A system for controlling a solvent refining unit so as to operate the refining unit at the maximum limit of its operating parameters. Three such operating parameters are the refining temperature which is limited by the miscibility of charge oil and the solvent, the flow rates of extract oil and refined oil, which are limited by the mechanical design of the refining unit, obtained from the refining of the charge oil. A plurality of computers determine the values of constants from equations, hereinafter disclosed, so that the operating parameter that is limiting may be determined. A plurality of analog computers generate control signals for the different limiting operating parameters. Switching means apply the proper control signals to the refining unit in accordance with the determination of which operating parameter is limiting.

14 Claims, 6 Drawing Figures
MEANS AND METHOD FOR CONTROLLING A
SOLVENT REFINING UNIT FOR MAXIMUM
YIELD

BACKGROUND OF THE INVENTION

1. Field of the Invention
The present invention relates to control systems and,
more particularly, to a control system for a solvent
refining unit.

2. Description of the Invention
Heretofore, control systems for solvent refining
units, such as disclosed in U.S. application Ser. No.
96,193, filed Dec. 8, 1970 by Robert A. Woodle, inven-
tor of the present invention, and assigned to Texaco
Inc., assignee of the present invention, provide op-
timum control of the refining unit. However, it may be
profitable to operate a solvent refining unit at its max-
imum capability even though that operation is not an
optimum operation. The control system of the present
invention determines which operating parameter is
limiting the yields of extract oil and refined oil from a
solvent refining unit and provides control of the solvent
refining unit accordingly to achieve a maximum operat-
ing capability while yielding refined oil of a desired
quality.

SUMMARY OF THE INVENTION

A system controls a solvent refining unit which treats
charge oil with a solvent in a refining tower to yield raff
inate and extract mix. The solvent is separated from the
raffinate and from the extract mix by strippers to
provide refined waxy oil and extract oil, respectively.
The solvent is then returned to the refining tower. This
control system comprises control devices receiving
control signals which cause the refining unit to operate
for a predetermined time period at a predetermined
solvent dosage-temperature combination for providing
refined oil of a desired quality. At least one condition
of the extract oil and the refined waxy oil is measured
by a circuit which provides corresponding signals.
Another circuit measures at least one property of the
charge oil and provides a signal corresponding thereto.
A signal source provides signals corresponding to the
limitation of the refining unit and the refining opera-
tion. A network determines which operating parameter
is limiting the refining of the charge oil from the mea-
surement signals and the signals from the signal source
and provides corresponding control signals to the con-
trol device. The operation of the refining unit is con-
trolled after the predetermined time period by the last
mentioned control signals.

One object of the present invention is to provide a
system controlling a refining unit so that the refining
unit operates at a maximum capability.

Another object of present invention is to operate a
solvent refining unit at a refining temperature that is
substantially lower than the temperature at which the
solvent and charge oil becomes miscible.

Another object of the present invention is to operate
a refining unit at a maximum refined oil flow rate to
yield refined oil of a desired quality.

Another object of the present invention is to operate
a refining unit at a maximum extract oil flow rate to
yield refined oil of a desired quality.

Another object of the present invention is to provide
a system which determines which operating parameter
of a refining unit is limiting and controls the refining
unit accordingly.

The foregoing and other objects and advantages of
the invention will appear more fully hereinafter from a
consideration of the detailed description which follows,
taken together with the accompanying drawings
wherein one embodiment of the invention is 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 is a simplified block diagram of a system, con-
structed in accordance with the present invention, for
controlling a solvent refining unit so that solvent refining
unit operates at a maximum capability.

FIG. 2 is a graphic representation of a correlation of
the viscosity of charge oil versus a mathematical con-
stant n.

FIGS. 3, 4, 5, and 6 are detailed block diagrams of
the b constant computer, the EO_LIM, RO_LIM, and CR
computers.

DESCRIPTION OF THE INVENTION

The aforementioned U.S. application is for a system
providing optimum control of a solvent refining unit.
However, it may be desirable to operate the refining
unit at its maximum capability even though the opera-
tion may not be optimum. There are at least three
operating parameters that limit the capability of the
refining unit and they are the refined oil flow rate, the
extract oil flow rate and the miscible temperature. The
miscible temperature is that temperature at which the
charge oil dissolves completely in the solvent. The flow
rates are limited by the physical design of the refining
unit.

Referring to FIG. 1, there is shown a system for con-
trolling a conventional type solvent refining unit to
operate at its maximum capability where the solvent is
N-methyl-2-pyrrolidinone. The rate of the flow of the
charge oil is controlled so as to regulate the flow rates
of refined waxy oil and the extract oil. The tempera-
ture, which is also controlled, at which the refining of
the crude oil takes place affects the yield of the refined
oil and the extract oil. The rate of the charge oil enter-
ing a refining tower 3 in a line 4 is sensed and con-
trolled by conventional types sensing element 5, flow
recorder controller 6 and valve 2. Sensing element 5
provides a signal to controller 6 corresponding to the
flow rate of the charge oil. Controller 6 operates valve
2 to control the rate of flow of the charge oil to tower 3
in accordance with the signal from sensing element 5
and a signal E_t. Signal E_t controls the set point of con-
troller 6.

