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[54] **APPARATUS FOR CONTROLLING CHEMICAL PROCESSES**

[75] Inventors: **Norman L. Carr; Sheldon J. Kramer; Donald L. Stahlfeld,** all of Pittsburgh, Pa.

[73] Assignee: **Gulf Research & Development Company,** Pittsburgh, Pa.

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[52] **U.S. Cl.**........**235/151.12,** 208/DIG. 1, 235/150.1

[51] **Int. Cl.** **G06g 7/58**

[58] **Field of Search**...235/151, 151.1, 151.12, 150.1, 235/151.3; 260/94.2, 94.3, 94.9, 698, 699, 700; 208/DIG. 1, 133, 134

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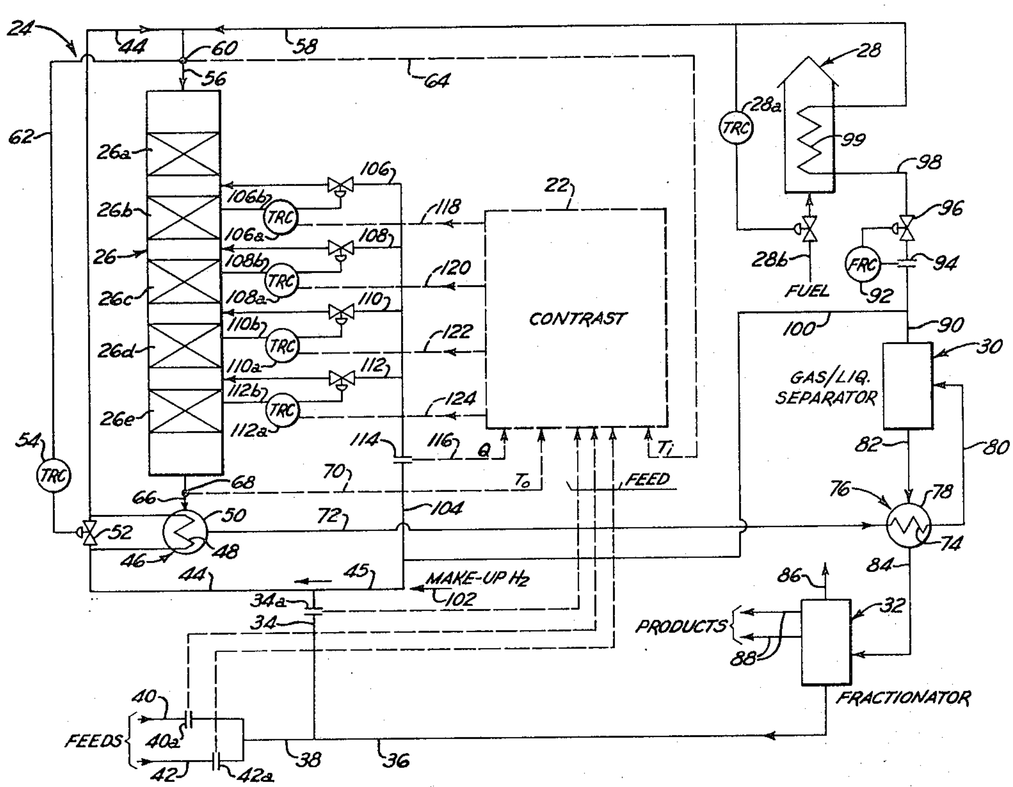
Primary Examiner—Joseph F. Ruggiero
Attorney—Meyer Neishloss, Deane E. Keith and William Kovensky

[57] **ABSTRACT**

Method and apparatus for controlling complex chemical processes comprising the use of a detailed model, a dynamic simulation, and intermediate steps to generate both a simplified monitoring model which will anticipate process responses and a dynamics compensation model, which are joined together to control the process in real time.

