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REDUCING CO2 EMISSIONS DURING A WELLBORE CLEAN-UP

Abstract

Systems and methods of the present disclosure includes a mixer configured to mix air and hydrocarbons and a burner configured to receive the mixed air and hydrocarbons and to generate syngas. The system also includes a cooling system configured to receive the syngas and to cool the syngas to form cooled syngas. The system further includes a collector configured to collect carbon from the cooled syngas as soot. Moreover, the system includes a flare stack configured to receive the cooled syngas and to burn off at least part of the cooled syngas.

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Background/Summary

FIELD OF THE INVENTION

[0001] This disclosure relates generally to hydrocarbon production and exploration and, more particularly, to methods and apparatuses to monitor CO_2 emissions during wellbore clean-up operations.

BACKGROUND INFORMATION

[0002] Wellbores may be drilled into subsurface rocks to create wells to access subterranean fluids, such as hydrocarbons, stored in subterranean formations. When these subterranean fluids are produced from the wells, it may be desirable to obtain certain characteristics of the produced fluids to facilitate efficient and economic exploration and production. For example, it may be desirable to obtain flow rates and/or other characteristics of the produced fluids. These produced fluids are often multiphase fluids (e.g., having some combination of water, oil, and gas).

[0003] Well clean-up is an initial phase of a well test and begins with opening the well. During this phase, non-reservoir fluids, such as completion, drilling, and stimulation fluids, are produced to the surface together with reservoir fluids. At this stage, the effluent composition may be at least partially unknown, and the flow can be unstable and characterized by a slug flow. The clean-up phase may vary from scenario to scenario and facility to facility and for different objective functions. Thus, a single clean-up flow plan may not be suitable for all scenarios, facilities, and objective functions. Furthermore, tracking CO_2 emissions may be difficult due to the various factors/parameters in such computations being derived from different simulator types.

SUMMARY

[0004] A summary of certain embodiments described herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure.

[0005] In one embodiment, a system includes a mixer configured to mix air and hydrocarbons and a burner configured to receive the mixed air and hydrocarbons and to generate syngas. The system also includes a cooling system configured to receive the syngas and to cool the syngas to form cooled syngas. The system further includes a collector configured to collect carbon from the cooled syngas as soot. Moreover, the system includes a flare stack configured to receive the cooled syngas and to burn off at least part of the cooled syngas.

[0006] In another embodiment, a method includes receiving one or more sets of parameters related to an operation corresponding to a wellbore. At a first time, simulating at least a portion of the operation using the one or more sets of parameters to determine CO_2 emissions during the operation and recording pertinent results from the simulation. The method also includes storing results comprising the CO_2 emissions for the operation in a table and at a second time, retrieving the determined CO_2 emissions from the table. Moreover, the method includes using the determined CO_2 emissions to control the operation.

[0007] In a further embodiment, a system includes a throat and nozzle system configured to mix air and hydrocarbons. The system also includes a burner configured to receive the mixed air and hydrocarbons from the throat and nozzle system and to generate syngas. Moreover, the system includes an air cooler configured to receive the syngas and to cool the syngas to form cooled syngas. The system further includes a collector configured to collect carbon from the cooled syngas as soot and a flare stack configured to receive the cooled syngas and to burn off at least part of the cooled syngas. Furthermore, the system includes a heat exchanger located between the air cooler and the collector to control a temperature of the flare stack.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Various aspects of this disclosure may be better understood upon reading the following detailed description and upon reference to the drawings, in which:

[0009] FIG. **1** illustrates a diagram of a data capturing system used to capture data in and/or around an oilfield, such as in a wellbore, in accordance with embodiments of the present disclosure;

[0010] FIG. **2** illustrates a computing system used to process data from the data capturing system of FIG. **1**, in accordance with embodiments of the present disclosure;

[0011] FIG. **3** illustrates a process for performing a deterministic optimization for a clean-up operation of the wellbore, in accordance with embodiments of the present disclosure;

[0012] FIG. **4** illustrates a process for performing an optimization for a clean-up operation of the wellbore with at least one uncertainty, in accordance with embodiments of the present disclosure;

[0013] FIG. **5** illustrates a process for computing a function for the processes of FIGS. **3** and **4** using a coupled configuration for two (or more) emulators, in accordance with embodiments of the present disclosure;