Although not shown, for ease of explanation, the
charge oil and refining solvent entering tower 3
through lines 4 and 7, respectively, have been heated
to a predetermined temperature. Tower 3 contains
packing 8 where the charge oil and solvent are con-
tacted in counter current flow effecting the extraction
of low viscosity index constituents of the crude oil. Raff
inate including the refined waxy oil and a small
amount of dissolved solvent is withdrawn through a line
10.
A temperature gradient is maintained in tower 3 by means of a cooling coil 11 having cooling water flowing through it. The temperature in tower 3 is sensed by conventional type sensing means 12 which provides a corresponding signal to a temperature recorder controller 14. Temperature recorder controller 14, which may be of a type well known in the art, operates a valve 15 in accordance with the signal from temperature sensing means 12 and a signal $E_{w1}$. Signal $E_{w1}$ controls the set points of temperature recorder controller 14. Valve 15 controls the rate of flow of the cooling water to control the temperature in tower 3.

Raffinate in line 10 enters a stripper 15 which strips the solvent from the raffinate to yield the refined waxy oil. The solvent is returned to tower 3 by line 7 while the refined waxy oil is provided to dewaxing means 16 through a line 17. Dewaxing means 16 removes the wax and provides refined oil for storage and blending with product lubricating oil. Elements having a numerical designation with a suffix are identical in operation and connection as elements having the same numerical designation without a suffix.

Sensing means 5A and a conventional type flow transmitter 20 measures the rate of flow of the refined waxy oil from stripper 15 and provides a corresponding signal $E_{w2}$.

Extract-mix comprising solvent and dissolved low viscosity index constituents of the charge oil is withdrawn from tower 3 through a line 22 at a temperature controlled by cooling coil 11. The extract-mix in line 22 is passed to a stripper 23 where the solvent is stripped from the extract oil which is discharged through a line 25. The recovered solvent is withdrawn through line 7 for return to tower 3 and re-use. The flow rate of the solvent is maintained at a maximum and the solvent dosage is controlled by controlling the flow rate of the charge oil. Sensing means 5B and a flow transmitter 20A senses the rate of flow of extract oil in line 25 and provides a corresponding signal $E_{s2}$. Initially the refining of the charge oil is done at a solvent dosage and temperature selected from various combinations of solvent dosage and temperature that yield the desired quality of refined oil. A source 26 of direct current voltage provides variable amplitude voltages $E_A, E_B$ corresponding to a selected flow rate $CO_{SRL}$ for the charge oil and to the selected temperature $T_{SRL}$. A switch 27 which may be of the 'momentary on' double pole single throw type is activated to momentarily apply voltages $E_{s1}, E_{s2}$ as signals $E_s$ and $E_{w2}$, respectively, to flow recorder controller 6 and to temperature recorder controller 14, respectively, to adjust the set points so that the refining is initially performed at the selected solvent dosage-temperature combination. The selected dosage $S_{SRL}$ is related to the selected flow rate by the following equation:

$$ S_{SRL} = (SOL_{SRL}/CO_{SRL}) $$ (1)

A sample of the charge oil in line 4 is continuously applied to a viscosity meter 28, which may be of the type described by J. M. Jones, Jr. in U.S. Pat. Nos. 2,791,902 and 3,025,232. The effluent from meter 28 may be returned to tower 3 or discarded as slop. Viscosity meter 28 provides an analog signal $E_v$, corresponding to the viscosity of the charge oil at 210°F, to a conventional type analog-to-digital converter 29 which converts analog signal $E_v$ to a digital signal. The digital signal from the analog-to-digital converter 29 controls a memory 30, which may be of a diode type with logic gating that is well known to one skilled in the art, to provide a digital signal corresponding to a characteristic constant $n$. The values of $n$ as related to the viscosity of charge oil, shown in the form of a graph in FIG. 2, are stored in memory 30 and the digital signal from converter 29 controls the logic gating in memory 30 to pass the signal corresponding to the proper value of $n$. The digital signal from memory 30 is converted to an analog signal $E_b$ by a digital-to-analog converter 31.

The $n$ constant is used to calculate a constant $a$ in accordance with the following equation:

$$ a = RO_m / (EO_m)^n $$ (2)

where $RO_m$ is the measured flow rate of the refined waxy oil and $EO_m$ is the measured flow rate of the extract oil. Signals $E_x$ and $E_b$, corresponding to the measured flow rates of $RO_m$, $EO_m$ of the refined waxy oil and the extract oil, respectively, and signal $E_x$ are applied to an a constant computer 34, which provides a signal $E_b$ corresponding to the $n$ constant. Computer 34 raises the measured extract oil flow rate $EO_m$ signal to the power $n$ using an exponential circuit 33 which includes a conventional type logarithmic amplifier 35, a multiplier 36, an operational amplifier 37, and a feedback element 38. Signal $E_x$ from flow transmitter 20A is applied to logarithmic amplifier 35 which in turn provides an output to a multiplier 36 whose output is multiplied with signal $E_b$ by multiplier 36. The product signal from multiplier 36 is applied to operational amplifier 37 having feedback element 38 connecting to its input and output. Feedback element 38 is in essence a function generator, which may be of the PC-12 type manufactured by Electronics Associates, that causes operational amplifier 37 to provide an output corresponding to $(EO_m)^n$. Signal $E_x$ from flow transmitter 20 is divided by the output from operation amplifier 37 by a divider 40 to provide signal $E_b$.