11 Claims, 8 Drawing Figures



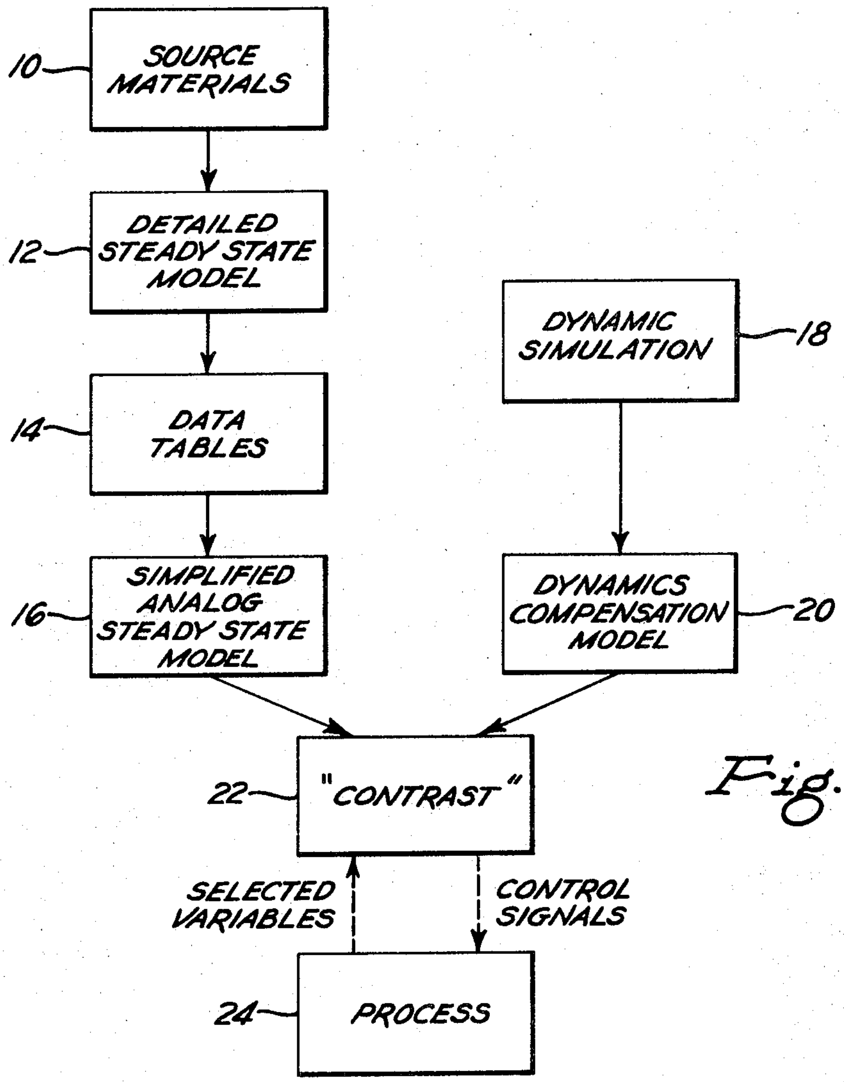


Fig. 1

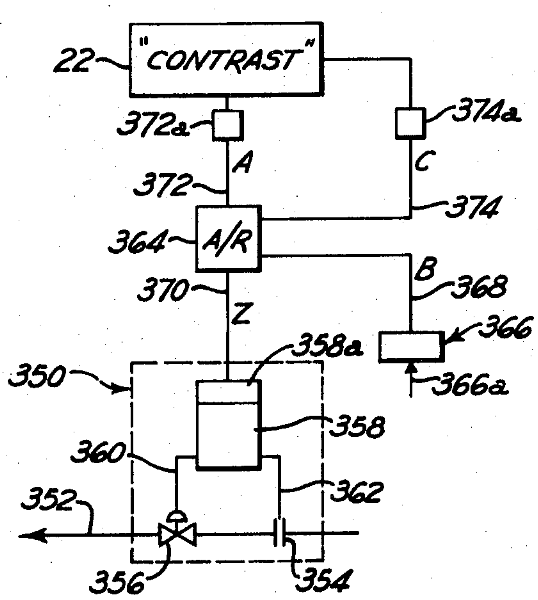


Fig. 4

INVENTORS.
NORMAN L. CARR
SHELDON J. KRAMER
DONALD L. STAHLFELD

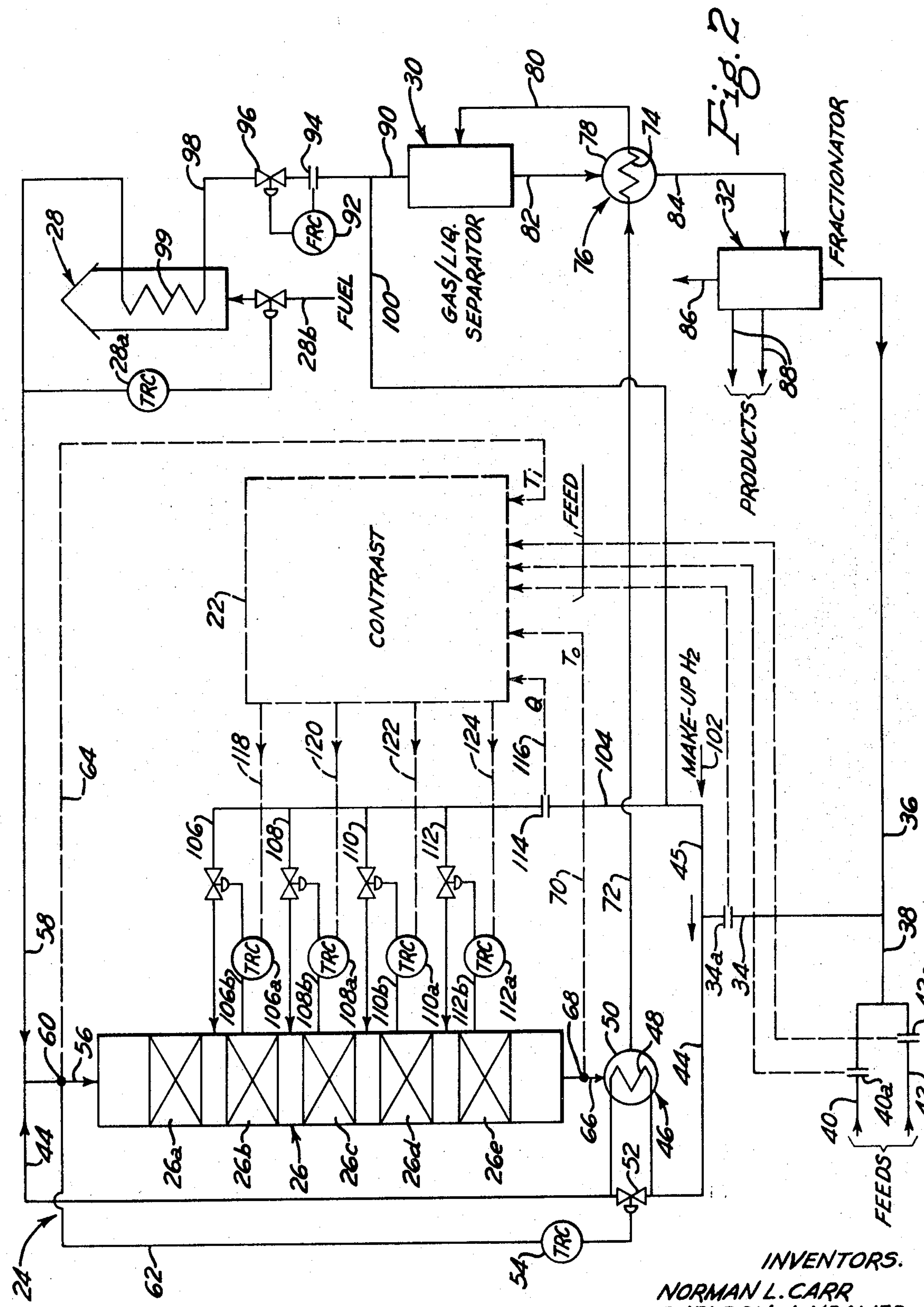


Fig. 2

INVENTORS.
NORMAN L. CARR
SHELDON J. KRAMER
DONALD L. STAHLFELD

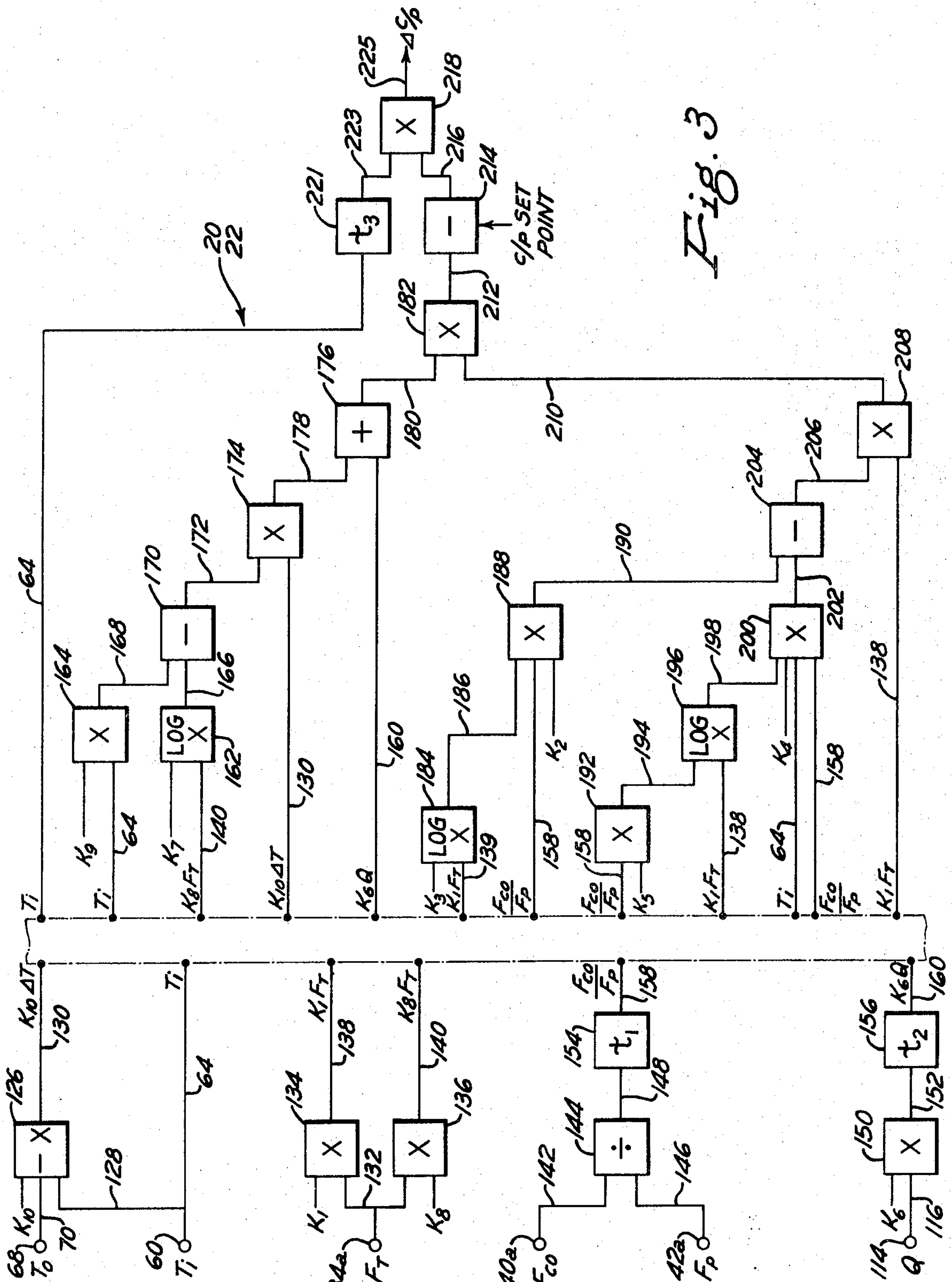


Fig. 3

INVENTORS.