[0014] FIG. **6** illustrates a multiple scenario computation using the coupled configuration for two (or more) emulators, in accordance with embodiments of the present disclosure;

[0015] FIG. **7** illustrates a process for performing a priori tabulation of simulations using the coupled configuration of the two (or more) emulators of FIG. **6**, in accordance with embodiments of the present disclosure;

[0016] FIG. **8** illustrates an isopleth showing radiation during an operation of the wellbore of FIG. **1**, in accordance with embodiments of the present disclosure;

[0017] FIG. **9** illustrates an elevation map showing dispersions of emissions during an operation of the wellbore of FIG. **1**, in accordance with embodiments of the present disclosure;

[0018] FIG. **10** illustrates a graph showing data points for different trials/simulations during the operation of the wellbore of FIG. **1**, in accordance with embodiments of the present disclosure;

[0019] FIG. **11** illustrates a graph of a Pareto Front for a multi-objective problem for the wellbore of FIG. **1**, in accordance with embodiments of the present disclosure;

[0020] FIG. **12** illustrates a system for reducing CO_2 emissions during an operation of the wellbore of FIG. **1**, in accordance with embodiments of the present disclosure; and

[0021] FIG. **13** illustrates a system for reducing CO_2 emissions during an operation of the wellbore of FIG. **1**, in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

[0022] In the following, reference is made to embodiments of the disclosure. It should be understood, however, that the disclosure is not limited to specific described embodiments. Instead, any combination of the following features and elements, whether related to different embodiments or not, is contemplated to implement and practice the disclosure. Furthermore, although embodiments of the disclosure may achieve advantages over other possible solutions and/or over the prior art, whether or not a particular advantage is achieved by a given embodiment is not limiting of the disclosure. Thus, the following aspects, features, embodiments, and advantages are merely illustrative and are not considered elements or limitations of the claims except where explicitly recited in a claim. Likewise, reference to "the disclosure" shall not be construed as a generalization of inventive subject matter disclosed herein and should not be considered to be an element or limitation of the claims except where explicitly recited in a claim.

[0023] Although the terms first, second, third, etc., may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer, or section. Terms such as "first," "second" and other numerical terms, when used herein, do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer, or section

discussed herein could be termed a second element, component, region, layer, or section without departing from the teachings of the example embodiments.

[0024] When introducing elements of various embodiments of the present disclosure, the articles "a," "an," and "the" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to "one embodiment" or "an embodiment" of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

[0025] Some embodiments will now be described with reference to the figures. Like elements in the various figures will be referenced with like numbers for consistency. In the following description, numerous details are set forth to provide an understanding of various embodiments and/or features. It will be understood, however, by those skilled in the art, that some embodiments may be practiced without many of these details, and that numerous variations or modifications from the described embodiments are possible. As used herein, the terms "above" and "below," "up" and "down," "upper" and "lower," "upwardly" and "downwardly," and other like terms indicating relative positions above or below a given point are used in this description to more clearly describe certain embodiments. Furthermore, "optimize" as used herein is intended to cover scenarios where certain objectives/parameters are enhanced or improved even if there may be further improvement available. In other words, an operation may be optimized without being the most optimized possible solution.

[0026] During the clean-up period of a well test, various operations may be implemented. For instance, pre-job wellhead surface equipment optimization may be implemented for a wellbore clean-up to maximize some objective function, F. For instance, F may non-exclusively include a function to maximize clean-up quality in a least amount of time, minimize CO_2 emissions, minimize an amount of area occupied by wellhead equipment and connections, minimize sound emission, and/or other suitable functions that may be used.

[0027] With the foregoing in mind, FIG. **1** illustrates a data capturing system **10** to capture and produce data output **12** in an oilfield that is captured as part of a clean-up operation, wireline operation, pumping operation, drilling operation, extraction operation, or any other operation being performed. In the illustrated embodiment, the data capture is being at least partially performed by a wireline tool **14** suspended by a rig **15** and into a wellbore **16** during drilling. During production/clean-out, data may be acquired using other tools (e.g., surface measurements). The wireline tool **14** is adapted for deployment into wellbore **16** for generating well logs, performing downhole tests, collecting samples, and/or collecting any other data. For instance, the wireline tool **14** may assist in performing a logging while drilling (LWD) operation. Additionally or alternatively, the wireline tool **14** may, for example, have an explosive, radioactive, electrical, or acoustic energy source **18** that sends and/or receives electrical signals to surrounding subterranean formations **20** and/or fluids therein. Return signals may be detected using the wireline tool **14** and/or other tools located at other locations at/near the oilfield.