A computer 34A operates in a similar manner as $a_{LIM}$ characteristic computer to provide a signal $E_b$ corresponding to an $n_{LIM}$ constant which is determined from the following empirically derived equation:

$$ a_{LIM} = RO_{LIM} / (EO_{LIM})^n $$ (3)

Direct current voltages $E_{wa}$, $E_{wb}$ from source 26 correspond to the maximum possible flow rates $RO_{LIM}$ and $EO_{LIM}$ of the refined waxy oil and the extract oil within the physical constraints of the refining system. All direct current voltages from source 41 are with respect to a ground reference which is not shown. In the similar operation of computer 34A, as compared with computer 34, signal $E_b$ replaces signal $E_{wa}$, while signal $E_{wb}$ replaces signal $E_{wb}$. Computer 34A also received signal $E_b$ from converter 31.

Another characteristic constant $b$ is determined in accordance with the following empirically derived equation:

$$ b = \frac{1}{1 + \left( \frac{RO_m}{EO_m} \right) (S_{SRL} / T_{SRL})^n} $$ (4)
where $S_{SEL}$ is a selected percent volume of solvent dosage, $T_{SEL}$ is a selected refining temperature and $m$ is a constant having a value in the range of 0.75 to 0.80, a preferred value being 0.775. It should be noted that although $S_{SEL}$ and $T_{SEL}$ are used, measured values of the charge oil flow rate and the refining temperature may be used in their place. A constant computer 42 provides a signal $E_{12}$ corresponding to the constant $b$, in accordance with equation (4), signals $E_{9}$, $E_{8}$ flow from transmitter 20 and 20A, respectively, and direct current voltages $E_{4}$, $E_{9}$, $E_{10}$, $E_{11}$, $E_{2}$, and $E_{26}$ from source 26. Direct current voltages $E_{3}$, $E_{9}$, $E_{12}$, $E_{27}$, $E_{28}$, and $E_{29}$ correspond to flow rate $CO_{SEL}$, the refining temperature $T_{SEL}$, the term 1 in equation 4, the exponent $m$ in equation 4, the maximum solvent flow rate $SOL_{LIM}$, and the term 100 in equation 1, respectively.

Referring to FIG. 3, computer 42 includes a divider 44 which divides signal $E_{11}$ with signal $E_{9}$. Summing means 45 sums the resulting output from divider 44 with direct current voltage $E_{9}$ and provides a corresponding sum signal to a divider 47. Divider 47 divides direct current voltage $E_{11}$ by the sum signal from summing means 45 to provide an output. A divider 46 divides $SOL_{LIM}$ signal $E_{9}$ with $CO_{SEL}$ voltage $E_{9}$ to provide a signal to a multiplier 49 where it is multiplied with voltage $E_{26}$ to provide a signal corresponding to $S_{SEL}$. The output from divider 47 is multiplied with the $S_{SEL}$ signal by a multiplier 48 to provide a product signal to another multiplier 50. Direct current voltage $E_{9}$ is raised to the power $m$ by an exponential circuit 33A receiving voltage $E_{4}$. The output from exponential circuit 33A is applied to multiplier 50 where it is multiplied with the output from multiplier 48 to provide signal $E_{26}$.

The maximum refined oil and extract oil yields are constrained by the physical limitations of the refining unit. Thus the maximum refined oil yield occurs when the flow rate of the refined oil is at its physical limitation. The same is true for the extract oil. The determination of whether to operate the refining unit at the refined oil flow rate limitation $RO_{LIM}$ or at the extract oil flow rate limitation $EO_{LIM}$ is controlled by the constant $a$. When $a$ is equal to or greater than $a_{LIM}$, the refinery unit is operated for the maximum possible refined oil flow rate $RO_{LIM}$ when $a$ is less than $a_{LIM}$, the refinery unit is operated for the maximum possible extract oil flow rate $EO_{LIM}$.

Referring to FIG. 1, an electronic switch 54 is controlled by a comparator 57, comparing signals $E_{9}$ and $E_{10}$ to pass signals $E_{29}$, $E_{30}$ from an $EO_{LIM}$ computer 51, when signal $E_{9}$ is from a constant computer 34 is equal to or greater than signal $E_{9}$ from $EO_{LIM}$ computer 51 and to blocking signals $E_{29}$, $E_{30}$ from $EO_{LIM}$ computer 51 when signal $E_{9}$ is less than signal $E_{9}$. Similarly, comparator 57, through an inverter 58, controls an electronic switch 54A to block signals $E_{28}$, $E_{29}$ from a $RO_{LIM}$ computer 52 when signal $E_{9}$ is equal to or greater than signal $E_{9}$ and to pass signals $E_{28}$, $E_{29}$ from $RO_{LIM}$ computer 52 when signal $E_{9}$ is less than signal $E_{9}$.

Signals $E_{29}$ and $E_{28}$, corresponding to the charge oil flow rate $CO_{R}$ and to the refining temperature $T_{R}$, respectively, are developed by $EO_{LIM}$ computer 51 in accordance with the following equations:

\[ RO_{R} = a \left( EO_{LIM} \right)^{n} \]  

\[ S_{R} = \left( \frac{SOL_{LIM}}{CO_{R}} \right) \]  

\[ T_{R} = \left( \frac{b}{S_{R}} \right) \left( 1 + \frac{RO_{R}}{EO_{LIM}} \right)^{1/m} \]  

where $S_{R}$ is the charge oil flow rate in percent volume and $SOL_{LIM}$ is the maximum possible flow rate of the solvent within the physical constraint of the refining unit. Source 26 provides direct current voltages $E_{10}$, $E_{11}$, $E_{26}$, $E_{29}$ and $E_{7}$ to $EO_{LIM}$ computer 51 which correspond to the following terms, respectively: $EO_{LIM}$, 1, $SOL_{LIM}$, 100 and $1/m$ in equations 5 through 8. Computer 51 also receives signals $E_{9}$, $E_{8}$ and $E_{12}$ from digital-to-analog converter 31, a constant computer 34 and a constant computer 42, respectively. Referring now to FIG. 4, an exponential circuit 33B provides a signal corresponding to $(EO_{LIM})^{a}$ to a multiplier 60 in accordance with signals $E_{9}$, $E_{8}$. Multiplier 60 multiplies the signal corresponding to $(EO_{LIM})^{a}$ with a constant signal $E_{9}$ to provide a signal corresponding to the flow rate $RO_{R}$ of the refined oil. Summing means 61 sums the $EO_{LIM}$ signal $E_{9}$ with the $RO_{R}$ signal from multiplier 60 to provide signal $E_{12}$ corresponding to the flow rate $CO_{R}$ of the charge oil.