NORMAN L. CARR
SHELDON J. KRAMER
DONALD L. STAHLFELD

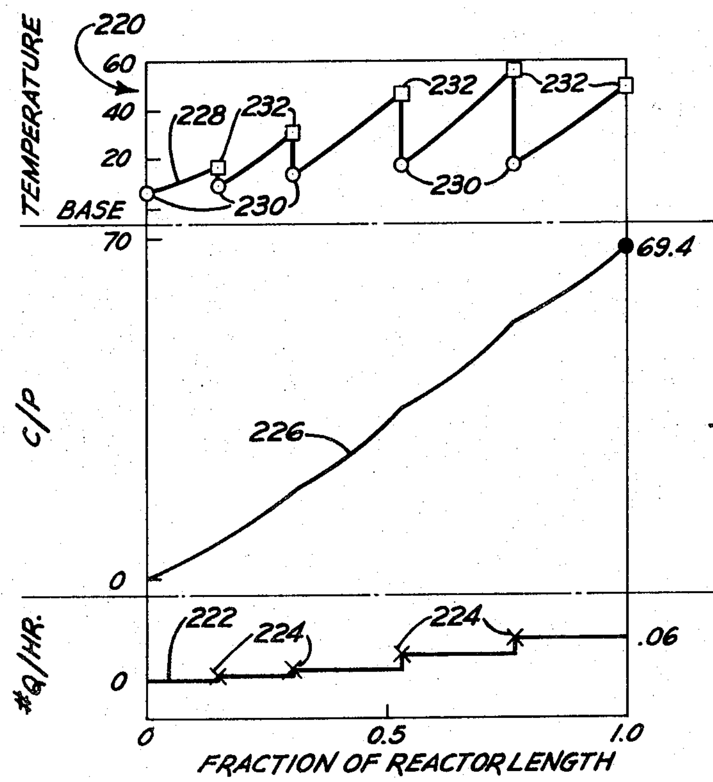


Fig. 5

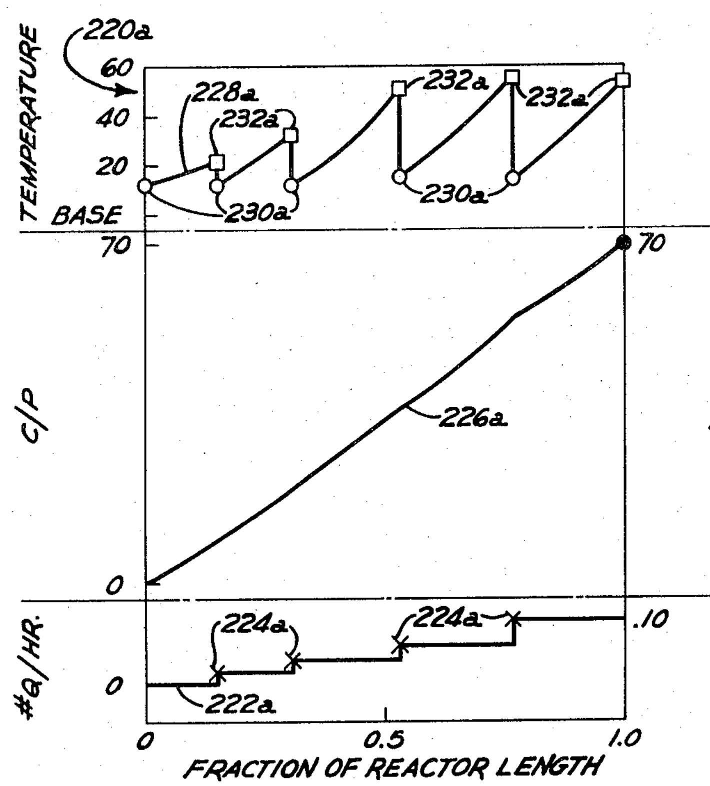
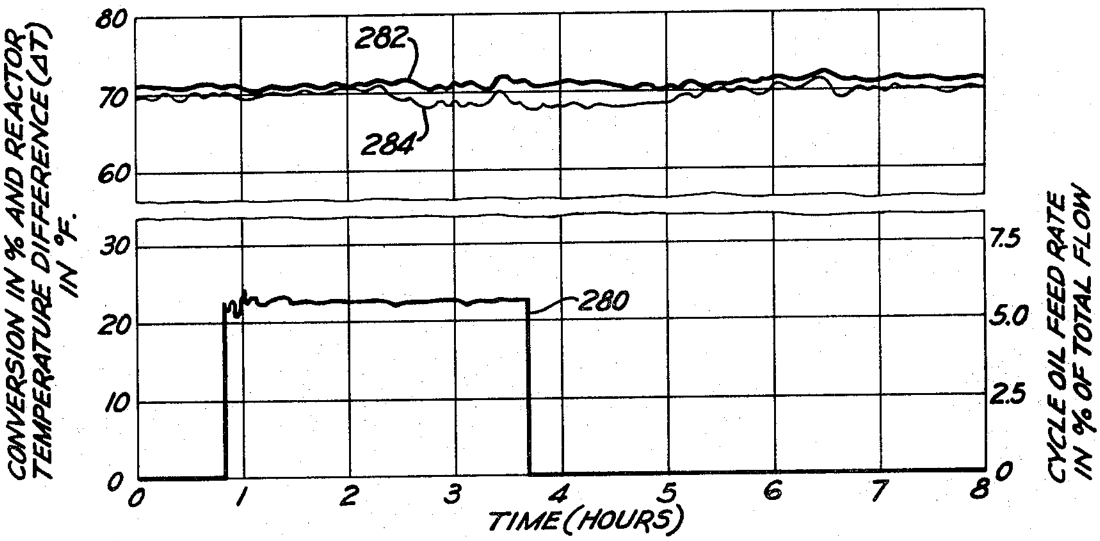


Fig. 6

INVENTORS.
NORMAN L. CARR
SHELDON J. KRAMER
DONALD L. STAHLFELD



RESPONSE OF THE CONTROLLED PROCESS TO FEED COMPOSITION CHANGE

Fig. 7

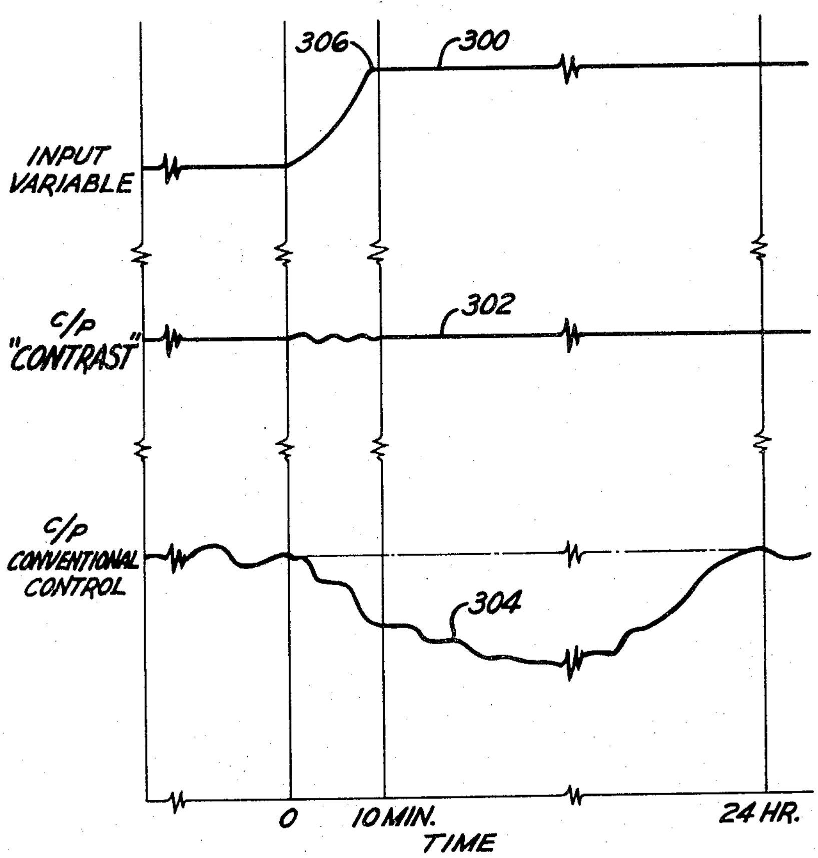


Fig. 8

INVENTORS.
NORMAN L. CARR
SHELDON J. KRAMER
DONALD L. STAHLFELD

APPARATUS FOR CONTROLLING CHEMICAL PROCESSES

This invention relates, in its broader aspects, to a method of controlling a complex chemical process with the use of several modern techniques, including computers. In its more specific aspects, the invention is directed to an apparatus for controlling a particular process using the techniques of the invention, and an array of electronic components comprising a special purpose analog computer.

The invention is particularly adapted for use in the petroleum refining industry, wherein it is desired to control a particular output or response variable of a continuous chemical process. For example, in hydrocracking of various hydrocarbon feed stocks to produce products having lower boiling point temperatures, it has been heretofore conventional to measure flow rates downstream from the hydrocracker, or to perform chemical analysis on the effluent stream in order to determine the desired output variable, which in the case of a hydrocracker is usually conversion per pass. These two methods are not completely satisfactory because they entail a considerable time delay and because, in the case of measuring flow rates only, the result is only approximate. On-stream analyzers are usually arranged so as to be a measurement of results only, and require relatively long periods of time to perform in and of themselves. The errors resulting from these disadvantages, time delay and approximate results, become amplified when the hydrocracker experiences a feed rate or other input variable change. These prior methods are not sufficiently time sensitive to such changes for determining changes in conversion because they are essentially measurements of results, and hence cannot anticipate what effect such changes within the process will have on results until the results actually occur. Generally, any system that depends solely or primarily upon measurements of results, in the broad connotation, will suffer from this disadvantage.

The present invention comprises a monitoring portion which will, in effect, predict changes in the output variable which is being controlled, conversion per pass in the example described. The importance of maintaining a constant conversion per pass, or at least knowing what the conversion level is, rests primarily on the economics of hydrocracking. These economics include material balance considerations in the refinery as a whole, which, in turn, is dictated by market place economics. It is desirable to have as little intermediate storage capacity and as little material as possible in such facilities in operating the refinery. As is known, all the various units in a refinery are interconnected to a greater or lesser extent. For example, the product of one unit may be the feed stock of another unit either by itself or mixed with final or intermediate product from still another unit or units. A fantastic number of combinations of this type exist in any one refinery.

Intermediate storage facilities are expensive in that they occupy land, they require equipment in the nature of tanks, pumps, safety equipment, and the like, as well as personnel. The whole concept of intermediate storage is, at best, a necessary evil, because products sitting idle are not earning revenue.

In summary, excessive conversion per pass adversely affects product selectivity, producing less valuable products, and conversion per pass below optimum levels increases plant capital and operating costs.

Therefore, it is essential to know the quantity of the output variable, conversion per pass, of each unit so that the flows through the refinery overall can be balanced to minimize intermediate storage, and to keep all units operating at whatever is their best, from the economic viewpoint, level of operation.

The invention has been applied to a hydrocracker in a commercial refinery. Prior to the addition of the invention, conversion per pass was kept below optimum, with the excess unconverted material being bled off as a less valuable product than it would have been if converted. It was essential to operate this way because if conversion per pass got too high, it would caUse the loss of operating levels in adjacent and/or feeder units which would cause shut down of those units, which in turn could cause shut down of the units feeding them, and which in a "domino-like" effect could constitute a major disaster in the refinery. However, by keeping conversion per pass below optimum, the financial loss ran in excess of $1,000 a day, which amounted to the substantial loss of about $300,000 to $500,000 per year. Since the addition of the invention, a substantial portion of that lost revenue has been saved and realized.

