

METHODS FOR OPERATING CONTINUOUS CATALYTIC REFORMER UNITS**CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims priority to U.S. Provisional Application No. 63/509,618, filed June 22, 2023, and to U.S. Non-Provisional Application No. 18/462,068, filed September 6, 2023, the entire contents of both of which are hereby incorporated in their entirety.

TECHNICAL FIELD

[0002] Embodiments of the present disclosure generally relate to chemical processing and, more specifically, to processes and systems for reforming hydrocarbon materials.

BACKGROUND

[0003] Catalytic reforming is a chemical process that can be utilized to convert refined hydrocarbons, such as naphtha streams distilled from crude oil, into higher-octane rated products sometimes called reformates. Such reformates may be utilized as gasoline. As there is great demand for gasoline and other products from reformates, improved methods for operating reformer units is desired in the industry.

SUMMARY

[0004] According to one or more embodiments, a method for operating a continuous catalytic reformer unit may comprise passing a hydrocarbon reactant stream to a continuous catalytic reformer unit to form one or more product effluent streams, the continuous catalytic reformer unit comprising at least one stream pre-heater, at least one catalytic reactor, and at least one separation unit; implementing a hydrocarbon reformer process control system comprising a hydrocarbon reformer variable data memory comprising processor-executable instructions, a hydrocarbon reformer output translation module, and one or more predictive hydrocarbon reformer modeling processors configured to execute the processor-executable instructions and cause the process control system to: receive one or more signals indicative of one or more present state variables from one or more state variable actuator hardware, wherein the present state variables are process variables that cannot be directly set in the continuous catalytic reformer unit;

and receive one or more signals indicative of one or more present control variables of the continuous catalytic reformer unit from one or more control variable actuator hardware, wherein the present control variables are process variables that can be directly set in the continuous catalytic reformer unit; and generate, by utilizing a machine learned model, an improved control variable that increases a selected performance variable based on the inputs of one or both of one or more present state variables or one or more present control variables, wherein the improved control variable wherein the machine learned model is trained utilizing inputs of at least historic state variable data, historic control variable data, and historic performance variable data; and adjusting one or more present control variables of the continuous catalytic reformer unit based on the improved control variable determined by the machine learned model.

[0005] Additional features and advantages of the described embodiments will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the described embodiments, including the detailed description which follows, the claims, as well as the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The following detailed description of specific embodiments of the present disclosure can be best understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

[0007] FIG. 1 is a generalized schematic diagram of a continuous catalytic reformer unit, according to one or more embodiments described in this disclosure;

[0008] FIG. 2 schematically depicts a machine learned model utilized in the operation of a continuous catalytic reformer unit, according to one or more embodiments described in this disclosure; and

[0009] FIG. 3 depicts an example model produced using a machine learned model utilized in the operation of a continuous catalytic reformer unit, according to one or more embodiments described in this disclosure.

[0010] For the purpose of describing the simplified schematic illustrations and descriptions of the relevant figures related to chemical processing systems, the numerous valves, temperature sensors, electronic controllers and the like that may be employed and well known to those of

ordinary skill in the art of certain chemical processing operations are not included. Further, accompanying components that are often included in typical chemical processing operations, such as air supplies, catalyst hoppers, and flue gas handling systems, are not depicted. Accompanying components that are in hydrocracking units, such as bleed streams, spent catalyst discharge subsystems, and catalyst replacement sub-systems are also not shown. It should be understood that these components are within the spirit and scope of the present embodiments disclosed. However, operational components, such as those described in the present disclosure, may be added to the embodiments described in this disclosure.

[0011] It should further be noted that relevant arrows in the drawings may refer to process streams. However, the arrows may equivalently refer to transfer lines which may serve to transfer process streams between two or more system components. Additionally, arrows that connect to system components define inlets or outlets in each given system component. The arrow direction corresponds generally with the major direction of movement of the materials of the stream contained within the physical transfer line signified by the arrow. Furthermore, arrows which do not connect two or more system components signify a product stream which exits the depicted system or a system inlet stream which enters the depicted system. Product streams may be further processed in accompanying chemical processing systems or may be commercialized as end products. System inlet streams may be streams transferred from accompanying chemical processing systems or may be non-processed feedstock streams. Some arrows may represent recycle streams, which are effluent streams of system components that are recycled back into the system. However, it should be understood that any represented recycle stream, in some embodiments, may be replaced by a system inlet stream of the same material, and that a portion of a recycle stream may exit the system as a system product.

[0012] Additionally, arrows in the drawings may schematically depict process steps of transporting a stream from one system component to another system component. For example, an arrow from one system component pointing to another system component may represent “passing” a system component effluent to another system component, which may include the contents of a process stream “exiting” or being “removed” from one system component and “introducing” the contents of that product stream to another system component.

[0013] It should be understood that according to the embodiments presented in the relevant figures, an arrow between two system components may signify that the stream is not processed between the two system components. In other embodiments, the stream signified by the arrow

may have substantially the same composition throughout its transport between the two system components. Additionally, it should be understood that in one or more embodiments, an arrow may represent that at least 75 wt.%, at least 90 wt.%, at least 95 wt.%, at least 99 wt.%, at least 99.9 wt.%, or even 100 wt.% of the stream is transported between the system components. As such, in some embodiments, less than all of the streams signified by an arrow may be transported between the system components, such as if a slip stream is present.