A temperature signal circuit 62 includes a divider 64 which divides the $SOL_{LIM}$ voltage $E_{9}$ with signal $E_{26}$ and the resultant signal is applied to a multiplier 65. The signal from divider 64 is multiplied with voltage $E_{26}$ so that multiplier 65 provides an output corresponding to the term $b_{e}$ in equations 7, 8. A divider 66 divides the $b$ constant signal $E_{12}$ with the output from multiplier 65 to provide a signal to a multiplier 69. The $RO_{R}$ signal from multiplier 60 is divided by the $EO_{LIM}$ signal $E_{9}$ by a divider 70 in the temperature signal circuit 62 and the resulting output is summed with voltage $E_{30}$ by summing means 71. Multiplier 69 multiplies the sum signal from summing means 71 with the signal from divider 66. An exponential circuit 33C provides $T_{R}$ signal $E_{12}$ in accordance with the product signal from multiplier 69 and voltage $E_{7}$.

Referring to FIG. 1, Signals $E_{29}$, $E_{30}$ corresponding to the charge oil flow rate $CO_{R}$ and to the refining temperature $T_{R}$ respectively, are developed by $RO_{LIM}$ computer 52 in accordance with the following equations:

\[EO_{R} = \left( \frac{RO_{LIM}}{a} \right)^{1/m} \]  

\[CO_{R} = EO_{R} + RO_{LIM} \]  

\[S_{R} = \left( \frac{SOL_{LIM}}{CO_{R}} \right) \]  

\[T_{R} = \left( \frac{b}{S_{R}} \right) \left( 1 + \frac{RO_{R}}{EO_{R}} \right)^{1/m} \]
Computer 52 receives direct current voltages \( E_{In} \), \( E_{In} \), \( E_{26} \), and \( E_{27} \), from source 26, corresponding to the \( RO_{LM} \), \( SOL_{LM} \), 100 and \( 1/m \) terms in equations 9 through 12. The \( a \), \( b \), and \( n \) constant signals \( E_a \), \( E_{12} \), and \( E_{25} \), respectively, are also applied to \( RO_{LM} \) computer 52.

Referring to FIG. 5, a divider 75 in \( RO_{LM} \) computer 52 divides signal \( E_{In} \) with signal \( E_5 \) and provides a resulting signal to an exponential circuit 33D. Another divider 76 divides the \( RO_{LM} \) signal \( E_5 \) with the a constant signal \( E_5 \) to provide a signal to an exponential circuit 33D. Exponential circuit 33D provides a signal which corresponds to the extract oil flow rate \( EO_T \) to summing means 77 where it is summed with the \( RO_{LM} \) signal \( E_5 \) to provide signal \( EO_2 \) corresponding to the charge oil flow rate \( CO_R \).

The \( EO_2 \) signal from exponential circuit 33D is applied to a temperature signal circuit 62A along with signals \( E_{12} \), \( E_{16} \), and \( E_{22} \) and with voltages \( E_{26}, E_{26}, \), and \( E_{25} \). Temperature signal circuit 62A provides \( T_R \) signal \( E_{26} \) in accordance with the applied signals and voltages and equation 12.

Referring again to FIG. 1, electronic switches 54B, 54C control the refining temperature and the charge oil flow rate to assure that refining temperature does not exceed a maximum temperature. The maximum temperature \( T_{MAX} \) is set at a temperature 10° to 20° F less than miscibility temperature \( T_{MISC} \). When the value of the refining temperature, as determined by \( EO_{LM} \) computer 51 or \( RO_{LM} \) computer 52, exceeds \( T_{MAX} \), \( T_{MAX} \) is used as the refining temperature and the charge oil flow rate is changed to provide the correct solvent dosage associated with the \( T_{MAX} \) temperature so that the desired quality of refined oil may be maintained. A charge oil flow rate \( CO_R \) signal \( E_{26} \) for the \( T_{MAX} \) condition is developed by a \( CO_R \) computer 90.