[0028] Computer facilities may be positioned at various locations about the oilfield (e.g., the surface unit **22**) and/or at remote locations. The surface unit **22** may be used to communicate with the wireline tool **14** and/or offsite operations, as well as with other surface or downhole sensors. The surface unit **22** is capable of communicating with the wireline tool **14**, pumps, a choke **23**, and/or other equipment. For instance, the choke **23** may be an adjustable choke that controls fluid flow out of the wellbore. The surface unit **22** may also collect data generated during the drilling operation, clean-out operation, production operation, and/or logging and produces data output **12**, which may then be stored or transmitted. In other words, the surface unit **22** may collect data generated during the clean-out operation and may produce data output **12** that may be stored or transmitted.

[0029] The surface unit **22** may include one or more various sensors and/or gauges that may additionally or alternatively be located at other locations in the oilfield. These sensors and/or gauges may be positioned about the oilfield (e.g., in/at the rig **15**) to collect data relating to various field operations. As shown, at least one downhole sensor **24** is positioned in the wireline tool **14** to measure downhole parameters which relate to, for example porosity, permeability, fluid composition and/or other parameters of the field operation. During drilling, different or more parameters, such as weight on bit, torque on bit, pressures, temperatures, flow rates, compositions, rotary speed, and/or other parameters of the field operation, may be measured.

[0030] The surface unit **22** may include a transceiver **33** to enable communications between the surface unit **22** and various portions of the oilfield or other locations. The surface unit **22** may also be provided with or functionally connected to one or more controllers for actuating mechanisms at the oilfield. The surface unit **22** may then send command signals to the oilfield in response to data received. The surface unit **22** may receive commands via the transceiver **33** or may itself execute commands to the controller. A computing system including a processor may be included to analyze the data (locally or remotely), make decisions, control operations, and/or actuate the controller. In this manner, the oilfield may be selectively adjusted based on the data collected. This technique may be used to enhance portions of the field operation, such as controlling drilling, weight on bit, pump rates, and/or other parameters. These adjustments may be made automatically based on an executing application with or without user input.

[0031] A mud pit **26** is used to draw drilling mud into the drilling tools via flow line **28** for circulating drilling mud down through the drilling tools, then up wellbore **16** and back to the surface. The drilling mud may be filtered and returned to the mud pit **26**. A circulating system may be used for storing, controlling, or filtering the flowing drilling muds. The drilling tools are advanced into subterranean formations **20** to reach a reservoir **30**. Each well may target one or more reservoirs.

[0032] Generally, the wellbore **16** is drilled according to a drilling plan that is established prior to drilling. The drilling plan sets forth equipment, pressures, trajectories and/or other parameters that define the drilling process for the wellsite. The drilling operation may then be performed according to the drilling plan. However, as information is gathered, the drilling operation may need to deviate from the drilling plan. Additionally, as drilling or other operations are performed, the subsurface conditions may change. The earth model may also be adjusted as new information is collected.

[0033] After the drilling operation is completed, at least some drilling mud and/or other materials other than the desired subterranean fluid may remain in the wellbore. To remove these unwanted materials, a clean-up operation may be performed. As effluent travel upwards through the wellbore **16**, it travels through the choke **23**. As previously noted, this effluent may be multiphase consisting of multiple fluids (e.g., oil, gas, and water). This multiphase fluid traverses the choke **23** and enters into a separation and analysis system **32**. The separation and analysis system **32** may be at least partially included in the surface unit **22**. The separation and analysis system **32** may include a horizontal separator, a vertical separator, and/or any other mechanisms that may facilitate separation of the incoming effluent. For instance, the separator may include a 3-phase gravity separator that separates the effluent into its separate gas, oil, and water sub-elements. The analysis portion of the separation and analysis system **32** may evaluate how successful the separation of the sub-elements has been. Additionally or alternatively, the analysis portion of the separation and analysis system **32** may determine flow rates of water and other liquids to determine whether the clean-up has been completed. Additionally, if the effluent contains solids, the analysis portion of the separation and analysis system **32** may determine the value of basic sediments and water (BSW) in the effluent to determine whether the clean-up operation has been completed.