The particular optimum in any particular refinery for each operating unit is determined by the market-place supplied by that refinery. For example, in most European markets, the refinery "mix" of products is heavy towards fuel oils, whereas in the United States the refinery "mix" of products is more heavily towards gasoline. This broad market demand is, of course, varied in day to day operation. For example, if a large tanker with an order for gasoline is expected in a few days, the mix will be adjusted so that the gasoline will be ready when the ship arrives.

One object of the present invention is to provide a means to control a process so that the adjustment time will be substantially less than the time required by conventional means. For example, if it is desired to maintain a particular conversion level, and if that unit experiences a feed rate change, some time will be required to adjust reactor conditions to the desired conversion level while and after the unit is experiencing the change. During this adjustment period, the conversion level will vary, and, in conventional methods, the services of one or more operators will be required. If this adjustment time is relatively long, the cost of making the feed rate change will be increased because of the services of the operators, and because the conversion level will have varied during the adjustment period resulting in a larger or smaller quantity of the desired product, if that quantity is known at all by conventional methods. Both excess and shortage of product are undesirable in any case. With the present invention, the adjustment period for the commercial unit with which the invention is used has been lowered from many hours by conventional methods, to only minutes under the automatic control of the apparatus of the invention.

Another object of the present invention is to provide a method and apparatus for controlling a process in real time, i.e., controlling reactor conditions as they occur.

Still another object of the invention is to provide improved interfacing between a process and a process controller which will permit manual override of the controller, which will provide a complete manual back-up system, and which will automatically cut-out the automatic control and institute manual control without disrupting the process in the event of computer or associated equipment failure.

The present invention provides methods and apparatus of the character described wherein no extraordinary process information other than that information which would otherwise normally be required is utilized in order to control the process. For example, in the case of the hydrocracker being described, only inlet and outlet temperature, quench flow, and feed quantities are measured to give conversion per pass. The values of these quantities are required in any case by the refinery for its normal operation.

The apparatus of the invention comprises a special purpose analog computer. An analog computer is used in preference to a digital computer because it has a lower initial cost, is highly reliable, provides a continuous output in an easily used form such as a continuously drawn curve and/or a C-R tube display, or the like, and because of its great flexibility. The flexibility factor in conjunction with the other advantages of analog computers generically is an important advantage for the present invention, because, for example, by simply changing the settings on the computer, wide ranges of changes within the process being controlled can be accommodated. In a similar situation, a special purpose digital computer often would require extensive re-programming, which is expensive and time-consuming. Further, in the analog computer of the invention, such setting changes can be made by relatively unskilled persons, whereas a similar change for a digital computer requires the services of at least one skilled computer programmer.

Other advantages of the invention will be pointed out or will become evident in the following detailed description and claims, and in the accompanying drawing also forming a part of the disclosure, in which:

FIG. **1** is a block diagram of the method of the invention;

FIG. **2** is a schematic diagram of a refinery process with which the invention has been used;

FIG. **3** is a block diagram of the circuitry of the invention;

FIG. **4** is a schematic diagram of an interfacing detail;

FIGS. **5** and **6** are curves showing predicted hydrocracker responses of various variables and measured values of certain of said variables;

FIG. **7** is a graph of the process'response, when under the control of the invention, to a feed composition change; and

FIG. **8** is a graphic illustration of one of the advantages of the apparatus of the invention.

Referring now in detail to the drawing, FIG. **1** shows the method of the invention in simplified form as it would be applied to any process adapted for use with the invention.

The invention is applicable to processes having certain characteristics. The process must take place in a chemical reactor; i.e., a vessel of any sort in which a chemical change occurs involving a thermal or catalytic reaction. The process must be significantly exothermic or endothermic to produce a temperature gradient in the reactor. There must be at least one quantitatively, as opposed to qualitatively, measurable response variable. FInally, there must be no unknown substantial heat loss from the vessel to atmosphere, i.e., substantially adiabatic operation in the reaction section or sections. The process should be continuous, since the invention would have little applicability or economic advantage if applied to a batch type process. A thermal response is required because by measuring the heat, the energetics of the process can be determined as changes occur. Thus, the method of the invention cannot be used with, for example, isothermal reactions. The method of the invention cannot be used with reactor systems wherein endothermic or exothermic reactions are effected under essentially isothermal conditions such as fluid catalytic cracking, which would also entail obtaining extraordinary process information in order to control a critical output response variable.

Examples of other types of reactions with which the invention may be used in addition to hydrocracking as described include aromatic distillate hydrogenation (ADH) hydrodesulfurization (HDS), thermohydrodealkylation (THD), benzene hydrogenation, catalytic reforming, thermal reforming, isomerization, dehydrogenation, and polymerization.

Referring to FIG. **1**, block **10** marked "Source Materials" represents data taken from wherever available concerning the process useful in determining the behavior of the process. In the example of hydrocracking being described, these source materials include kinetics, reaction heat data, thermo-chemical data, pilot plant studies, energy balances, material balances, vapor-liquid equilibrium data, and data on the particular physical plant reactor and process. Utilizing all of the above information and data concerning the process to be controlled, a "Detailed Steady State Model," block **12**, is generated. It is significant that model **12** is highly generalized and must be supplied with additional conditions to model a process in a particular unit. After said conditions are supplied, this model **12** is not a practical tool for a refinery because of the high cost of the equipment required to implement it. Model **12** is a set of complex mathematical equations which are programmed into a relatively large general purpose analog or digital computer for use in the following step of the method of the invention.

Block **14**, marked "Data Tables," are obtained from model **12**. It will be understood that "Data Tables" **14** represent lists of figures, or graphical representations in the form of curves or other form as put out by the means used to implement model **12**. By utilization of the complete and highly detailed information about the process contained in model **12**, a set of data tables or performance curves are generated by the use of a digital or analog computer, or by hand, or in any other suitable manner, relating a small number of selected input variables to a selected one or two output variables, one output variable in the example being described. It is an advantage that the input variables selected are those that are otherwise normally monitored, and which are critical to the operation of the process, thereby eliminating the need for any additional special equipment, on-stream analyzers, for example, when the apparatus of the invention is applied to the operating unit. The selected output variable, in hydrocracking, is conversion per pass. In generating data tables or curves **14**, the ranges through which all variables of the process are varied are chosen so that they are at least equivalent to the corresponding ranges it is anticipated the process will undergo during normal operation.

Thus, the information in detailed model **12** is modified by its passage through the step of "Data Tables" **14** in two significant ways. Firstly, all process changes are tied to changes in the selected input and output variables only. Since model **12** behaves substantially identically to the actual process, "Data Tables" **14** reflect complete process responses. The selected input and output variables are critical, so any significant change in the process will be reflected in at least one, but usually more than one, of said selected variables. The second significant modification concerns the limitation of the data to only reasonable ranges of process variations, to thereby permit the fabrication of that portion of the apparatus of the invention represented by block **16**.

From the Data Tables or curves **14** obtained from detailed model **12** as described above, a second set of equations comprising a second model **16** is generated. Model **16** contains substantially all of the information contained in the very complete and complex model **12**, but limited and modified for the special purpose as described above. Model **16**, if built into a computer apparatus, can be used at this stage to monitor the process from which Source Materials **10** where taken. Model **16** is a steady state model, i.e., it does not include the dynamic responses. As used herein, the term "dynamics" or "dynamic responses," or the like, shall be understood to mean the response characteristic of a process resulting from process variable changes, measured in real time. For example, a feed perturbation will not effect reactor operation for the period of time required for that change to arrive at the reactor. The dynamic correction compensates for this travel time by not changing reactor conditions until that length of real time elapses. This is a time delay. The total output variable response in real time to an input variable change is equal to this time delay plus a real time lag equal to the time required for the output variable to experience its characteristic response.

Referring back to FIG. **1**, block **18** marked "Dynamic Simulation" represents a simulation of all of these dynamic responses.

The information necessary to make the dynamic simulation can be obtained from the process in the actual unit to be controlled by empirical measurement of these various times and characteristic responses at various performance levels. In some cases, a dynamic simulation will already be in existence, and it, and the appropriate apparatus, computer or the like, can be used to make the dynamic simulation. Such a simulation may have been made previously to develop a conventional control system.

Utilizing simulation **18**, a "Dynamics Compensation Model" represented by block **20** is created. Model **20** is created with the use of Model **16** and simulation **18** by changing the various inputs individually and in combinations with each other, and noting responses in the output variable, conversion per pass. A determination is made as to by what quantity quench flow must be changed in order to move the process back to the set conversion per pass. As will appear more clearly below, manipulation of the quench flow is the process variable which is used to control the process. The processes of changing inputs, and noting responses and corrections is repeated until sufficient data is generated to permit fabrication of model **20**.

After steady state model **16** and dynamics compensation model **20** are both generated, the two models are combined to produce the control computer designated **22** and marked "CONTRAST." The word "CONTRAST" is an acronym meaning Controlling Reactors by Analog Simulation Techniques. The models are combined by physically joining the two pieces of electronic equipment in which models **16** and **20** are embodied into a new piece of electronic equipment in which CONTRAST is thereby embodied. The joining is accomplished by well known computer techniques.

Block **24** on FIG. **1** representing the process, and the two arrows marked "Selected Variables" and "Control Signals" show the interaction between CONTRAST and the process being controlled diagrammatically. The interfacing is set forth in FIG. **4** and by the accompanying explanation below.