Source 26 provides a variable amplitude direct current voltage \( E_{96} \) corresponding to \( T_{MISC} \) and another direct current voltage \( E_{96} \) corresponding to a temperature greater than 10° but less than 20° F. The value of \( T_{MISC} \) may be determined experimentally from heating two volumes of M-naphthyl-2-pyrroldione and one volume of charge oil until they become miscible. Subtracting means 91 subtracts voltage \( E_{96} \) from voltage \( E_{96} \) to provide a signal \( E_{96} \) corresponding to \( T_{MAX} \), to a comparator 57A, to \( CO_R \) computer 90 and to electronic switch 54C. Comparator 57A compares signal \( E_{96} \) with temperature signal \( E_{96} \) or \( E_{96} \) passed by switch 54 or 54A, respectively. Electronic switch 54B is controlled by comparator 57A, through an inverter 94, to pass the signals passed by electronic switch 54 or 54A when signal \( E_{96} \) is equal to or greater than signal \( E_{96} \) or \( E_{96} \) passed by switch 54 or 54A, respectively, and block the signals from switch 54 or 54A when signal \( E_{96} \) is less than signal \( E_{96} \) or \( E_{96} \). Electronic switch 54C is controlled by comparator 57A to block signals \( E_{96} \) from \( CO_R \) computer 90 and subtracting means 91, respectively, when signal \( E_{96} \) is equal to or greater than signal \( E_{96} \) or \( E_{96} \) and to pass signals \( E_{96} \), \( E_{96} \) when signal \( E_{96} \) is less than signal \( E_{96} \) or \( E_{96} \).

Computer 90 develops \( CO_R \) signal \( E_{96} \) in accordance with the following equations:

\[
EO_T = a(EO_T)^n
\]

\[
CO_T = RO_T + EO_T
\]

where \( EO_T \), \( RO_T \) and \( CO_T \) are the flow rates for the extract oil, the refined oil and the charge oil when the refining temperature is \( T_{MAX} \). The \( CO_T \) computer 90 receives direct current voltages \( E_{96}, E_{96}, E_{96}, E_{96}, \) and \( E_{96} \) from source 26, corresponding to the \( 1, SOL_{LM}, 100, 2 \) and \( m \) terms, respectively, in equation 13. Source 26 provides another direct current voltage \( E_{96} \) to computer 90 which does not correspond to a term in the aforementioned equations. Computer 90 also receives the \( n \) constant signal \( E_{96} \), the a constant signal \( E_{96} \), the b constant signal \( E_{96} \) and the \( T_{MAX} \) signal \( E_{96} \). Referring now to FIG. 6, voltage \( E_{96} \) is applied to a potentiometer 100 connected to ground having a movable wiper arm 101 which is positioned by a direct current motor 102. It should be noted that all direct current voltages from source 26 are with respect to a ground reference which is not shown. A voltage \( E_{96} \) present at wiper arm 101 corresponds to the extract oil flow rate \( EO_T \) for the \( T_{MAX} \) condition. Voltage \( E_{96} \) is raised to the \( n \) power by an exponential circuit 33E receiving the \( n \) constant signal \( E_{96} \). A multiplier 103 multiplies the output from exponential circuit 33E with the \( a \) constant signal \( E_{96} \) to provide a signal \( E_{96} \) corresponding to the refined oil flow rate \( RO_T \) for the \( T_{MAX} \) condition. Signal \( E_{96} \) is multiplied with voltage \( E_{96} \) by a multiplier 108 to provide a product signal corresponding to the term \( 2(aEO_T)^2 \) in equation 13.

The a constant signal \( E_{96} \) is effectively squared by a multiplier 109 and the resulting signal is applied to another multiplier 110. The \( n \) constant signal \( E_{96} \) is multiplied with voltage \( E_{96} \) by a multiplier 111 and a resulting signal has voltage \( E_{96} \) subtracted from it by subtracting means 114. An exponential circuit 33F raises signal \( E_{96} \) to a power determined by the output from subtracting means 114 and the resulting signal is multiplied with the signal from multiplier 109 by multiplier 110. Multiplier 110 provides a signal corresponding to the term \( a(EO_T)^{2-1} \) in equation 13. Subtracting means 115 sums signal \( E_{96} \) and the signals from multipliers 108, 110 to provide a signal, corresponding to the left side of equation 13, to subtracting means 116.

Signal \( E_{96} \) is raised to the power 0.775 by an exponential circuit 33G, receiving signal \( E_{96} \) and voltage \( E_{96} \). The \( SOL_{LM} \) voltage \( E_{96} \) is multiplied with voltage \( E_{96} \) by a multiplier 120 and the product signal is multiplied with the signal from exponential circuit 33G by another multiplier 121. The product signal from multiplier 121 is divided with the \( b \) constant signal \( E_{96} \) by a divider 122 to provide a signal to subtracting means 116 corresponding to the right side of equation 13. Subtracting means 116 subtracts the signal from divider 122 from the signal from subtracting means 115 to provide an output. When the output from subtracting means 116 is zero, signal \( E_{96} \) corresponds to the correct value of \( EO_T \). The output from subtracting means 116 is amplified by an amplifier 125 to energize motor 102, when the output from subtracting means 116 is positive. Motor 102 moves wiper arm 101 of potentiometer 100 in a direction to reduce signal \( E_{96} \) until the output from subtracting means 116 is zero. Similarly, when the output from subtracting means 116 is negative, motor
102 moves wiper arm 101 in a direction to increase signal E₀₁ until the output from subtracting means 116 is zero.

Summing means 118 sum EOᵣ signal E₀₁ with the ROᵣ signal from multiplier 103 to provide the COᵣ signal E₂₃.

Referring back to FIG. 1, the signals passed by electronic switch 54B or 54C are applied to a double pole, single throw switch 130 which may be of the 'momentary on' type. An operator closes switch 130 to provide the signals from electronic switch 54B or 54C as signals E₁, E₂ to flow recorder controller 6 and to temperature recorder controller 14, respectively, to adjust their set points accordingly.

As conditions change, the operator may change the amplitudes of the voltage from source 26 or the computed constant signals may change accordingly. The operator can then control the charge oil flow rate and the refining temperature by closing switch 130 to affect the refining of the charge oil in accordance with the new condition or conditions.