[0034] The data gathered by sensors **24** may be collected by the surface unit **22** and/or other data collection sources for analysis or other processing. The data collected by the sensors **24** may be used alone or in combination with other data. The data may be collected in one or more databases

and/or transmitted to another location on-site or offsite. The data may be historical data, real time data, or combinations thereof. The real time data may be used in real time or stored for later use. The data may also be combined with historical data and/or other inputs for further analysis. The data may be stored in separate databases and/or combined into a single database.

[0035] FIG. 2 is a block diagram of a system **250** that may be used for analyzing/utilizing the data output **12** from the data capturing system **10**, as described in FIG. **1**. The data output **12**, as described in FIG. **1**, is received as input data **252** at a computing device **254**. The computing device **254** may be implemented in the surface unit **22** and/or may be implemented at other locations within the oilfield or remotely from the oilfield where the remote locations are able to receive the data via the transceiver **33**. The various functional blocks shown in FIG. **2** may include hardware elements (including circuitry), software elements (including computer code stored on a tangible computer-readable medium), or a combination of both hardware and software elements. It should be noted that FIG. **2** is merely one example of a particular implementation and is intended to illustrate the types of components that may be present in the computing device **254**.

[0036] As illustrated, the computing device **254** includes one or more processor(s) **256**, a memory **258**, a display **260**, input devices **262**, one or more neural networks(s) **264**, and one or more interface(s) **266**. In the computing device **254**, the processor(s) **256** may be operably coupled with the memory **258** to facilitate the use of the processors(s) **256** to implement various stored programs. Such programs or instructions executed by the processor(s) **256** may be stored in any suitable article of manufacture that includes one or more tangible, computer-readable media at least collectively storing the instructions or routines, such as the memory **258**. The memory **258** may include any suitable articles of manufacture for storing data and executable instructions, such as random-access memory, read-only memory, rewritable flash memory, hard drives, and optical discs. In addition, programs (e.g., an operating system) encoded on such a computer program product may also include instructions that may be executed by the processor(s) **256** to enable the computing device **254** to provide various functionalities.

[0037] The input devices **262** of the computing device **254** may enable a user to interact with the computing device **254** (e.g., pressing a button to increase or decrease a volume level). The interface(s) **266** may enable the computing device **254** to interface with various other electronic devices. The interface(s) **266** may include, for example, one or more network interfaces for a personal area network (PAN), such as a Bluetooth network, for a local area network (LAN) or wireless local area network (WLAN), such as an IEEE 802.11x Wi-Fi network or an IEEE 802.15.4 wireless network, and/or for a wide area network (WAN), such as a cellular network. The interface(s) **266** may additionally or alternatively include one or more interfaces for, for example, broadband fixed wireless access networks (WiMAX), mobile broadband Wireless networks (mobile WiMAX), and so forth.

[0038] In certain embodiments, to enable the computing device **254** to communicate over the aforementioned wireless networks (e.g., Wi-Fi, WiMAX, mobile WiMAX, 4G, LTE, and so forth), the computing device **254** may include a transceiver (Tx/Rx) **267**. The transceiver **267** may include any circuitry that may be useful in both wirelessly receiving and wirelessly transmitting signals (e.g., data signals). The transceiver **267** may include a transmitter and a receiver combined into a single unit.

[0039] The input devices **262**, in combination with the display **260**, may allow a user to control the computing device **254**. For example, the input devices **262** may be used to control/initiate operation of the neural network(s) **264**. Some input devices **262** may include a keyboard and/or mouse, a microphone that may obtain a user's voice for various voice-related features, and/or a speaker that may enable audio playback. The input devices **262** may also include a headphone input that may provide a connection to external speakers and/or headphones.

[0040] The neural network(s) **264** may include hardware and/or software logic that may be arranged in one or more network layers. In some embodiments, the neural network(s) **264** may be

used to implement machine learning and may include one or more suitable neural network types. For instance, the neural network(s) **264** may include a perceptron, a feed-forward neural network, a multi-layer perceptron, a convolutional neural network, a long short-term memory (LSTM) network, a sequence-to-sequence model, and/or a modular neural network. In some embodiments, the neural network(s) **264** may include at least one deep learning neural network.