Referring to FIG. **2**, there is shown a schematic diagram of a hydrocracking process **24** which has been successfully controlled by the apparatus of the invention. The major elements in process **24** are a hydrocracker **26**, a furnace **28**, a gas/liquid separator **30** and the fractionator **32**. Hydrocracker **26** contains a series of five catalyst beds, ***26a***, ***26b***, ***26c***, ***26d***, and ***26e***. Spaces are provided between each two beds, in which a stream of coolant, known in the art as quench, is injected in order to control the inlet temperature of beds ***26b*** through ***26e***, to thereby control the overall rate of conversion in hydrocracker **26**.

The major operative element in process **24** is the hydrocracker **26**, which converts kerosine into naphtha to make gasoline in subsequent processes. More specifically, the total feed to hydrocracker **26** in a line **34** is made up from three sources. The particular feed arrangement described below resulted from the unique situation existing in the refinery in which process **24** is incorporated, but it will be understood by those skilled in the art that the invention could be just as well practiced if line **34** fed the total feed stock to the hydrocracker from one source. One feed component is delivered by a line **36** from the fractionator **32**. This material is recycled, unconverted feed, and is mostly kerosine. A line **38** adds the joint flows from a feed line **40** and a feed line **42** to the feed in line **36** to thereby make up the total feed in line **34**. Line **40** contains kerosine delivered from a crude tower, not shown, in another part of the refinery and is known as virgin material. Line **42** feeds material from a fluid catalytic cracking unit, not shown, in another part of the refinery and is known as cycle oil. Each of lines **34**, **40** and **42** include a flow rate detecting orifice ***34a***, ***40a***, and ***42a*** respectively, the information from which is fed into control computer **22** by suitable electrical wires indicated by dash lines in FIG. **2**. These three signals make up the feed information which is one of the four system measurements used to make computer **22** by the method of the invention described above, and which computer **22** uses to control hydrocracker **26** as will appear in more detail below.

The total liquid feed in line **34** proceeds to hydrocracker **26** through a line **44**. A line **45** delivers gaseous material, almost entirely hydrogen, from other parts of the process, to the liquid feed in line **34** so that the material in line **44** is the mixture of kerosine plus hydrogen required by hydrocracker **26**. As is known, hydrocracking is a process in which petroleum fractions react with hydrogen to form lower molecular weight hydrocarbons in the presence of excess hydrogen. Means are provided to preheat the feed stock in line **44** to a variable degree as required for efficient operation of the hydrocracker. To this end, a heat exchanger **46** is provided, comprising an internal coil **48** and an external housing **50**. The showing of heat exchanger **46** is diagrammatic, but it will be understood that heat exchange will occur between the material in coil **48** and the material in vessel **50**, with the hotter material serving to heat the cooler material towards equilibrium. A valve **52** is provided in line **44** between the junction points of the ends of coil **48** and line **44**. Thus, closure of valve **52** will cause the gas/liquid feed stock to shunt through coil **48** in heat exchanger **46**. If valve **52** is left open, the heat exchanger **46** will be bypassed by the feed stock, and any degree of adjustment between these two extremes is obtainable. Vessel **50** of heat exchanger **46** is in the outlet line of hydrocracker **26**, as will appear in more detail below. Valve **52** is remotely controlled by a temperature-recorder-controller (TRC) **54**. As is well understood in the art, a TRC is a device activated by a thermal sensing unit which will open and close a valve or put out control signals in response to changes in temperature at the thermal sensing unit with respect to the pre-set temperature in the TRC. The device also records the temperature changes, and may be remotely or control panel mounted.

The combined gas and liquid feed stock in line **44** feeds into the hydrocracker inlet line **56**, which is also fed by a line **58** carrying recycled hydrogen which has been additionally heated, as will appear in more detail below. A temperature sensor **60** is provided in line **56** to sense the hydrocracker inlet temperature. A wire **62** feeds a signal proportional to reactor inlet temperature to TRC **54** from element **60**, and another wire **64** feeds the same signal to control computer **22**.

A line **66** carries the effluent from hydrocracker **26** into housing **50** of heat exchanger **46**. A temperature sensor **68** is provided in line **66** to generate a signal proportional to reactor outlet temperature which is sent through a wire **70** to control computer **22**.

The hydrocracker effluent, a mixture of the desired products, unconverted material, hydrogen, and other substances in minor quantities, is delivered by a pipe **72** to the coil **74** of a heat exchanger **76** also comprising a housing **78**. Heat exchanger **76** is similar to heat exchanger **46** described above. It is desirable to cool the hydrocracker effluent stream in order to maximize the amount of hydrogen in the gas which will be removed by separator **30**. It is desirable that the gas from separator **30** be as close to pure hydrogen as possible. A line **80** delivers the cooled hydrocracker effluent from heat exchanger **76** to the inlet of separator **30**.

The liquid portion of the effluent stream is directed by separator **30** into a line **82** wherein it passes through housing **78** of heat exchanger **76** to serve as the coolant for the feed to separator **30**. The now somewhat heated liquid fraction is directed through a pipe **84** to the inlet of fractionator **32**. Fractionator **32** produces gases, indicated by arrow **86**, which are butanes and lighter hydrocarbons. These gases are used in other parts of the refinery. A plurality of products are produced by fractionator **32**, indicated by arrows **88**, and include pentanes, hexanes, and naphtha (gasoline). The remaining material is kerosine and is recycled back to the hydrocracker via line **36**, as explained above.

The gaseous portion of the hydrocracker effluent is delivered by separator **32** through a line **90**. This gaseous portion is almost wholly hydrogen. Means are provided to divide the gas in line **90** and direct a portion of it to line **58** to be added to the hydrocracker feed stock, and to use the remaining portion of the hydrogen as quench. To this end, a FRC **92** including a flow measuring orifice **94** and a line valve **96** is provided in a line **98** comprising one leg of a Y-connection off of the end of line **90**. The other leg of said Y-connection feeds a line **100** which is connected to line **45**, described above, which feeds the hydrogen added to the feed stock going to the hydrocracker. A portion of the hydrogen in line **100** proceeds through line **45** to the hydrocracker, and additional hydrogen, indicated by arrow **102**, from other sources not shown, is added to line **45** to makeup the hydrogen consumed in the reactor. The remaining gas in line **100** proceeds through a line **104** and is divided into four lines **106**, **108**, **110**, and **112**, each under the control of a TRC **106**a, **108**a, etc. associated with the second through fifth beds **26**b through **26**e, and comprises means to sense the inlet temperature of said bed, which means are indicated by the lines **106*b***, **108*b***, etc.

Control computer **22** utilizes adjustments in the amount of quench in the lines **106**, **108**, **110**, and **112** to control the process. Adjustment of the temperature profile in a given reactor is the lever used to obtain the desired conversion under a given set of operating conditions (i.e., feed rate, feed composition, pressure etc.). This temperature is controlled by manipulation of the quench. The control function is accomplished by adjusting the set points on the TRCs by means of four lines **118**, **120**, **122** and **124** running from computer **22** to each of the TRCs, respectively.

The division of the amount of hydrogen directed through line **104** and the amount directed through line **45** is controlled by the combined effect of the four TRCs **106*a***, **108*a***, **110*a***, and **112*a***. That is, if the computer **22** sends signals to these TRCs indicating that a reduction in the temperature set points is necessary, the TRCs will open their associated valves, and a larger fraction of the hydrogen will be drawn through line **104** rather than through line **45** than before the sending of those control signals.

In order to achieve efficient operation of the hydrocracker **26**, it is necessary that the hydrogen in line **58** which is added to the feed in line **44** going to the inlet of the hydrocracker be additionally heated. To this end, the furnace **28** is provided. Line **98** is formed with a coil **99** which is positioned within said furnace. A TRC **28***a* detects the temperature of the hydrogen in line **58** and controls the amount of fuel supplied through line **28***b* by its associated valve in said line **28***b* to maintain the temperature of the hydrogen in line **58** at the pre-set temperature controlled by TRC **28***a*.

It will be understood that the showing of FIG. **2** is highly schematic in that many components such as compressors, additional TRCs and FRCs, additional coolers, and the like, have be omitted for the sake of clarity.

Referring now to FIG. **3**, there is shown a simplified schematic diagram of the computer apparatus of the invention which was made according to the method of the invention described above specifically for use with the process shown in FIG. **2**. The input variables are feed and total quench in volumetric flow rate units, and inlet and outlet temperatures. As will be understood by those skilled in the art, any suitable means or technique, usually already existing in the refinery, may be used to obtain the input signals. In the particular example being described, the feed information comprises the total feed in line **34** and the two fresh feeds in lines **40** and **42**. In this particular case, the amounts of cycle and virgin materials are measured because their ratio to each other and to total feed, affects the amount of hydrogen consumed in the unit at any time. The system's overall energetics are closely tied to the temperature patterns in the unit, which patterns are closely tied to hydrogen consumed in the unit. In summary, feed stock composition affects hydrogen consumption, hydrogen consumption affects temperature patterns, and temperature patterns affect conversion. By controlling the hydrogen quench, CONTRAST controls the unit. Therefore, the cycle/virgin ratio to total feed is important because it effects hydrogen supplied from line **102**.