[0014] It should be understood that two or more process streams are “mixed” or “combined” when two or more lines intersect in the schematic flow diagrams of the relevant figures. Mixing or combining may also include mixing by directly introducing both streams into a like reactor, separation device, or other system component. For example, it should be understood that when two streams are depicted as being combined directly prior to entering a separation unit or reactor, that in some embodiments the streams could equivalently be introduced into the separation unit or reactor and be mixed in the reactor.

[0015] Reference will now be made in greater detail to various embodiments, some embodiments of which are illustrated in the accompanying drawings. Whenever possible, the same reference numerals will be used throughout the drawings to refer to the same or similar parts.

DETAILED DESCRIPTION

[0016] Described herein are methods of operating continuous catalytic reformer units (sometimes referred to herein as “CCR” units) that process hydrocarbon reactant streams, such as those that convert naphtha into product effluent streams, such as reformates. Such continuous catalytic reformer units may utilize hydrocarbon reformer process control systems that may predict system attributes of the continuous catalytic reformer units by use of machine learned models, as is described in detail herein. Specifically, the continuous catalytic reformer units described herein may be operable to generate an improved control variable based on a machine learned model developed from at least historic control variable data and historic state variable data. Based on the model, the continuous catalytic reformer units may be adjusted such that the present control variable is adjusted to the generated improved control variable.

[0017] As described herein, continuous catalytic reformer units generally process a hydrocarbon reactant stream into one or more product streams that may be further processed or collected as a product to use. For example, continuous catalytic reformer units may utilize naphtha streams or straight run gasolines as reactant streams, and may generally improve the octane rating

of such reactant stream. Reforming, the process performed in the continuous catalytic reformer unit, in general, may be defined as the total effect of the molecular changes (i.e., hydrocarbon reactions) produced by, for example, the dehydrogenation of cyclohexanes, dehydroisomerization of alkylcyclopentanes, and dehydrocyclization of paraffins and olefins to yield aromatics; isomerization of n-paraffins; isomerization of alkylcycloparaffins to yield cyclohexanes; isomerization of substituted aromatics; and/or hydrocracking of paraffins which produces gas, and coke. Catalytic reforming utilizes a catalyst. Some such catalysts may include a metal hydrogenation-dehydrogenation (hydrogen transfer) component, or components, sometimes platinum, substantially atomically dispersed on the surface of a porous, inorganic oxide support, such as alumina. The support, which typically contains a halide, particularly chloride, may provide the acid functionality that is functional for isomerization, cyclization, and hydrocracking reactions.

[0018] As used in this disclosure, a “catalyst” refers to any substance that increases the rate of a specific chemical reaction. Catalysts described in this disclosure may be utilized to promote various reactions, such as, but not limited to, dehydrogenation, dehydroisomerization, isomerization, and hydrocracking. As used in this disclosure, “cracking” generally refers to a chemical reaction where carbon-carbon bonds are broken. For example, a molecule having carbon to carbon bonds is broken into more than one molecule by the breaking of one or more of the carbon to carbon bonds, or is converted from a compound which includes a alkyl or cyclic moiety, such as a alkane, cycloalkane, naphthalene, an aromatic or the like, to an olefinic compound and/or a compound which does not include a cyclic moiety or contains fewer cyclic moieties than prior to cracking.

[0019] Now referring to FIG. 1, a continuous catalytic reformer unit 100 is depicted that generally includes a chemical processing portion 104 (including all of the chemical processing parts of the continuous catalytic reformer unit 100) and a hydrocarbon reformer process control unit 200. It should be understood that other continuous catalytic reformer units may be utilized in the processes presently disclosed, and that the continuous catalytic reformer unit 100 of FIG. 1 is an example continuous catalytic reformer unit.

[0020] The chemical processing portion 104 of the continuous catalytic reformer unit 100 may generally comprise a stream pre-heater 110, a catalytic reactor 130, and a separation unit 150. The continuous catalytic reformer unit 100 of FIG 1 includes two stream pre-heaters 110 and two catalytic reactors 130, arranged alternating series. Specifically, the continuous catalytic reformer

unit 100 includes a first grouping 180 of a stream preheater 110 and a catalytic reactor 130, following by a second grouping 182 of another stream preheater 110 and catalytic reactor 130. It is contemplated that additional groupings of stream preheaters 110 and a catalytic reactors 130 may be included in continuous catalytic reformer units 110, such that three, four, five, or even more stream pre-heaters 110 and catalytic reactors 130 may be present (but only two groupings are depicted in FIG. 1).

[0021] As used in this disclosure, a “reactor” such as the catalytic reactor 100, refers to a vessel in which one or more chemical reactions may occur between one or more reactants optionally in the presence of one or more catalysts. For example, a reactor may include a tank or tubular reactor configured to operate as a batch reactor, a continuous stirred-tank reactor (CSTR), or a plug flow reactor. Example reactors include packed bed reactors such as fixed bed reactors, and fluidized bed reactors. One or more “reaction zones” may be disposed in a reactor. As used in this disclosure, a “reaction zone” refers to an area where a particular reaction takes place in a reactor. For example, a packed bed reactor with multiple catalyst beds may have multiple reaction zones, where each reaction zone is defined by the area of each catalyst bed.