[0041] The output of the neural network(s) **264** may be based on the input data **252**, such as flow rates or other data captured during drilling, clean-out, and/or other operations. This output may be used by the computing device **254**. Additionally or alternatively, the output from the neural network(s) **264** may be transmitted using a communication path **268** from the computing device **254** to a gateway **270**. The communication path **268** may use any of the communication techniques previously discussed as available via the interface(s) **266**. For instance, the interface(s) **266** may connect to the gateway **270** using wired (e.g., Ethernet) or wireless (e.g., IEEE 802.11) connections. The gateway **270** couples the computing device **254** to a wide-area network (WAN) connection **272**, such as the Internet. The WAN connection **272** may couple the computing device **254** to a cloud network **274**. The cloud network **274** may include one or more computing devices **254** grouped into one or more locations (e.g., data centers). The cloud network **274** includes one or more databases **276** that may be used to store the output of the neural network(s) **264**. In some embodiments, the cloud network **274** may perform additional transformations on the data using its own processor(s) **256** and/or neural network(s) **264**.

[0042] The computing device **254** may be used to perform an optimization process to optimize for the objective function, F. For instance, FIG. **3** is a block diagram of a process **300** for performing a deterministic optimization that may be performed using the computing device **254**. As illustrated, the computing device **254** receives F and bounds of control variables (CVs) (block **302**). For instance, F may be received as defined by a user via the input devices **262**, pulled from the memory **258**, received as a selection from presented possible functions, and/or other mechanisms suitable for defining the objective function, F. Similarly, the bounds for the CVs may be defined and/or received by the computing device **254**. Furthermore, the computing device **254** receives a convergence tolerance and max count (block **304**). The convergence tolerance and/or the max count may be defined similarly to how the CVs and/or F is received. The convergence tolerance and/or the max count control how many iterations are to be performed. A larger convergence tolerance deems the optimization converged or optimized at an earlier time while the max count defines a maximum number of iterations before the optimization using the process **300** is halted. In other words, a higher threshold condition will be met earlier than a lower one.

[0043] The computing device **254** initializes the CVs and a count (block **306**). For instance, the count may set an index (e.g., n) for values (e.g., x) to a first value (e.g., $x_n = 1$). Using these CV values, the computing device **254** computes a corresponding F for the count (e.g., F_n) (block **308**). As is described below in further detail, the computation of the corresponding F using the CV values may be calculated using coupled emulators that perform a "trial" using the CVs in tandem. The computing device **254** may determine a maximum change from a maximum of the previous iteration (e.g., initially set to some default value, such as undefined) (block **310**). For instance, the computing device **254** may determine a maximum change of the corresponding F and a previously computed F (or undefined value).

[0044] The computing device **254** may then determine whether the change is less than or equal to the convergence tolerance (block **312**). For instance, the computing device **254** may subtract the corresponding function from the max of the previous iteration. If the absolute value of the difference is less than or equal to the convergence tolerance, the corresponding function may be deemed "optimized," and the process **300** may end.

[0045] If the difference is not less than or equal to the convergence tolerance, the computing device **254** may determine whether the maximum count, as previously defined, has been reached (block **314**). If the max count has been reached, the computing device **254** may end the process **300**. If the

count is less than the maximum count, the computing device **254** increments the count (block **316**). The computing device **254** then updates the CVs (e.g., x.sub.n) based on the incremented count (block **318**). With the updated CVs, the computing device **254** may re-compute the new corresponding function F, and the process **300** starts over from block **308**.