The device of the present invention, as heretofore described, controls a solvent refining unit so that refining unit operates at a maximum capability. The solvent refining unit is operated at a temperature substantially less than the temperature at which the charge oil and the solvent become miscible. The solvent refining unit has been controlled to operate at the maximum refined oil flow rate possible when the refined oil flow rate is limiting and the computed refining temperature is substantially less than the miscibility temperature. The solvent refining unit has also been controlled to operate at the maximum extract oil flow rate possible when the extract oil flow rate is limiting and the computed refining temperature is substantially less than the miscibility temperature.

1. A control system for a solvent refining unit which treats charge oil with a solvent in a refining tower to yield raffinate and extract-mix, strippers separate the solvent from the raffinate and from the extract-mix to provide refined waxy oil and extract oil, respectively, the solvent is returned to the tower and the refined waxy oil is subsequently dewaxed to provide refined oil, comprising means for controlling the operation of the refining unit, first means connected to the control means for providing control signals to the control means to operate the refining unit for a predetermined time period at a predetermined solvent dosage-temperature combination so as to provide refined oil of a desired quality, means for measuring at least one condition of the extract oil and one condition of the refined waxy oil and providing signals corresponding thereto, means for measuring at least one property of the charge oil and providing a corresponding signal, signal means for providing signals corresponding to limitations of operating parameters of the refining unit and the refining operation, means connected to the condition measuring means, to the property measuring means and to the limitation signal means for determining which operating parameter is limiting and providing signals corresponding thereto, and second means connected to the determining means and to the control means for providing control signals to the control means after the predetermined time period in accordance with the signals from the determination means to control the operation of the refining unit so that the refining unit operates at a maximum capability while maintaining the quality of the refined oil.

2. A system of the kind described in claim 1 in which the solvent is N-methyl-2-pyrrolidone and the solvent flows at a maximum possible rate SOL₉₁₅.

3. A system as described in claim 2 in which the first control signal means includes means for providing direct current control signals corresponding to a selected charge oil flow rate COₛ₁ₑ₅ and to a selected refining temperature Tₛₑ₅, and switching means connecting the COₛ₁ₑ₅, Tₛₑ₅ signal means to the control devices for momentarily applying the COₛ₁ₑ₅ and the Tₛₑ₅ signals to the control devices to control the refining unit so that the refining unit operates with the selected charge oil flow rate and refining temperature until other control signals are applied to the control devices.

4. A system as described in claim 3 in which the signal means provides signals corresponding to the maximum possible flow rates EOᵣₑ₅ and ROᵣₑ₅ of the extract oil and the refined waxy oil, respectively.

5. A system as described in claim 4 in which the measured property of the charge oil is the viscosity, and the measured conditions of the extract oil and the refined waxy oil are the extract oil flow rate EOᵣₑ₅ and the refined waxy oil flow rate ROᵣₑ₅ and the determining means includes means connected to the property measuring means for providing a signal corresponding to a correlation constant n in accordance with the viscosity signal from the property measuring means, means connected to the condition measuring means and to the n constant signal means for providing a signal corresponding to an a constant in accordance with the EOᵣₑ₅ and ROᵣₑ₅ signals from the condition signal means and for providing a signal corresponding to an a constant in accordance with the EOᵣₑ₅ and ROᵣₑ₅ signals from the condition signal means and a comparator connected to the a constant signal means and to the a constant signal means for comparing the a constant signal to the a constant signal and to determine whether the refined waxy oil flow rate is the limiting operating parameter, the extract oil flow rate is the limiting operating parameter, or the refining unit is balanced.

6. A system as described in claim 5 in which the n constant signal means includes memory means in various values of n have been stored, and selection means connected to the memory means and to the viscosity measuring means for selecting the proper n value from the memory means in accordance with the viscosity signal from viscosity measuring means; the a constant signal means is an a constant analog computer providing the a constant signal in accordance with the following first equation:

\[ a = ROᵣₑ₅(EOᵣₑ₅)^n \]

and the aᵣₑ₅ constant signal means is an aᵣₑ₅ constant analog computer providing the aᵣₑ₅ constant signal in accordance with the following second equation:
7. A system as described in claim 6 in which the comparator provides a signal having one amplitude when the a constant signal is equal to or greater than the $a_{LIM}$ constant signal and another amplitude when the a constant signal is less than the $a_{LIM}$ constant signal; and the determining means includes a b constant analog computer receiving direct current voltages and being connected to the condition measuring means and to the first control means for providing a signal corresponding to the b constant in accordance with the $EOM$ and $RO_{M}$ signals from the condition measuring means, the $S_{SEL}$ and $T_{SEL}$ signals from the $CO_{SEL}$, $T_{SEL}$ signal means, the direct current voltages and the following third equation:

$$b = \left[ \frac{1}{1 + \left( \frac{RO_{M}}{EO_{M}} \right)} \right] \left( \frac{S_{SEL}}{T_{SEL}} \right)^{n}$$