[0022] As used in this disclosure, a “separation unit” such as the separation unit 150 refers to any separation device or system of separation devices that at least partially separates one or more chemicals that are mixed in a process stream from one another. For example, a separation unit may selectively separate differing chemical species, phases, or sized material from one another, forming one or more chemical fractions. Examples of separation units include, without limitation, distillation columns, flash drums, knock-out drums, knock-out pots, centrifuges, cyclones, filtration devices, traps, scrubbers, expansion devices, membranes, solvent extraction devices, and the like. It should be understood that separation processes described in this disclosure may not completely separate all of one chemical constituent from all of another chemical constituent. It should be understood that the separation processes described in this disclosure “at least partially” separate different chemical components from one another, and that even if not explicitly stated, it should be understood that separation may include only partial separation. As used in this disclosure, one or more chemical constituents may be “separated” from a process stream to form a new process stream. Generally, a process stream may enter a separation unit and be divided, or separated, into two or more process streams of desired composition. Further, in some separation processes, a “lesser boiling point fraction” (sometimes referred to as a “light fraction”) and a “greater boiling point fraction” (sometimes referred to as a “heavy fraction”) may

exit the separation unit, where, on average, the contents of the lesser boiling point fraction stream have a lesser boiling point than the greater boiling point fraction stream. Other streams may fall between the lesser boiling point fraction and the greater boiling point fraction, such as an “intermediate boiling point fraction.”

[0023] According to embodiments of FIG. 1 described herein, a hydrocarbon reactant stream 102 may be passed to the continuous catalytic reformer unit 100. Hydrogen 190 may be mixed with the hydrocarbon reactant stream 102 prior to being passed to the continuous catalytic reformer unit 100. Specifically the hydrocarbon reactant stream 102, mixed with hydrogen 190, may be passed to the stream preheater 110 of the first grouping 180. The stream preheater 110 may generally heat the contents of the hydrocarbon reactant stream 102. Heating in the stream preheater 110 may be accomplished by a variety of methods, such as the combustion of hydrocarbon fuels, or by heat exchange with other medium. For example, a fuel gas may be burned in the stream preheater 110 to heat the hydrocarbon reactant stream 102.

[0024] The heated hydrocarbon reactant stream 102 may exit the stream preheater 110 as a heated reactant stream 112 and be passed to the catalytic reactor 130. In the catalytic reactor 130, the heated reactant stream 112 is contacted by a catalyst and the heated reactant stream 112 undergoes one or more reactions to form the intermediate catalytic reactor effluent stream 132. As shown in FIG. 1, the intermediate catalytic reactor effluent stream 132 may be passed to another stream preheater 110, and subsequently to another catalytic reactor 130 (shown as the second grouping 182 of stream preheater 110 and catalytic reactor 130). That is, the intermediate catalytic reactor effluent stream 132 may be heated in the stream preheater 110 to form a heated catalytic reactor effluent stream 114, and the heated catalytic reactor effluent stream 114 may be passed to a catalytic reactor 130 and reacted by contact with catalyst in the catalytic reactor 130 of the second grouping 182 to form a final catalytic reactor effluent stream 134.

[0025] Still referring to FIG. 1, the catalyst may generally be passed through the one or more catalytic reactors 130, where it contacts the feed material such as the heated reactant stream 112 or the heated catalytic reactor effluent stream 114. In the embodiments described herein, the catalytic reforming unit is a “continuous” catalytic reforming unit 100, meaning that that one or more catalytic reactors 130 are moving-bed reactors, as opposed to fixed-bed reactors, with continuous addition and withdrawal of catalyst. As shown in FIG. 1, the catalyst may circulate via catalyst streams 172, 174, 176 between catalytic reactors 130 and a catalyst regenerator 170. The catalyst regenerator 170 may remove coke from the catalyst, which may form in the reactions in

the catalytic reactors 130. Additionally, the catalyst may be treated with chloride via stream 192 to re-chlorinate the catalyst, which may lose chloride over time. While the scheme depicted in FIG. 1 is that of a catalyst that circulates between two catalytic reactors 130 before being returned to the catalyst regenerator 170, other configurations are contemplated, such as where catalyst is only circulated through a single catalytic reactor 130 before being returned to the catalyst regenerator 170.

[0026] According to embodiments, the reactions taking place in the one or more catalytic reactors 130 may include dehydrogenation of naphthenes, isomerization of naphthenes, and/or dehydrocyclization of paraffins. Dehydrogenation of naphthenes may generally refer to a reaction that is rapid and very endothermic. It may be promoted by a metal catalyst function and may be favored by high temperature and low pressure. Naphthenes are typically the most desirable feed components because in addition to being easy to promote they may produce by-product hydrogen as well as the aromatic hydrocarbon. Isomerization of naphthenes generally includes isomerization involves ring rearrangement and the probability of ring opening to form paraffins may be relatively high. Paraffins dehydrocyclization may generally refer to a very endothermic reaction and, due to its relative low rate, operating conditions typically may be more severe for this reaction to occur, resulting in increased coke formation. The paraffin cyclization step may become easier as the molecular weight of the paraffin increases. Dehydrocyclization may be favored by low pressure and high temperatures, and both metal and acid catalyst functions are typically needed to promote this reaction.