[0046] FIG. **4** is a flow chart of a process **330** that is an optimization with one or more uncertainty samples using the computing device **254**. Such uncertainty may be related to static reservoir **30** properties, depth, and severity of fluid invasion in the near wellbore region, and/or layer-specific productivity indexes. As illustrated, the computing device **254** receives F, bounds of control variables (CVs), risk aversion factors, and one or more uncertainties (e.g., U.sub.1, U.sub.2, . . . U.sub.K) (block **332**). Furthermore, the computing device **254** receives a convergence tolerance and max counts (block **334**). The function F, bounds of CVs, the risk aversion, the one or more uncertainty samples, the convergence tolerance, and/or the max count may be received/determined in any of the methods discussed above in relation to the function F, the bounds of the CV, the convergence tolerance, or the max count in relation to FIG. **3**. Specifically, in some embodiments, the risk aversion may be a user-defined risk aversion used to indicate how much risk to take during the optimization and may be any positive value (e.g., 0-3). If the risk aversion factor is 0, the optimization may be for the mean, but at a higher value (e.g., 1), the optimization may be for some number greater than the mean in the likelihood of obtaining the value of F or higher.

[0047] As previously described, the convergence tolerance and/or the max count control how many iterations are to be performed. As previously noted, a larger convergence tolerance deems the optimization converged or optimized at an earlier time while the max count defines a maximum number of iterations before the optimization using the process **330** is halted. The block **334** may be similar to the block **302** except that there are additional counts. A count (e.g., count j) may be used to index risk aversion factors to enable computing F for different risk aversion factors. Another count (e.g., count s) may be used to index uncertainty samples to enable computing F for multiple uncertainty samples. Each of the counts may be used with their own max counts.

[0048] The computing device **254** initializes the CVs, counts, and risk aversion factor j (block **336**) similar to block **306**. The computing device **254** selects one uncertainty value/sample (U.sub.k) from the uncertainty samples using the count (block **338**). Using these CV values, the risk aversion factor, and the selected uncertainty sample, the computing device **254** computes a corresponding F for the count (e.g., F.sub.n) (block **340**). As previously noted, and as is described in further detail below, the computation of the corresponding F using the CV values, risk aversion factor, and selected uncertainty sample may be calculated using coupled emulators that perform a "trial" using the CVs in tandem. The computing device **254** then determines whether there are more uncertainty samples to be used for the set of CVs (block **342**). If more uncertainty samples are to be used, the computing device **254** selects another uncertainty sample (e.g., U.sub.1) (block **338**) and computes an alternative corresponding function (block **340**).

[0049] If there are no more uncertainty samples, the objective function is to be evaluated (block **343**). $F=\mu-\lambda\sigma$ is a generic optimization under uncertainty measure where u is the mean and o is a standard deviation. Using the CV values and corresponding uncertainty samples, the computing device **254** may determine a maximum change from a maximum of the previous iterations (e.g., initially set to some default value, such as undefined) (block **344**). Furthermore, this computation may be based on the risk aversion factor with $F(x.sub.n|\lambda.sub.j, U)=\mu(x.sub.n|U) -\lambda.sub.j\sigma(x.sub.n|U)$, wherein x.sub.n are the CVs, λ.sub.j is the risk aversion factor indexed with count j.

[0050] The computing device **254** may then determine whether the change is less than or equal to the convergence tolerance (block **346**). For instance, the computing device **254** may subtract the corresponding function from the value of the previous iteration. If the absolute value of the difference is less than or equal to the convergence tolerance, the corresponding function may be deemed "optimized." Once the convergence tolerance is reached, the computing device **254**

determines whether the current count j is greater than a count j max (block **348**). If the count j has reached its maximum number, the process **330** ends. If the count j has not reached its max, the computing device **254** increments count j (block **350**) and proceeds to repeat computations for a different risk aversion factor. In some embodiments, the CVs and/or at least some of the counts may be initialized to a starting point for the new computations.

[0051] If the difference is less than the convergence tolerance or the count j has been incremented, the computing device **254** determines whether the maximum count, as previously defined, has been reached (block **352**). If the max count has been reached, the computing device **254** may proceed the process **330** to block **348** to check whether the count j max has been reached. If the count is less than the maximum count, the computing device **254** increments the count (block **354**). The computing device **254** then updates the CVs (e.g., x.sub.n) based on the incremented count (block **356**). With the updated CVs, the computing device **254** may re-compute the new corresponding function F, and the process **330** starts over from block **338**.

[0052] As previously discussed, to ensure correct simulator response for each facility scenario and the associated wellbore clean-up, two or more simulators may be used. Two simulators, a wellbore clean-up simulator, and a commercial process facility simulator, are to be coupled together in a single optimization "trial." In this trial, previously defined CVs are fed into both a wellbore clean-up simulator and (if necessary) commercial process facility simulator to furnish a user-specified objective function, F, in tandem.