where $m$ is a constant having a value within the range of 0.75 to 0.80; and the second control signal means includes connected means connected to the a constant computer, to the b constant computer and to the n constant signal means and receiving direct current voltages for providing signals corresponding to the charge oil flow rate $CO_{R}$ and to the refining temperature $T_{R}$ for the condition where the refined wax oil flow rate is at its maximum possible rate $EO_{LIM}$; means connected to the a and b constant computers and to the n constant signal means for providing signals corresponding to the charge oil flow rate $CO_{R}$ and to the refining temperature $T_{R}$ for the condition where the refined wax oil flow rate is at its maximum possible rate $RO_{LIM}$; switching means means connected to the $CO_{R}$, $T_{R}$ signal means, to the $CO_{R}$, $T_{R}$ signal means and to the comparator and controlled by the signal from the comparator to pass the $CO_{R}$ and $T_{R}$ signals from the $CO_{R}$, $T_{R}$ signal means; and to the second comparator and the $CO_{R}$ and $T_{R}$ signals from the $CO_{R}$, $T_{R}$ signal means when the signal from the comparator is of the one amplitude and to pass the $CO_{R}$ and $T_{R}$ signals from the $CO_{R}$, $T_{R}$ signal means when the signal from the comparator is of the other amplitude; subtracting means receiving direct current voltages, corresponding to the miscible temperature $T_{MISC}$ of the charge oil and the N-methyl-2-pyrrolidone and to a temperature $T_{1}$ occurring within the range of 10° to 20° F. for subtracting the $T_{1}$ voltage from the $T_{MISC}$ voltage to provide a signal corresponding to the maximum permissible refining temperature $T_{MAX}$; means connected to the a and b constant computers, to the n constant signal means and to the subtracting means and receiving direct current voltages for providing a signal corresponding to the charge oil flow rate $CO_{R}$ for the condition where the refining temperature is at its maximum permissible level $T_{MAX}$; a second comparator connected to the first switching means and to the subtracting means for comparing the $T_{MAX}$ signal with the $T_{R}$ or $T_{R}$ signal passed by the first switching means and providing a signal of one amplitude when the $T_{R}$ or $T_{R}$ signal is less than the $T_{MAX}$ signal and of another amplitude when the $T_{R}$ or $T_{R}$ signal is equal to or greater than the $T_{MAX}$ signal, and second switching means connected to the subtracting means, to the first switching means, to the $CO_{R}$ signal means, to the control devices and to the second comparator for blocking the signals from the first switching means, from the subtracting means and from the $CO_{R}$ signal means during the predetermined time period and for passing the $CO_{R}$, $T_{R}$ or the $CO_{R}$, $T_{R}$ signals from the first switching to the control devices as the control signals after the predetermined time period in response to the signal from the second comparator being of the one amplitude and for passing the $CO_{R}$ signal from the $CO_{R}$ signal means and the $T_{MAX}$ signal from the subtracting means to the control devices as the control signals after the predetermined time period in response to the signal from the second comparator being of the other amplitude.

8. A system as described in claim 7 in which the $CO_{R}$, $T_{R}$ signal means is an analog computer providing the $CO_{R}$ and the $T_{R}$ signals in accordance with the following fourth through seventh equations:

$$RO_{R} = a \left( EO_{LIM} \right)^{n}$$

$$CO_{R} = RO_{R} + EO_{R}$$

$$S_{R} = \left( \frac{SO_{LIM}}{CO_{R}} \right)$$

$$T_{R} = \left[ b \left( 1 + \frac{RO_{R}}{EO_{LIM}} \right) \right]^{1/m}$$

where $RO_{R}$ and $S_{R}$ are the refined wax oil flow rate and the solvent dosage for the condition where the extract oil is flowing at its maximum possible flow rate $EO_{LIM}$ and the received direct current voltages correspond to the term 100 in the sixth equation and the term 1 and the exponent $m$ in the seventh equation, where $m$ has a value within the range of 0.75 to 0.80; the $CO_{R}$, $T_{R}$ signal means is an analog computer providing the $CO_{R}$ and the $T_{R}$ signals in accordance with the following eighth through 11th equations:

$$EO_{R} = \left( \frac{RO_{LIM}}{a} \right)^{1/n}$$

$$CO_{R} = RO_{LIM} + EO_{R}$$

$$S_{R} = \left( \frac{SO_{LIM}}{CO_{R}} \right)$$

$$T_{R} = \left[ b \left( 1 + \frac{RO_{LIM}}{EO_{R}} \right) \right]^{1/m}$$

where $EO_{R}$ and $S_{R}$ are the extract oil flow rate and the solvent dosage, respectively, for the condition where the refined wax oil is flowing at its maximum possible flow rate $RO_{LIM}$ and the received direct current voltages correspond to the term 100 in the 10th equation and the term 1 and the exponent $m$ in the 11th equation; and the $CO_{R}$ signal means is an analog computer providing the $CO_{R}$ signal in accordance with the following 12th through 14th equations:

$$BO_{R} + 2a \left( EO_{R} \right)^{n} + a \left( BO_{R} \right)^{n-1} = \left( \frac{100 \left( SO_{LIM} \right)}{b} \right) \left( T_{MAX} \right)^{n}$$

$$BO_{R} = a \left( BO_{R} \right)^{n}$$

$$CO_{R} = RO_{R} + EO_{R}$$

where $EO_{R}$ and $RO_{R}$ are the extract oil and refined wax oil flow rates, respectively, for the condition where the refining temperature is at the maximum permissible level $T_{MAX}$ and where the received direct current voltages correspond to the exponent $m$ and the term 2 in the 12th equation.

9. A method for controlling a solvent refining unit in which charge oil is treated with solvent in a refining tower to yield raffinate and extract-mix, strippers
separate the solvent from the raffinate and extract-mix to provide refined waxy oil and extract oil, respectively, the solvent is returned to the tower and the refined waxy oil is subsequently dewaxed to provide refined oil, which comprises refining the charge oil for a predetermined time period at a predetermined solvent dosage and a predetermined temperature to achieve a desired quality of refined oil, measuring at least one property of the charge oil, measuring at least one condition of the refined waxy oil and one condition of the extract oil, providing signals corresponding to the measurements, providing signals corresponding to limitations of the refining unit and the refining operation, utilizing the signals to determine which operating parameter is limiting, and controlling the operation of the refining unit after the predetermined time period in accordance with the determination.