[0027] According to one or more embodiments, the final catalytic reactor effluent stream 134 may be passed to a separation unit 150, where the contents of the final catalytic reactor effluent stream 134 are separated into multiple product effluent streams 160. The product effluent streams 160 may include an off-gas 152, a hydrogen-rich gas stream 154, an LPG stream 156, and a reformate stream 158. The various product effluent streams 160 may be passed to downstream processing units and further processed, or may be pooled as final products for sale and distribution. For example, the off-gas 152 may be passed to a fuel gas network for use as fuel gas as a heat input, the hydrogen-rich gas stream 154 may be utilized in pressure swing adsorption (“PSA”) processing, isomerization processing, and/or naphtha hydrotreating (“NHT”), the LNG 156 may be passed to liquefied natural gas (“LNG”) storage, and/or the reformate stream 158 may be passed to a gasoline blending pool.

[0028] Now that the chemical processing portion 104 has been described in detail, it should be appreciated that the continuous catalytic reformer unit 100, in operation, may include numerous “state variables” and numerous “control variables.” As described herein, control variables are those variables that can be directly set in the continuous catalytic reformer unit 100. On the other hand, state variables are variables that cannot be directly set in the continuous catalytic reformer unit 100. For example, an operator of the continuous catalytic reformer unit 100 could directly set a control variable, such as the amount of catalyst passed to a certain catalytic reactor 130. However, a variable such as the pressure in a certain catalytic reactor 130 could not be directly set by an operator of the continuous catalytic reformer unit 100, and it is thus a state variable since there is not a direct input available to the system to control the pressure in a catalytic reactor 130. Said another way, control variables may be understood as inputs to the system that can be directly chosen by a plant operator or by the hydrocarbon reformer process control unit 200, and state variables are those that are a function of the various control variables of the continuous catalytic reformer unit 100 and are indirectly controllable by adjustment of control variables.

[0029] Without limitation, contemplated state variables in the continuous catalytic reformer unit 100 include catalyst activity, the average pressure of a catalytic reactor, reactor down time, product yield of reformate, product yield of hydrogen, product yield of off-gas, product yield of LPG, consumption of fuel-gas, consumption of cooling water, consumption of power, the temperature of a separation unit, or heat exchanger duty of the combined feed and effluent.

[0030] Additionally, without limitation, contemplated control variables in the continuous catalytic reformer unit 100 include the weighted average inlet temperature of the reactant stream, reactant stream feed rate, quality of reactant feed stream (e.g., the N+2A feed value, the initial boiling point, and the final boiling point), the chloride injection rate, average carbon burn rate in the catalyst regenerator 170, catalyst circulation rate, hydrogen/hydrocarbon ratio, and energy consumption in the stream preheater 110.

[0031] According to embodiments, both state variables and control variables may be monitored by one or more control variable monitoring hardware 232 and/or one or more state variable monitoring hardware 234, respectively. Additionally, control variables may be controlled by one or more control variable actuator hardware 236. Example positions of control variable monitoring hardware 232, state variable monitoring hardware 234, and control variable actuator hardware 236 are depicted in FIG. 1, merely by way of example, and these various sensors and actuators may be present in other positions in the continuous catalytic reformer unit

100, consistent with the herein description. None of the specifically depicted control variable monitoring hardware 232, state variable monitoring hardware 234, and control variable actuator hardware 236 should be construed as essential to the continuous catalytic reformer unit 100.

[0032] According to embodiments, generally, control variable monitoring hardware 232 and/or one or more state variable monitoring hardware 234 may be sensors specific to the type of variable being monitored (i.e., measured). For example, a control variable monitoring hardware 232 and/or one or more state variable monitoring hardware 234 related to pressure may be a pressure gage, and a control variable monitoring hardware 232 and/or one or more state variable monitoring hardware 234 related to temperature may be a thermometer. Likewise, the control variable actuator hardware may be any device specific to the type of variable controlled. For example, a control variable monitoring hardware 236 that controls flowrate may be an actuator on a valve that controls in flow rate. In some embodiments, a control variable monitoring hardware 232 and a control variable monitoring hardware 236 may be integrated, such as for a control variable of stream flowrate where a single integrated valve is capable of both monitoring and controlling flowrate and acts as both a control variable monitoring hardware 232 and a control variable actuator hardware 236. Specific equipment suitable for use a control variable monitoring hardware 232, a state variable monitoring hardware 234, and/or a control variable monitoring hardware 236 would be recognizable and selectable to those skilled in the art based on the particular control variable or state variable or its operation.

[0033] Still referring to FIG. 1, according to embodiments described herein, the continuous catalytic reformer unit 100 further comprises a hydrocarbon reformer process control system 200. The hydrocarbon reformer process control system 200 may generally interact with and, in some embodiments, directly control, the chemical processing portion 104. In one or more embodiments, the hydrocarbon reformer process control system 200 may comprise a hydrocarbon reformer variable data memory 210 that may comprise processor-executable instructions, and a predictive hydrocarbon reformer modeling processor 220 that may be configured to execute the processor-executable instructions. The hydrocarbon reformer process control system 200 may further include a hydrocarbon reformer output translation module 230. The hydrocarbon reformer variable data memory 210, the predictive hydrocarbon reformer modeling processor 220, and the hydrocarbon reformer output translation module 230 may be in communication as depicted in FIG. 1, where at least the hydrocarbon reformer variable data memory 210 is in direct communication with the hydrocarbon reformer process control system 200, and the predictive

hydrocarbon reformer modeling processor 220 is in direct communication with the hydrocarbon reformer output translation module 230.