[0053] Accordingly, FIG. **5** shows a flow chart of an embodiment of a process **370** that may be implemented in the blocks **308** and/or **340**. As illustrated, the computing device **254** passes the CVs to a wellbore clean-up simulator (block **372**). The computing device **254** may implement the wellbore clean-up simulator or may be coupled to another computing device/cloud that implements the wellbore clean-up simulator as instructions stored in memory and executed by a processor. The computing device **254** causes the wellbore clean-up simulator to be run using the CVs (block **374**). The computing device **254** runs or causes the commercial process facility simulator to be run in a coupled configuration with the wellbore clean-up simulator (block **376**). The commercial process facility simulator may be implemented as instructions stored in memory and executed by a processor. Furthermore, the commercial process facility simulator may be implemented on a same computing device as the wellbore clean-up simulator or may be implemented on a separate computing device. A coupled configuration, as used herein, indicates that the commercial process facility simulator and the wellbore clean-up simulator are communicatively coupled to share the same CVs, share outputs with each other, or otherwise depend on each other for at least some data in a single, combined trial of an optimization. For instance, the wellbore clean-up simulator may use the CVs in simulation, and the commercial process facility simulator may be used to simulate and control operations in the oilfield or other commercial process facility. The commercial process facility simulator may run simulations based on the CVs by using the CVs directly, using outputs from the wellbore clean-up simulator that were generated based on the CVs, or a combination thereof. The commercial process facility simulator then outputs the computed function F based on both simulators in the coupled configuration (block **378**).

[0054] Moreover, in some embodiments, the solution accuracy using the process **370** may be enhanced and/or accelerated by performing pre-job sensitivity analysis and identification of key drivers that impact the objective function, F. FIG. **6** shows a block diagram **400** for performing such sensitivity analysis. Using the process **370** and/or real-world measurements, results for the objective function, F, may be obtained with different input scenarios (block **402**). The results of the different input scenarios may be compared and used to determine how the different input scenarios impact the results. In other words, the results may be used to determine sensitivity of the objective function to the variation of the input scenarios (block **404**).

[0055] Additionally or alternatively, history matching (HM) may be used with the process **370** to enable real-time (RT) application of the coupled simulators. In other words, previous results may

be HM with RT data to utilize the RT data. HM may include feedback and/or fine-tuning of matches and associated controls, such as those performed using a proportional integral derivative (PID) controller and/or any other feedback-oriented controller types. Practical implementation of any real-time model is contingent upon sufficient compute resources and sufficient simulation controls to enable a match of realized rates and pressures with those predicted. To HM a wellbore clean-up, the wellbore clean-up simulator is to adjust key parameters at any point in time. The quality of HM is established by fitting to outputs, such as well head pressure P_{WH}, bottom hole pressure P_{BH}, surface gas flow rate Q_G, surface oil flow rate Q_O, surface mixture flow rate Q_m, and the like.

[0056] The HM may entail varying various parameters in time to facilitate a fit to historical data. Some parameters, such as reservoir parameters, may be adjustable only at some times (e.g., at initialization) and not at others (e.g., during a wellbore clean-up). Thus, new adjustable parameters may be generated to be adjustable at times that were not previously adjustable. For instance, this new parameter/keyword may be designated as a HM reservoir (HMRES).

[0057] The new parameter/keyword may be defined by defining a condition in the wellbore clean-up simulator that indicates that CONSTPRODIDX is specified in the wellbore clean-up simulator and whether a specific parameter (e.g., perforation type) is declared. The new parameter/keyword may also have a defined time that may be coupled to the CONSTPRODIDX and the parameter. Furthermore, a skin factor is multiplied over all layers, and a radius multiplier of zone with damaged permeability is applied over all layers.

[0058] Additionally or alternatively, the new parameter/keyword may be defined by defining a condition in the wellbore clean-up simulator that indicates that CONSTPRODIDX is specified in the wellbore clean-up simulator. The new parameter/keyword may also have a defined time that may be coupled to the CONSTPRODIDX. A productivity index (PI) multiplier may be applied over all layers.