10. A method as described in claim 9 in which the solvent is N-methyl-2-pyrrolidone.

11. A method as described in claim 10 in which the measured property of the charge oil is the viscosity, the limitation signals correspond to the maximum possible flow rates $EO_{LIM}$ and $RO_{LIM}$ of the extract oil and the refined waxy oil, respectively, and to the maximum permissible refining temperature $T_{MAX}$, the measured conditions of the extract oil and the refined waxy oil are their flow rates $EO_a$ and $RO_a$, respectively, and the charge oil flow rate and the refining temperature are controlled in accordance with the determination.

12. A method as described in claim 11 in which the determining step includes providing an $n$ constant signal in accordance with the measured viscosity signal, providing an $a$ constant signal in accordance with the measured extract oil flow rate $EO_a$ signal, the measured refined waxy oil flow rate $RO_a$ signal, the $n$ constant signal and the following equation:

$$ a = RO_a(EO_a)^a, $$

providing an $a_{LIM}$ constant signal in accordance with the maximum possible extract oil and refined waxy oil flow rates $EO_{LIM}$ and $RO_{LIM}$ signals, respectively, the $n$ factor signal and the following equation:

$$ a_{LIM} = RO_{LIM}(EO_{LIM})^a, $$

providing an $m$ constant signal, having a value within the range of 0.75 to 0.80, and providing a $b$ constant signal in accordance with the selected dosage $S_{REL}$ signal, the selected refining temperature $T_{SEL}$ signal, the measured extract oil and refined waxy oil flow rates $EO_a$ and $RO_a$ signals, direct current voltages corresponding to a value of 1 and to an exponent $m$, respectively, and the following equation:

$$ b = \left[ \frac{1}{1 + \frac{RO_a}{EO_a}} \right] (S_a(T))(T)^m. $$

13. A method as described in claim 12 in which the determining step includes comparing the $a$ constant and the $a_{LIM}$ constant signals, providing a comparison signal having one amplitude when the $a$ constant signal is less than the $a_{LIM}$ constant signal and another amplitude when the $a$ constant signal is equal to or greater than the $a_{LIM}$ constant signal, providing control signals $CO_a$ and $T_a$ corresponding to a flow rate for the charge oil and a refining temperature, respectively, when the comparison signal is of the one amplitude, providing control signals $CO_a$ and $T_a$ when the comparison signal is of the other amplitude, determining themiscible temperature of the charge oil and the solvent, providing a signal corresponding to a maximum refining temperature $T_{MAX}$ which is substantially less than the miscible temperature, comparing the $T_a$ or $T_a$ signal, whichever is provided, with the $T_{MAX}$ signal, providing a second comparison signal having one amplitude when the $T_a$ or $T_a$ signal is less than the $T_{MAX}$ signal and another amplitude when the $T_a$ or $T_a$ signal is equal or greater than the $T_{MAX}$ signal, providing a $CO_a$ signal, corresponding to a flow rate for the charge oil, and the $T_{MAX}$ signal as control signals after the predetermined time period when the second comparison signal is of the other amplitude, and providing the $CO_a$, $T_a$ signals or the $CO_a$, $T_a$ signals as control signals after the predetermined time period when the second comparison signal is of the one amplitude.

14. A method as described in claim 13 in which the $CO_a$ and $T_a$ signals are provided in accordance with the $n$ constant signal, the $RO_{LIM}$ signal, the $SOL_{LIM}$ signal, the $a$ constant signal, direct current voltages corresponding to values of 1, 100, and $m$ and the following equations:

$$ EO_a = \left( \frac{RO_{LIM}}{a} \right)^{\frac{1}{n}}, $$

$$ CO_a = EO_a + RO_{LIM}, $$

$$ S_{REL} = \left( \frac{SOL_{LIM}}{CO_a} \right)^{100}, $$

and

$$ T_a = \left[ \frac{b}{S_{REL} \left( 1 + \frac{RO_{LIM}}{EO_a} \right)} \right]^{100}. $$

The $CO_a$ and $T_a$ signals are provided in accordance with the $n$ factor signal, the $EO_{LIM}$ signal, the $SOL_{LIM}$ signal, the $a$ constant signal, the direct current voltages corresponding to the values of 1, 100 and $m$ and the following equations:

$$ RO_a = a(EO_{LIM})^n, $$

$$ CO_a = RO_a + EO_{LIM}, $$

$$ S_{REL} = \left( \frac{SOL_{LIM}}{CO_a} \right)^{100}, $$

and

$$ T_a = \left[ \frac{b}{S_{REL} \left( 1 + \frac{RO}{EO_{LIM}} \right)} \right]^{100}. $$
the $CO_T$ signal is provided in accordance with the $T_{MAX}$ signal, and $m$ and $n$ factor signals, the $a$ and $b$ constants signals, the $SO_{LIM}$ signal, direct current voltages corresponding to the values of 1, 2, and 100, and the following equations:

$$BO_T + 2a(BO_T)^n + a^2 BO_T = \frac{100(SO_{LIM}(T_{MAX})^m}{b}$$

$$RO_T = RO_T$$

$$CO_T = RO_T + RO_T$$