[0034] As described herein, “present” control variables or “present” state variables are variables that are currently present in the continuous catalytic reformer unit 100, as opposed to “historic” state or control variable data, which is data from the past related to control variables and/or state variables. Generally, historic state or control variable data may be collected over a substantially long period of time, such that the data is suitable for use in a machine learned model, as described herein.

[0035] According to embodiments, the control variable monitoring hardware 232 may monitor any control variable of the chemical processing portion 104, and such data collected from the control variable monitoring hardware 232 may be passed to the process control unit 200, such that the process control unit 200 may receive, in real-time or in near real-time, one or more signals indicative of one or more present state variables. In such embodiments, the one or more control variable monitoring hardware 232 may be in communication with the hydrocarbon reformer variable data memory 210 via transmission modules, as depicted in FIG. 1, such as receiver module 272, which is in communication with the hydrocarbon reformer variable data memory 210. Similarly, the state variable monitoring hardware 234 may monitor any control variable of the chemical processing portion 104, and such data collected from the control variable monitoring hardware 232 may be passed to the process control unit 200, such that the process control unit 200 may receive, in real-time or in near real-time, one or more signals indicative of one or more present control variables. In such embodiments, the one or more state variable monitoring hardware 234 may be in communication with the hydrocarbon reformer variable data memory 210 via transmission modules, as depicted in FIG. 1, such as receiver module 274, which is in communication with the hydrocarbon reformer variable data memory 210. As described herein, for example, the control variable monitoring hardware 232 and/or the state variable monitoring hardware 234 may be thermometers, pressure gauges, valves, etc.

[0036] According to one or more embodiments, the hydrocarbon reformer variable data memory 210 stores data related to one or more of a machine learned model and/or present state variables and present control variables. The hydrocarbon reformer variable data memory 210 may be configured as any conventional or yet-to-be developed structure for storing sensor data, e.g., as a random access memory (RAM), a read only memory (ROM), data registers, a database, and/or other hardware for storing sensor data. The predictive hydrocarbon reformer modeling processor

220 represents hardware and software suitable for executing operations on the data obtained from at least the hydrocarbon reformer variable data memory 210 of the process control unit 200. More specifically, in one or more embodiments, the predictive hydrocarbon reformer modeling processor 220 may comprise specific software-based logic modules, such as, e.g., data collecting logic, modeling logic, etc., for generating, in real-time or near real-time, one or more improved control variables based on the inputs of a present state variable, a present control variable, and a selected performance variable. For example, the predictive hydrocarbon reformer modeling processor 220 may receive one or more present state variables and one or more present control variables from the hydrocarbon reformer variable data memory 210, and receive a selected performance variable from the hydrocarbon reformer output translation module 230, and may calculate a model to determine an improved control variable, as described hereinbelow.

[0037] Referring still to FIG. 2, the hydrocarbon reformer process control system 200 may include a hydrocarbon reformer output translation module 230. The hydrocarbon reformer output translation module 230 may comprise any hardware configured to translate the output of the predictive hydrocarbon reformer modeling processor 220 into a form that can be used in the control of technical operations associated with the chemical processing portion 104 and which, for example, may comprise a hardware driver or controller, a control data transmitter, a document printer, a data display, or any other hardware that generates an operations output that can be used in the chemical processing portion 104 to alter, enhance, or otherwise control technical operations or create a technical effect within the continuous catalytic reformer unit 100.

[0038] In embodiments, the hydrocarbon reformer output translation module 230 may communicate with the predictive hydrocarbon reformer modeling processor 220 to receive at least the improved control variable. Additionally, the hydrocarbon reformer output translation module 230 may be in communication with the one or more control variable actuator hardware 236 of the continuous catalytic reformer unit 100. The control variable actuator hardware 236 may be operable to change a present control variable. For example, a control variable actuator hardware 236 may include a controller or valve actuator that can change a control variable in the continuous catalytic reformer unit 100. For example, the hydrocarbon reformer output translation module 230 may, in some embodiments, send a message to one or more of the control variable actuator hardware 236 to make an adjustment to the continuous catalytic reformer unit 100. The hydrocarbon reformer output translation module 230 may further provide an interface for a plant operator to input a selected control variable upon which to generate an improved control variable.

The hydrocarbon reformer output translation module 230 may also provide an interface for a plant operator to view suggested improved control variables, machine learned models, etc., and then instruct the hydrocarbon reformer output translation module 230 to send a message to one or more of the control variable actuator hardware 236 to adjust a control variable of the continuous catalytic reformer unit 100.

[0039] According to embodiments, the method for operating the continuous catalytic reformer unit 100 may further comprise adjusting one or more present control variables of the continuous catalytic reformer unit based on the one or more improved control variables determined by the machine learned model. In some embodiments, this adjustment may be automatically performed by the process control unit 200 by having the hydrocarbon reformer output translation module 230 signal to a control variable actuator hardware 236 to adjust a control variable. For example, the process control unit 200 may automatically command a control variable actuator hardware 236 to change a present control variable. In other embodiments, the hydrocarbon reformer output translation module 230 may display the improved control variable to a plant operator, and the plant operator may adjust the one or more present control variables unit based on the improved performance variable after consideration of the change.