The cycle/virgin ratio is important in and of itself because the aromatics content of both feeds are substantially entirely saturated with hydrogen. The reaction of saturating a compound with hydrogen is exothermic, i.e., gives off heat. The cycle feed as a larger aromatics content than the virgin material, on the orders of 75 percent vs. 15 percent. The amount of heat released, and the amount of hydrogen consumption, is not dependent on only aromatics content, since other reactions occur and other characteristics of the feed affect hydrogen consumption and thereby heat release. For example, it is known that a cycle oil feed stock of certain characteristics, i.e., percent aromatics content, boiling range, aromatics types, specific gravity, etc., will consume a certain known quantity of hydrogen and will release a certain known quantity of heat. Similar information is known for the virgin feed stocks. However, percent aromatics content is the single most important indicator of eventual hydrogen consumption and heat release for any specific material. The numerical value of hydrogen consumption/heat release for all materials commonly used in the refinery is known. This value is called a cracking characteristic of the feed stock and is expressed in BTUs/lb. of material converted. The volume of each of the cycle and virgin feeds going into the total feed is known, and therefore the cracking characteristic of the total feed is automatically obtained in the computer apparatus of the invention by simple arithmetic averaging.

By way of example, if a volume of cycle material having a cracking characteristic of 100 BTU/lb. and an equal volume of virgin material having a cracking characteristic of 50 BTU/lb. goes into the total feed, then the cracking characteristic of the total feed is 75 BTU/lb.

Referring now to the detailed schematic of the computer apparatus of the invention of FIG. **3**, the desired output variable is, first, percent conversion per pass, and then a correction signal to move the actual value to the set value of conversion per pass. The following steady state formula was derived by the above steps of first assembling the source materials, then generating the highly detailed and generalized first model, and utilizing said first model in a manner so as to condense the information therein through the steps of the data tables or performance curves **14** to produce the steady state model **16**. By going through these steps, the following equation (1) resulted:

$$C/P=\left\{K_1F_T\left[K_2\left(\frac{F_{co}}{F_p}\right)(K_1F_T)^{K3} -K_4\left(\frac{F_{co}}{F_p}\right)(T_i)(K_1F_T)^{K_5\left(\frac{F_{co}}{F_p}\right)}\right]\right\}[K_6Q + (K_7{}^{K_8F_T}-K_9T_i)(K_{10}\Delta T)]$$

In the above formula, T_i is inlet temperature, F is the total feed rate in volume units, F_{co} is the cycle feed rate in volume units, F_p is the virgin feed rate in volume units,ΔT is the inlet and outlet temperature difference, and Q is total quench flow rate in volume units. The various constants in the above formula (K_1, K_2, etc.) are determined dependent upon the physical and chemical characteristics of the particular unit. These conditions also accommodate the quench inlet temperature, which is substantially constant in a hydrocracker; hence, the quench flow Q is a measure of the thermal effect of the quench. That is, a higher volumetric flow rate of quench results in a proportionally greater cooling effect.

Referring now to FIG. **3**, there is shown a schematic diagram of an analog computer to carry out the above computation to determine percent conversion per pass of the hydrocracker **26**, and which will also generate correction signals to bring conversion to the set value. The dynamics compensation model **20** is in the schematic of FIG. **3**, as will be described below. The input variables from the process are detected and fed to computer **22** by the transducers and lines described above.

Referring to FIG. **3**, the vertical space is only a matter of drafting convenience. Each line terminating at the vertical space on the drawing is marked to show to what line or lines on the opposite side it is connected. For example, the second line down on the left supplies a signal proportional to the inlet temperature, and this same signal is picked up by the first, second and tenth lines down to the right of the space.

The various sensors, orifices, or other transducers, and the dotted lines supplying electrical signals to computer **22** on FIG. **2** are indicated by the same numbers on FIG. **3**. Line **70** from transducer **68** supplies a signal proportional to hydrocracker outlet temperature to a subtracting and multiplying module **126**. Line **128** supplies a signal from line **64** proportional to inlet temperature to module **126**. Means are provided to supply a signal proportional to constant K_{10} to module **126**, and said module puts out a signal in a line **130** proportional to the value of $K_{10}\Delta T$. Module **126** comprises any suitable means to first subtract the two temperatures one from the other, and then to multiply the resultant value times the value of constant K_{10}. The value and sign of constant K_{10}, as well as the values and signs of all the other constants described below, are provided from a source or sources including an adjusting element, such as a potentiometer, in the usual manner of the computer art. Means are provided to provide the appropriate sign to every signal in the circuit, as required, in any usual manner.

A signal proportional to total feed (F_T) from transducer **34***a* is supplied through both arms of a branching line **132** to two multiplication modules **134** and **136**. Module **134** is provided with a signal proportional to the value of constant K_1, and puts out a signal proportional to the quantity of K_1F_T in a line **138**. Module **136** is provided with a signal proportional to the value of constant K_8, and puts out a signal proportional to the quantity K_8F_T in a line **140**. A line **142** supplies a signal from transducer **40a** to a division module **144**, which is also supplied with a signal from transducer **42a** via a line **146**. Module **144** puts out a signal in a line **148** proportional to the value of F_{co}/F_p . Line **116** supplies the signal from quench transducer **114** to a multiplication module **150**, which is also supplied with a signal proportional to the value of constant K_6. Module **150** puts out a signal proportional to the quantity K_6Q, in a line **152**.

Line **148** and **152** feed into a pair of sub-circuits indicated by reference numerals **154** and **156** which are marked t_1 and t_2, respectively. These sub-circuits **154** and **156** form part of the dynamics compensation model **20** shown in FIG. **1** and described above. The sub-circuits t_1, t_2, and t_3 described below, incorporate system time constants. As is known to those skilled in this art, a time constant is the time required for an output variable to reach approximately 63 percent of its final steady state value following a change in an input variable of the system. The value of about 63 percent used in the definition of time constants generically flows from the mathematical derivation of time constants, which derivation is a known mathematical fact and is not pertinent here.

Without the two sub-circuits t_1 and t_2, and the third sub-circuit t_3, described below, the circuitry shown in FIG. **3** would be equivalent to the steady state model **16**. A steady state model cannot in and of itself be used to control the process which it models because it will show what is at any given moment then occurring in the process but makes no compensation or allowance for the various dead, lead and lag times existing in and around the process. For example, referring to FIG. **2**, the total quench flow to the process is measured in the orifice and transducer **114** in line **104**. A certain finite length of time must elapse before the reaction zones in hydrocracker **26** experience any effect from that flow, since it takes that period of time for the quench material to travel from the orifice **114** to and through the reaction zone. Similarly, the quantity of total feed detected in orifice **34***a* will not arrive at the reaction zone for a different finite period of time which is equal to the time required for that material to travel throughout the system to the hydrocracker. In order to control the process, the control signals must accommodate or correct for these periods of time. If corrections were based on steady state conditions only, corrections would be applied too early, that is, before the conditions necessitating the corrections are being experienced by the process.

Referring back to FIG. **3**, the two sub-circuits **154** and **156** lag the feed composition signal in line **148** and the quench flow rate signal in line **152** in accordance with the dynamic characteristics of these two process variables. It will, of course, be understood that after continuous operation is established, there will always be a signal present in lines **158** and **160**, and that those signals will be proportional to feed composition and quench then entering the process, respectively.

The sub-circuits **154** and **156**, and sub-circuit t_3 described below, are built around a number of integrators equal to the order, first derivative, second derivative, etc., of the dynamic lag, plus adjusting devices such as potentiometers, in the conventional manner.

Referring to equation 1 above, and FIG. 3, the right hand side of said equation is computed as follows. Line **140** feeds a signal proportional to the value of the quantity K_8F_T into a logarithmic multiplier **162** in which a signal proportional to constant K_7 is raised to the K_8F_T power. Line **64** connects to multiplication module **164** which is also supplied with a signal proportional to K_9. The output of module **162** in line **166**, and the output of module **164** in line **168** are both fed to a subtracting module **170** which puts out a signal in line **172**. Line **130** supplies a signal proportional to the quantity $K_{10}\Delta T$ to a multiplication module **174** which is also supplied by line **172**. Line **160** feeds a signal proportional to the quantity K_6Q with dynamic compensation, to an addition module **176**, which is also fed by a line **178** carrying the output signal from multiplication module **174**. The output of addition module **176**, representing the entire right hand side of the conversion per pass equation 1 above, is present in a line **180** which is one input to a multiplication module **182**.

The left hand side of equation 1 is computed as follows. Line **138** feeds a signal proportional to the quantity K_1F_T to a logarithmic multiplication module **184** which is also supplied with a signal proportional to K_3. The output signal of module **184** is fed by a line **186** to a multiplication module **188**. Line **158** feeds a signal proportional to the delayed value of F_{co}/F_p to module **188**, which is also supplied with a signal proportional to the constant K_2. The output of module **188**, proportional to the quantity $K_2\overline{(F_{co}/F_p)}\,\overline{(K_1F_{TT})}K_3$ is present in a line **190**. Line **158** carrying the feed composition signal with dynamic compensation is also connected to a multiplication module **192** which is supplied with a signal proportional to the constant K_5. It will be noted that, as explained above, certain connecting lines in the circuit have been omitted for the sake of clarity.

