a stored minimum cost, compare the present cost with the stored cost.
13. If the stored cost is less than the present cost, select a next combination of base oil quantities and repeat steps 7 through 12.
14. If the stored cost is not less than the present cost, store the present cost and the blend combination quantities values associated with the present cost.
15. Select a next combination of blend oils quantities values and repeat steps 6 through 14 until all of the different combination of quantities values have been processed, at that time the digital signals corresponding to the stored values of quantities of base oils and additive are provided as the digital outputs.

The apparatus of the present invention as hereinafore described controls the blending of base oils with an additive to achieve a blend oil meeting predetermined characteristics. The apparatus also computes the cost for difference blend oils and effectively controls the blending of the base oils and additives to achieve the blend oil meeting the predetermined specifications but also having a minimum cost. The apparatus may be an analog computer specifically arranged to solve the equations hereinafore described or it may be a general purpose digital computer program to solve the equations and to provide outputs controlling the blending of the base oils and additives.

What is claimed is:

1. A system for controlling the blending of base oils and additive, to achieve a desired blend having predetermined characteristics, being provided to blending means, comprising means for controlling the quantities of base oils and additive being provided to the blending means to be blended in accordance with control signals, means for providing signals corresponding to the predetermined characteristics for a desired blend of base oils and the additive, means for providing signals corresponding to the economic values of the base oils, memory means for storing values of different combinations of the base oils and the additive quantities, means connected to the value signals, to the memory means and to the characteristic signal means for selecting a desired combination of base oil and additive quantities in accordance with the economic value signals and the characteristic signals and providing signals corresponding thereto to the control means as control signals so as to achieve the desired blend of base oils and the additive.

2. A system as described in claim 1 in which the selecting means includes means connected to the memory means for controlling the memory means to provide signals corresponding to quantities of base oils & additive for different combination thereof comprising different blends in an iterative manner, means connected to the memory means and to the value signal means for providing a signal corresponding to the cost of a combination of the quantities represented by the signals provided by the memory means in accordance with the economic value signals and the following equation:

$$C = \sum_{i=2}^{n} c_i \frac{x_i}{1 - x_i}$$

where $c_i$ is the cost of a particular base oil, $x_i$ is the percent volume of the particular base oil and $x_i$ is the percent volume of the additive, means connected to the characteristic signal means for determining those combinations of base oil quantities that meet the predetermined characteristics in accordance with the characteristic signals and providing a signal corresponding thereto, and output means connected to the cost signal means, to the determining means, to the memory means and to the control means for providing the quantity signals from the memory means, corresponding to the combination of quantities of the base oils and the additive having a minimum cost that meet the predetermined characteristics as the control signals in accordance with the determination signal and the cost signal.

3. A system as described in claim 2 in which the predetermined characteristics are the $H$ value, the pour blend value PBV, and ASTM color blend value, the flash point blend value BV and the aniline point blend value and the determining means includes means receiving direct current voltages corresponding to terms $h$, $a$ and $b$ for the different base oils and $i$, associated with the following equations, and connected to the memory means for providing a signal corresponding to $H$ for a present combination of base oils quantities in accordance with the following equation:

$$H = \sum_{i=2}^{n} \left\{ (h_i + a_i(1 - e^{-b_i r})) \right\} \frac{x_i}{1 - x_i}$$

where $h_i$ is the $H$ value for a base oil $i$, $a_i$ and $b_i$ are constants associated with the base oil $i$, and $e$ is a constant; means receiving direct current voltages corresponding to $p$, $v$, $b$, $c$, $d$, and $l$ and connected to the memory means.
for providing a signal corresponding to the pour blend value PBV of the present combination of base oils quantities in accordance with the following equation:

$$PBV = \sum_{i=2}^{n} \left\{ (p_{vbi} - c_i(1 - e^{-d_i c_i})) \right\} \frac{x_i}{1 - x_i}$$

where $p_{vbi}$ is the pour blend value of the base oil $i$ and $c_i$ and $d_i$ are constants associated with the base oil $i$, means receiving direct current voltages corresponding to blend values $bv$ for the ASTM color, flash point and aniline point of the different base oils and 1 and connected to the memory means for providing signals corresponding to blend values $BV$ of the ASTM color, the flash point value and aniline point of the present combination of base oils quantities in accordance with the following equation:

$$BV = \sum_{i=2}^{n} (bv_i) \frac{x_i}{1 - x_i}$$

where $BV$ is the blend value of a particular characteristic such as the ASTM color, the flash point and the aniline point for the present combination of base oil quantities and $bv_i$ is the blend value of a particular characteristic for the base oil $i$; and means connected to the H signal means to the PBV signal means, to the BV signal means and to the output means and receiving direct current voltages corresponding to limits for the H value, the pour blend value $PBV$, the ASTM color blend value $BV$, the flash point blend value $BV$ and the aniline point blend value $BV$ for providing a signal to the output means as the determination signal having one amplitude when the H factor, the pour blend value $PBV$, the ASTM color blend value $BV$, the flash point blend value $BV$ and the aniline point blend value $BV$ are within their respective limits and another amplitude when at least one of the determined characteristics is not within its corresponding limits.