[0040] Now, a more detailed description of operation of the hydrocarbon reformer process control system 200 utilizing a machine learned model is presented, according to one or more embodiments. Such description may, in some instances, be limited to selected control variables, selected state variables, and selected performance variables. However, this description should be relevant to an expanded appreciation for the subject matter presently described, such as embodiments with different selected control variables, selected state variables, and selected performance variables.

[0041] In some embodiments, the machine learned model is trained utilizing inputs of at least historic state variable data, historic control variable data, and historic performance variable data. Historic performance variable data may include any prior data that is related to a performance variable, as described herein. Performance variables, as described herein, refer to variables of the chemical processing portion 104 related to the performance of the system. For example, the one or more performance variables may be chosen from product yield of reformat, product yield of hydrogen, product yield of off-gas, product yield of LPG, reactant stream input rate, chloride injection rate, or catalyst time in system. It should be understood that performance variables may be state variables, but that, generally, the machine learned model may use a different performance

variable as an output than state variable as an input. The machine learned model may be trained on past data collected from the chemical processing portion 104 over a prior period of time. Such data may be collected by the control variable monitoring hardware 232 and/or the state variable monitoring hardware 234.

[0042] Now referring to FIG. 2, without limitation, the machine learned model may utilize a neural network model. Another contemplated machine learned model that may be utilized is a random forest classifier model. As shown in FIG. 2, in a neural network model state variable data and control variable data may be utilized as inputs and performance variable data may be utilized as an output. Historic values of these data may be utilized to train the neural network model, assigning improved values for each node consistent with data regression to render the model most accurate for predictive use based on historic data.

[0043] A neural network model generally includes one or more layers having one or more nodes, connected by node connections. The one or more layers may include an input layer 405, one or more hidden layers and an output layer. The neural network model may be a deep neural network, a convolutional neural network, or other type of neural network. The neural network model may include one or more convolution layers and one or more fully connected layers. The input layer represents the raw information that is fed into the neural network model. In embodiments, state variable data and control variable data may be input into the neural network model at the input layer, and an output layer may be the performance variable. For example, when learning, historic state variable data and historic control variable data may be input into the neural network model at the input layer and historic performance variable data at the output layer. In the training mode, there neural network model may employ one or more feedback or back-propagation techniques to train the neural network paths.

[0044] The neural network model processes the raw information received at the input layer through nodes and node connections. The one or more hidden layers depending on the inputs from the input layer and the weights on the node connections, carry out computational activities. In other words, the hidden layers perform computations and transfer information from the input layer to the output layer through their associated nodes and node connections.

[0045] In general, when a neural network model is learning, the neural network model is identifying and determining patterns within the raw information received at the input layer (i.e., historic control variable data and historic state variable data). In response, one or more

parameters, for example, weights associated to node connections between nodes, may be adjusted through a process known as back-propagation. It should be understood that there are various processes in which learning may occur, however, two general learning processes include associative mapping and regularity detection. Associative mapping refers to a learning process where a neural network model learns to produce a particular pattern on the set of inputs whenever another particular pattern is applied on the set of inputs. Regularity detection refers to a learning process where the neural network learns to respond to particular properties of the input patterns. Whereas in associative mapping the neural network stores the relationships among patterns, in regularity detection the response of each unit has a particular 'meaning'. This type of learning mechanism may be used for feature discovery and knowledge representation.

[0046] Neural networks possess knowledge that is contained in the values of the node connection weights. Modifying the knowledge stored in the network as a function of experience implies a learning rule for changing the values of the weights. Information is stored in a weight matrix of a neural network. Learning is the determination of the weights.

[0047] In order to train a neural network model to perform some task, adjustments to the weights are made in such a way that the error between the desired output and the actual output is reduced. This process may require that the neural network model computes the error derivative of the weights. In other words, it must calculate how the error changes as each weight is increased or decreased slightly. A back propagation algorithm is one method that is used for determining the weights.

[0048] The data related to the trained machine learned model (such as the node weights) may be stored in the hydrocarbon reformer variable data memory 210 and utilized by the predictive hydrocarbon reformer modeling processor 220 to generate the improved control variable output. As described herein, an improved control variable refers to a control variable that is improved as compared to the present control variable based on the information resulting from the machine learned model, which is described herein. Such an improved control variable output can be utilized to adjust the settings of the chemical processing portion 104. It should be understood that the improved control variable need not be completely optimized, but only improved as compared to the present control variable.

[0049] According to embodiments, the present state variable (received to the hydrocarbon reformer variable data memory 210 from a control variable monitoring hardware 232) and/or a

present control variable (received to the hydrocarbon reformer variable data memory 210 from a state variable monitoring hardware 234) may be transmitted to the predictive hydrocarbon reformer modeling processor 220. In some embodiments, the predictive hydrocarbon reformer modeling processor 220 may utilize the trained machine learned model to generate a machine learned model for a performance variable as a function of present state and present control variables, such as that shown in FIG. 3. In other embodiments, the predictive hydrocarbon reformer modeling processor 220 may retrieve the data of the machine learned model for particular control and state variables from the hydrocarbon reformer variable data memory 210 (e.g., not calculating the model in real time but relying on past calculation of such a model).