The output of module **192** is carried by a line **194** to a logarithmic multiplication module **196** which is also fed by line **138**. The output signal of module **196** is carried by a line **198** to a multiplication module **200** which is also fed by line **158** carrying the feed composition signal, line **64** carrying the inlet temperature signal, and a signal proportional to the value of constant K_4. The output of multiplication module **200** representing the quantity

$$K_4(F_{co}/F_p)\,(T_1)\,(K_1F_T)^{K_5\left(\frac{F_{co}}{F_p}\right)}$$

is delivered by a line **202** to a subtracting module **204** which is also fed by line **190**. The output of module **204** is fed by a line **206** to a multiplication module **208** which is also supplied with a total feed signal via line **138**. The output of module **208**, representing a signal proportional to the entire left hand side of equation 1, is fed by a line **210** to multiplication module **182**. Multiplication module **182** multiplies the signal in line **180** proportional to the right hand side of the equation with the signal in line **210** proportional to the left hand side of the equation, and produces an output signal proportional to conversion per pass, including the dynamic corrections on the feed composition and the quench, in a line **212**. The signal in line **212** is fed to a circuit component **214**, which acts essentially like a subtracting module. Component **214** subtracts a signal marked "C/P SET POINT" and the signal in line **212** to arrive at the correction signal required to bring conversion per pass in the reactor to the value set by the operator on component **214**. This signal is fed by a line **216** to a multiplication module **218**. Line **64** feeds a signal proportional to the inlet temperature into a sub-circuit **221**, (t_3), the output of which is fed by a line **223** to multiplication module **218**. Because of the specific nature of the process that CONTRAST controls, there is no computer control of the hydrocracker inlet temperature. However, in accordance with the discussion above, the inlet temperature has a large effect on the temperature pattern or profile within the hydrocracker **26**, and it must be compensated for dynamically. A finite period of time coupled with the real time for the dynamic characteristic to expire is required for the effect of an inlet temperature perturbation to have any effect on hydrocracker **26**. Hence, it is necessary to dynamically compensate for changes in inlet temperature, and this is accomplished by sub-circuit **221**, t_3.

The final correction signal is fed from module **218** via a line **225** to finally branch off into the lines **118**, **120**, **122** and **124** shown in FIG. **2** and described above, to control the process.

Referring now to FIG. **4**, the interfacing between the control computer of the invention and the process is shown in schematic form as applied to one control point. The novel interfacing means and techniques of the invention yields several advantages over prior known means of and techniques for interconnecting a controller with a process to be controlled. One prior known method is to simply use the control signal from the computer, appropriately scaled of course, to directly operate a valve or the like which controls a particular variable. There are several disadvantages to this and all other forms of direct control. In case of malfunction of the computer, the process valve or the like will either remain open, or, under the control of a safety device, automatically go to a closed position, both of which are highly disruptive to the process. Another disadvantage is that many kinds of direct control are not easily overridden manually. According to the interfacing of the invention, the prior control means are retained, and additional means are provided to override the control signal from the computer, if desired, and also to provide an automatic return to manual control and automatic cutting out of the computer in the event of computer malfunction.

The portion of the showing of FIG. **4** enclosed in the dotted line box indicated by reference numeral **350** represents a conventional control loop. A process stream flows in a line **352** which contains a measuring transducer **354**. The transducer **354** may be a pressure sensing device, a flow rate orifice, a temperature detector, or any other suitable type in accordance with what particular characteristic of the flow stream is control control the operation of the valve or other controller **356**. Reference numeral **358** indicates the conventional analog control means, which operates the valve **356** through a line **360** in accordance with the signals received from transducer **354** through a line **362**, and further in accordance with a set point in the "manual setting" portion **358*a*** of device **358**. Portion **358*a*** is operated by hand in conventional usage. However, it will be understood by those skilled in this art that "-manual setting" portion **358*a*** is suitably modified so that it may be operated by the control signal in line **370**. For example, assuming that boxed portion **350** is a flow recorder controller (FRC), transducer **354** would then be a flow measuring orifice, and valve **356** would be a true valve. A certain desired flow rate would be set on portion **358*a***, and device **358** will operate valve **356** so as to maintain a flow in line **352** equal to the flow rate set on portion **358*a***. The same reasoning is applied if it were desired to heat or cool the fluid, control its pressure, or the like, as will be obvious to those skilled in this art.

According to the invention, this standard loop is retained, thereby providing a complete "back-up" system in the event the automatic computer control is removed from service. That is, the refinery operator always has the option of returning to the conventional control system. The interfacing of the invention comprises this conventional loop in combination with an adding relay **364** interposed between the computer and the existing process control **350** in such a manner as to both permit manual override and to cause automatic computer cutout and reversion to manual control in the event of computer failure.

A manual load station **366**, including an adjustable element **366**a, is joined to adding relay **364** by a line **368**. A line **370** interconnects the output side of adding relay **364** to control device **358**. Control computer **22** is connected to adding relay **364** by a pair of lines **372** and **374**, each of which carries a different signal and includes automatic cutout means **372*a*** and **374*a***, respectively. The cutout means **372*a*** and **374*a*** are chosen in accordance with the control medium. That is, if a pneumatic control system is used, the cutout means **372*a*** and **374*a*** will comprise pneumatic relief valves which will cause venting to atmosphere in the event of either no signal or an excessive signal from the computer. If the control system is electrical, the cutout means **372*a*** and **374*a*** will comprise solenoid relays or the like set to open the line in the event of no signal or an excessive signal from the computer. Other equivalent devices are available to match any other control medium.

Adding relay **364** operates in accordance with the equation, $Z=A-C+B$, wherein A is a control signal from computer **22** present in line **372**, C is a constant or scaling factor signal from the control computer **22** present in line **374**, B is a signal proportional to the set value on manual setting device **366** present in line **368**, and Z is the output control signal from in signal relay

364 present in line 370. During normal operation, at any one particular time, signals *C* and *B* will be constant, and the process will respond directly to changes in signal *A* from control computer 22, i.e., the process will operate under computer control. If it is desired to override the computer signal during normal operation, signals *A* and *C* will be neutralized, by manual operation of devices 372*a* and 374*a* or by other means not shown, and the process will respond directly to changes in signal B from the manual load station. In the event of a failure in computer 22 or associated equipment, devices 372*a* and 374*a* will automatically operate causing signals *A* and *C* to go to zero, leaving the process directly under the control of signal B from manual load station 366. In the event of such a failure, it will of course be understood that other warning devices such as lights and/or bells and the like will become activated, none of which warning means are shown for the sake of clarity.

For example, in the successfully built embodiment of the invention, a pneumatic control medium is utilized, and adding relay 364 is pneumatic and available from the Foxboro Company of Foxboro, Massachusetts, and is known as their model number M/56.

The above example illustrates the interfacing methods and apparatus of the invention with a simple single conventional control loop. More sophisticated control arrangements, such as two or more control loops arranged in cascade, or control arrangements which anticipate and implement necessary corrections to accommodate time lags or the like, may also be incorporated by the interfacing of the invention. Such sophisticated control arrangements are easily coupled with certain minor re-arrangements of components which are obvious to one skilled in this art.

In order to establish the validity of model 12, a commercial furnace oil hydrocracker (F.O.H.C.) was run and data was collected during the run. Later, the measured data for inlet bed temperatures and feed stock only were fed into an appropriately modified model 12 and by running said model 12 all of the other data shown in FIGS. 8 and 9 were generated and certain of them compared to certain other of the measured data.

The two curves of FIGS. 5 and 6 differ in that in the family of curves of FIG. 5 the two compressors that provide the gas which is used for recycle and for quench were both used, and only one of these compressors was used in the FIG. 6 curves to illustrate reactor conditions if one of the compressors should be taken off line for repair, or to simulate a breakdown, or the like. Thus, proving of model validity was accomplished at both normal operating conditions, and at the abnormal condition wherein only half compressor capacity is available.

Referring now to FIG. 5 in detail, the three curves are all plotted against reactor length on the x-axis, and each against its own operating variable on the y-axis. The lowermost curve 222 represents weight flow in pounds of hydrogen quench per pound of reactor inlet fluid plotted against reactor length as a fraction of the entire reactor length. The step-like curve 222 shows the quench rates predicted as being required by the hydrocracker in order to maintain the desired conversion per pass. The points 224 marked with "x's" represent measured quench rates, it being understood that the vertical distances between any two *x's* represent the amount of quench added at that particular point. It is noteworthy that the predicted curve passes substantially exactly through all of the measured points.

Curve 226 next above curve 222 charts conversion per pass (C/P). For the particular run used for FIG. 5, the final conversion happened to be 69.4 percent. This value was determined by laboratory analysis of samples collected during the test run of the commercial F.O.H.C. Model 12 indicated a conversion of 69.4 percent. The remainder of curve 226 shows intra-reactor conversion data. These data are difficult to collect in a commercial installation, and therefore are not ordinarily measured, but are easily produced by model 12, and are of both general interest and of particular interest as an intermediary step in the generation of both models 12 and 16.

Uppermost curve 228 charts inlet and outlet bed temperatures within the reactor. The inlet temperature points for each catalyst bed, indicated by circles 230, were preset and were one of the two inputs to model 12. The outlet bed temperatures indicated by squares 232 are the points which were measured. The curve 228 was predicted by model 12, and, of course, passes through preset points 230, but, significantly, also passes very accurately through the observed outlet temperatures 232.