[0050] Now referring to FIG. 3, a simplified schematic of one example of a model formed by utilizing of a machine learned model is depicted. As depicted, the performance variable can be calculated based on inputs of the present state variable and present control variable. The performance variable model (shown as the half-sphere in FIG. 3) is a function of the present control variable and the present state variable. Based on the results of this model, such as that shown in FIG. 3, the process control unit 200 may determine and generate an improved control variable based at least on the present state variable and present control variable of the continuous catalytic reformer unit 100. For example, the inputs to the machine learned model are a present control variable and a present state variable, which is utilized to calculate a model of a performance variable. This model can then be utilized to determine and generate an improved control variable. For example, in FIG. 3, c^* may depict the present control variable and the model may be utilized to generate an improved control variable along the dotted line that increases performance. The improved control variable need not be optimized, but only improve the performance to any degree as projected by the machine learned model.

[0051] As described herein, the machine learned model may be trained by utilizing inputs that include both historic state variables and historic control variables, and the predictive modeling of the process control unit 200 may generate the improved control variable based on both present control variables and present state variables. It has been discovered that, in at least some embodiments, utilizing a machine learned model that utilizes at least a state variable and a control variable may lead to more accurate modeling of improved control variables, as opposed to utilizing only control variables or only state variables.

[0052] In some embodiments, the operation of the process control unit's 200 control over the chemical processing portion 104 may be in real-time or near-real time. That is, for example,

one or more of the one or more signals indicative of one or more present state variables is received by the process control system in real-time or near-real time, the one or more signals indicative of one or more present control variables is received by the process control system in real-time or near-real time, and/or the process control system generates the one or more improved control variables in real-time or near-real time. As described herein, real-time refers to the calculation and/or actuation on the chemical processing portion 104 by the process control unit 200 as inputs such as the present control variable data and present state variable data are received to the process control unit 200. Near real-time may refer to longer delays between such computation and/or actuation on the chemical processing portion 104 by the process control unit 200, such as delays of seconds, minutes, or even hours. In some embodiments, control and adjustment to the continuous catalytic reformer unit 100 via the one or more control variable actuator hardware 236 may be in real time. In other embodiments, control and/or adjustment of the control variable actuator hardware 236 may be by input of a plant operator who has reviewed data displayed on the hydrocarbon reformer output translation module 230.

[0053] In some embodiments, multiple machine learned models, utilizing different state variables and control variables, are combined to determine the improved control variable. In other embodiments, multiple control variables and/or multiple state variables are utilized in the same machine learned model.

[0054] Numerous, non-limiting technical aspects are presently described herein, listed below as Aspects 1-15.

[0055] Aspect 1. A method for operating a continuous catalytic reformer unit, the method comprising: passing a hydrocarbon reactant stream to a continuous catalytic reformer unit to form one or more product effluent streams, the continuous catalytic reformer unit comprising at least one stream pre-heater, at least one catalytic reactor, and at least one separation unit; implementing a hydrocarbon reformer process control system comprising a hydrocarbon reformer variable data memory comprising processor-executable instructions, a hydrocarbon reformer output translation module, and one or more predictive hydrocarbon reformer modeling processors configured to execute the processor-executable instructions and cause the process control system to: receive: one or more signals indicative of one or more present state variables from one or more state variable actuator hardware, wherein the present state variables are process variables that cannot be directly set in the continuous catalytic reformer unit; and one or more signals indicative of one or more present control variables of the continuous catalytic reformer unit from one or more

control variable actuator hardware, wherein the present control variables are process variables that can be directly set in the continuous catalytic reformer unit; and generate, by utilizing a machine learned model, an improved control variable that increases a selected performance variable based on the inputs of one or both of one or more present state variables or one or more present control variables, wherein the improved control variable wherein the machine learned model is trained utilizing inputs of at least historic state variable data, historic control variable data, and historic performance variable data; and adjusting one or more present control variables of the continuous catalytic reformer unit based on the improved control variable determined by the machine learned model.

[0056] Aspect 2. The method of aspect 1, wherein the hydrocarbon reformer output translation module sends one or more signals to one or more control variable actuator hardware to adjust the one or more present control variables.

[0057] Aspect 3. The method of any previous aspect, wherein the process control system automatically adjusts, in real-time, the one or more present control variables based on the one or more improved control variables determined by the machine learned model.

[0058] Aspect 4. The method of any previous aspect, wherein: the one or more signals indicative of one or more present state variables is received by the process control system in real-time or near-real time; and the one or more signals indicative of one or more present control variables is received by the process control system in real-time or near-real time.

[0059] Aspect 5. The method of any previous aspect, wherein the process control system generates the one or more improved control variables in real-time or near-real time.

[0060] Aspect 6. The method of any previous aspect, wherein the one or more state variables are chosen from reactant stream input rate, catalyst activity, the average pressure of a catalytic reactor, reactor down time, product yield of reformate, product yield of hydrogen, product yield of off-gas, product yield of LPG, consumption of fuel-gas, consumption of cooling water, consumption of power, the temperature of a separation unit, heat exchanger duty of the combined feed and effluent, or catalyst time in system.