The curves in FIG. 6 are quite similar to those of FIG. 5 with the exception that the test run on which the FIG. 6 curves are based was run with only half compressor capacity, as explained above. All curves were plotted against the same response variables and against fraction of reactor length as in the case of FIG. 5, and therefore, similar curves and points in FIG. 6 are indicated by the same reference numerals used in FIG. 5 followed by "a". It is noteworthy that measured conversion, which in the case of the test run on which FIG. 6 was based was 70 percent, corresponded to the model 12 indicated conversion, also 70 percent, despite the extraordinary reactor condition of half compressor capacity.

Thus, the ability of highly detailed and generalized model 12 to predict significant variable responses of a highly complex chemical process is verified by the close correspondence of the measured data to the predicted data, under varying conditions, as shown by the families of curves of FIGS. 5 and 6. Further, model 12 yields other data, such as intra-reactor conversion levels, and other data not shown, which are otherwise unavailable or at least extremely difficult and expensive to obtain.

The validity of model 22 was proved after the analog computer embodying it was installed in a refinery to control the hydrocracker for which it was built. The following table shows the correlation:

COMPARISON OF CONVERSIONS CONTRAST — LABORATORY ANALYSIS

Total hydrocracker feed rate	cycle oil feed rate	conversion by laboratory analysis	conversion per CONTRAST	conversion difference: CONTRAST minus analysis
H	H	71.0	71.4	+.4
H	H	69.5	69.6	+.1
M	M	70.5	72.0	+1.5
L	O	67.5	67.5	0
L	O	65.5	64.7	−.8

L	O	65.5	67.3	+1.8
L	O	66.5	68.0	+1.5
H	O	70.0	70.3	+.3
H	O	70.5	69.5	−1.0
H	O	70.0	69.4	−.6
H	O	69.0	69.8	+.8

H = High or design feed rate
M = Intermediate feed rate
L = Low or half design feed rate
O = No feed

From the above, it can be seen that the largest absolute difference between the conversion per pass determined by CONTRAST and the conversion per pass by laboratory analysis was 1.8 percent. Allowable error in the laboratory analysis is ± about 2 percent. Thus, the accuracy of the invention can be considered identical to the accuracy of the laboratory technique, since it is within the allowable error of he laboratory technique. Another noteworthy point is that the difference in conversion per pass runs both plus and minus, which is deemed desirable in that the error tends to cancel. Further, totaling and averaging the **11** difference figures, in absolute terms without regard to sign, the average difference comes out to 0.8 percent.

An important advantage of the control computer of the invention is its ability to maintain a constant conversion level despite severe process input variable changes. Referring to FIG. **7**, curve **280** shows a very sharp and severe change in feed composition. As explained above, the total feed is made up of virgin material, cycle oil, and recycle material, and the feed composition could have a large effect on conversion level, if uncorrected, because of the difference in aromatics content in the cycle oil and the virgin material, and the effect that difference has on temperature patterns in the reactor.

The test was performed by applying a step change from zero cycle oil to about 5.5 percent cycle oil as a percent of total flow, substantially instantaneously. The total feed rate was held constant while the step change was made by means of other adjustments around the reactor. The curve **282** is the recorded conversion level over an **8** hour period including the slightly less than **3** hour period that the reactor experienced the step change in feed composition. Curve **284** represents the temperature difference across the reactor over this same period. It is noteworthy that conversion remained within in the range of from about 70 percent to about 72 percent during this entire time, which represents a change of plus or minus 1 percent form the 71 percent set point. The temperature difference curve **284** varied slightly more, but it is significant that despite the step change in feed composition and the fact that the temperature difference also varied during this time, still conversion was held to plus or minus 1 percent of the set value.

Another important advantage of the control computer of the invention is the speed with which it will bring the controlled output variable, conversion per pass in the case of the hydrocracker described, back to the set level. Referring to FIG. **8**, the uppermost curve **300** represents a sharp perturbation in an input variable, for example, feed rate, feed composition, or inlet temperature. The other two curves **302** and **304** represent the conversion response to the same perturbation, to the same vertical scale under conventional control, curve **304**, and under "CONTRAST" control, curve **302**. In both cases, conversion per pass does not

return to the set level until sometime after the end of the input variable perturbation, the point marked **306** on curve **300**. The time for the input variable to experience the perturbation was slightly less than 10 minutes. The time for conversion to return to the preset level when the process was under the control of the invention, was substantially the same, **10** minutes. Referring to curve **304**, it can be seen that under conventional control about **24** hours elapsed before conversion could be brought back to the preset level. The swings in conversion level during the perturbation in curve **304**, are substantially negligible, i.e., conversion experienced no effect, for all practical purposes, as a result of the input variable perturbation. On the other hand, under conventional control, conversion experienced a substantial change with relatively wide swings, and went through a long period of instability before returning to the set level. The lack of conversion stability causes a reduction in product selectivity and quality. Thus, substantially eliminating instability in the critical output variable in response to changes in input variables results in a substantial economic advantage for the method and apparatus of the invention.

While the invention has been described in detail above, it is to be understood that this detailed description is by way of example only, and the protection granted is to be limited only within the spirit of the invention and the scope of the following claims.

We claim:

1. A method of automatically and continuously controlling an output response variable of a chemical process that is housed in a vessel and is characterized by a substantial exchange of heat and no substantial unaccountable heat loss from the vessel, comprising the steps of continuously measuring the values of a plurality of critical input variables of said process in real time, continuously generating a first signal representative of a combined value of a first combination of values of said critical input variables in said plurality of critical input variables, continuously generating a second signal representative of a combined value of a second combination of values of said critical input variables in said plurality of critical input variables, continuously generating a third signal indicative of said output response variable from said first and second signals in real time, continuously comparing said third signal to a signal proportional to a predetermined value of said output response variable to generate a correction signal in real time, and utilizing said correction signal to control said output response variable by adjusting at least one of said critical input variables to thereby cause said process to operate at said predetermined value of said output response variable.

2. The method of claim **1**, wherein said chemical process is a hydrocracker and said output response variable is conversion per pass.

3. The method of claim **2**, the feed to said process consisting of a plurality of feed stocks, said plurality of critical input variables consists of the percentage of said feed stocks in total feed, total feed rate, total quench flow rate, and inlet and outlet temperatures, said first combination of critical input variables consisting of the percentage of said feed stocks in total feed, said total feed rate and said inlet temperature, and said second combination of said critical input variables consisting of said quench, said inlet temperature, said total feed rate, and the difference between said inlet and outlet temperatures.

4. The method of claim 1, wherein said at least one of said critical input variables is total quench flow rate.

5. In combination, a continuous chemical process that is housed in a vessel, which process produces a temperature gradient therein, and includes means to prevent any unaccountable substantial heat loss from the vessel, a special purpose analog computer, means to feed signals to said computer proportional to the values of selected critical input variables of said chemical process in real time, said computer comprising means to determine present value of a selected output response variable of said process in real time from said signals and means to generate a correction signal from said present value and a signal proportional to a pre-set value of said selected output response variable, and means to feed said correction signal to said process to control at least one of said critical input variables to cause said process to operate at said pre-set value of said selected output response variable.

6. The apparatus of claim 5, wherein said chemical process is a hydrocracking process, said selected input variables comprising total feed rate, inlet and outlet temperatures, and total quench flow rate, and said selected output response variable comprising conversion per pass.

7. The apparatus of claim 6, the feed to said process consisting of a plurality of feed stocks, said selected input variables further comprising the percentage of said feed stocks in the total feed.

8. A method of interfacing a closed loop process controller comprising process variable control means and a control device for operating said process variable control means with a control computer by the use of an adding relay, comprising the steps of continuously generating a first signal in said computer proportional to the desired value of the setting of the variable control means in the control loop, continuously generating a second scaling signal in said computer, continuously generating a third signal in manual setting means proportional to a predetermined value of the process variable controlled by said control loop, feeding said first, second, and third signals to said adding relay to continuously generate a fourth signal proportional to and scaled to the computer determined value of the process variable being controlled, and feeding said fourth signal from said adding relay to the control device in said control loop.

9. In combination an analog control computer a preexisting control loop comprising process variable control means and a control device adapted to operate said process variable control means, an adding relay, means to feed a first control signal and a second scaling signal from said computer to said adding relay, means to feed a third signal proportional to a predetermined set-point of the process variable controlled by said control loop to said adding relay, means to feed a fourth signal from said adding relay to the control device in said control loop, said fourth signal being generated in accordance with the relationship, $Z=A-C+B$, wherein A represents said first signal, C represents said second signal, B represents said third signal, and Z represents said fourth signal.

10. The apparatus of claim 9, said signal feeding means for said first and second signals including automatic cut-out means adaptable to nullify the effect of said first and second signals in the event of failure of said computer, whereby such a failure will cause minimal disruption of the process by causing said process variable to automatically come under the control of said third signal.

11. The apparatus of claim 10, wherein a pneumatic control medium is utilized, said cut-out means comprising pneumatic relief valves adapted to automatically vent the pneumatic pressure in the lines carrying said first and second signals to atmosphere in the event of failure of said computer.

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