[0061] Aspect 7. The method of any previous aspect, wherein the one or more control variables are chosen from the weighted average inlet temperature of the reactant stream, reactant stream feed rate, quality of reactant feed stream, the chloride injection rate, average carbon burn

rate in the catalyst regenerator, catalyst circulation rate, hydrogen/hydrocarbon ratio, and energy consumption in the stream pre-heater.

[0062] Aspect 8. The method of any previous aspect, wherein the selected performance variable is chosen from product yield of reformate, product yield of hydrogen, product yield of off-gas, product yield of LPG, reactant stream input rate, chloride injection rate, or catalyst time in system.

[0063] Aspect 9. The method of aspect 8, wherein the selected performance variable is the product yield of reformate.

[0064] Aspect 10. The method of aspect 8, wherein the selected performance variable is the product yield of hydrogen.

[0065] Aspect 11. The method of aspect 8, wherein the selected performance variable is chosen from product yield of off-gas or product yield of LPG.

[0066] Aspect 12. The method of aspect 8, wherein the selected performance variable is chosen from reactant stream input rate, chloride injection rate, or catalyst time in system.

[0067] Aspect 13. The method of any previous aspect, wherein the reactant stream comprises refinery naphtha.

[0068] Aspect 14. The method of any previous aspect, wherein the machine learned model comprises a neural network model.

[0069] Aspect 15. A continuous catalytic reformer unit operating the method of any previous aspect.

[0070] The subject matter of the present disclosure has been described in detail and by reference to specific embodiments. It should be understood that any detailed description of a component or feature of an embodiment does not necessarily imply that the component or feature is essential to the particular embodiment or to any other embodiment. Further, it should be apparent to those skilled in the art that various modifications and variations can be made to the described embodiments without departing from the spirit and scope of the claimed subject matter.

CLAIMS

1. A method for operating a continuous catalytic reformer unit, the method comprising:
 - passing a hydrocarbon reactant stream to a continuous catalytic reformer unit to form one or more product effluent streams, the continuous catalytic reformer unit comprising at least one stream pre-heater, at least one catalytic reactor, and at least one separation unit;
 - implementing a hydrocarbon reformer process control system comprising a hydrocarbon reformer variable data memory comprising processor-executable instructions, a hydrocarbon reformer output translation module, and one or more predictive hydrocarbon reformer modeling processors configured to execute the processor-executable instructions and cause the process control system to:
 - receive:
 - one or more signals indicative of one or more present state variables from one or more state variable actuator hardware, wherein the present state variables are process variables that cannot be directly set in the continuous catalytic reformer unit; and
 - one or more signals indicative of one or more present control variables of the continuous catalytic reformer unit from one or more control variable actuator hardware, wherein the present control variables are process variables that can be directly set in the continuous catalytic reformer unit; and
 - generate, by utilizing a machine learned model, an improved control variable that increases a selected performance variable based on the inputs of one or both of one or more present state variables or one or more present control variables, wherein the improved control variable wherein the machine learned model is trained utilizing inputs of at least historic state variable data, historic control variable data, and historic performance variable data; and
 - adjusting one or more present control variables of the continuous catalytic reformer unit based on the improved control variable determined by the machine learned model.
2. The method of claim 1, wherein the hydrocarbon reformer output translation module sends one or more signals to one or more control variable actuator hardware to adjust the one or more present control variables.

3. The method of any previous claim, wherein the process control system automatically adjusts, in real-time, the one or more present control variables based on the one or more improved control variables determined by the machine learned model.
4. The method of any previous claim, wherein:
the one or more signals indicative of one or more present state variables is received by the process control system in real-time or near-real time; and
the one or more signals indicative of one or more present control variables is received by the process control system in real-time or near-real time.
5. The method of any previous claim, wherein the process control system generates the one or more improved control variables in real-time or near-real time.
6. The method of any previous claim, wherein the one or more state variables are chosen from reactant stream input rate, catalyst activity, the average pressure of a catalytic reactor, reactor down time, product yield of reformat, product yield of hydrogen, product yield of off-gas, product yield of LPG, consumption of fuel-gas, consumption of cooling water, consumption of power, the temperature of a separation unit, heat exchanger duty of the combined feed and effluent, or catalyst time in system.
7. The method of any previous claim, wherein the one or more control variables are chosen from the weighted average inlet temperature of the reactant stream, reactant stream feed rate, quality of reactant feed stream, the chloride injection rate, average carbon burn rate in the catalyst regenerator, catalyst circulation rate, hydrogen/hydrocarbon ratio, and energy consumption in the stream pre-heater.
8. The method of any previous claim, wherein the selected performance variable is chosen from product yield of reformat, product yield of hydrogen, product yield of off-gas, product yield of LPG, reactant stream input rate, chloride injection rate, or catalyst time in system.
9. The method of claim 8, wherein the selected performance variable is the product yield of reformat.

10. The method of claim 8, wherein the selected performance variable is the product yield of hydrogen.
11. The method of claim 8, wherein the selected performance variable is chosen from product yield of off-gas or product yield of LPG.
12. The method of claim 8, wherein the selected performance variable is chosen from reactant stream input rate, chloride injection rate, or catalyst time in system.
13. The method of any previous claim, wherein the reactant stream comprises refinery naphtha.
14. The method of any previous claim, wherein the machine learned model comprises a neural network model.
15. A continuous catalytic reformer unit operating the method of any previous claim.