[0059] In some embodiments, a simple global multiplier, J, may be a part of PI. J operates over all layers declared in the reservoir. In certain embodiments, instead of all multipliers being applied over all zones, at least some zone-specific multipliers may be defined. Furthermore, other parameters in other wellbore clean-up simulator keywords may be eligible candidates as uncertainty samples.

[0060] During operations measured data is HM'd to create a proxy of the wellbore clean-up simulator. A proxy of the wellbore clean-up simulator may be a lighter weight approximation of the wellbore clean-up simulator instead of the full-blown model used in the wellbore clean-up simulator. Using this proxy, operations may be optimized for real-time or near-real-time output. One example of the proxy may be a neural network proxy, such as implemented in the neural network(s) **264**, or some other form of machine learning proxy. The machine learning proxies use training, but such data suitable for training may be restricted and/or have relatively low amount of data. This is at least partially due to the asset-specific nature of such proxies and that the machine learning proxy is for the specific asset without physics modelling and may be unsuited for forecasting of properties outside the domain of its training for the specific asset. In fact, the machine learning proxy may be directed to a specific outcome, such as P_{WH} or some other parameter. The neural network(s) **264** may include one or more deep or conditional neural networks with any suitable number of hidden layers between input and output layers.

Enhanced Constraint Handling

[0061] In some embodiments, different sets of constraints may be used. For instance, simple and complex constraints may be used where simple constraints may be evaluated easily directly either linearly or non-linearly using a mathematical expression. Complex constraints use solutions via the wellbore clean-up simulator that are more complex to determine whether the particular complex constraint has been violated or not. For example, simple constraints may include facility capacity for handling produced gas during a cleanup (flaring limits), facility capacity for handling produced

oil during a cleanup (burning), facility capacity for handling produced water during cleanup, specified limits for combined fluids, maximum solids as mass or volumetric flow rate, and/or other constraints. Complex restraints may include complex situations, such as drawdown pressure at a formation that may cause sand production if drawdown is too high, erosional velocity where the pipe is eroded by a choke orifice being too open, and/or other like constraints. Some estimates may be made for complex constraints (e.g., drawdown pressure as a function of flow rate), but since such estimates may be problematic (e.g., drawdown may vary along the length of the wellbore due to wellbore friction and local inflow variations due to rock heterogeneity), some analysis in the wellbore clean-up simulator may be applied causing the constraint to be a complex constraint. In some situations, a simple constraint (e.g., burner and flare operations) may be limited in time. For instance, batch burning may be intermittent or periodic rather than continuous as required by regulations and/or client policy. Similarly, flaring may be permissible only within certain times (e.g., during daylight hours). The time constraints in combination with the simple constraints may be facilitated in the wellbore clean-up simulator similar to complex constraints.

[0062] At least some of the constraints may be related to environmental factors. For example, the commercial process facility simulator may include a flare simulator that may be used to analyze heat radiation while considering local environment conditions along with targets and/or constraints. For instance, the local environment conditions may include wind speed, wind direction, humidity, ambient temperature, solar radiation, background noise, and/or other relevant local environment conditions. These conditions may be computed using the coupled simulators previously discussed. Additionally or alternatively, at least some a priori tabulation may be used as illustrated in FIG. **7**. FIG. **7** shows a flow diagram of a process **420** that may be implemented to perform a priori tabulations of simulations to pre-define complex constraints to avoid potentially computationally expensive fully-coupled simulation. One or more sets of parameter definitions are received that define certain conditions and/or constraints that may be used for simulations (block **422**). The sets of parameters may relate to different real world conditions to represent different conditions that may occur for wellbore cleanup operations. In some embodiments, the sets may be defined in dynamic linked libraries that are defined in an input file to the wellbore clean-up simulator for specific modeling aspects, such as different wellbore flow and invasion models. Using a set of the one or more sets, a simulation is run (block **424**). For instance, the simulation may be performed using a flare simulator portion of the commercial process facility simulator. Using the simulations, pertinent results are obtained and stored in memory (block **426**). When at least one of the sets to be simulated remains (block **428**), the process **420** returns to block **424** to run simulations on a different sets of the one or more sets of parameters. When all sets are simulated, the results are stored into one or more tables for interpolation (block **430**). The tables may be in any data file (e.g., ASCII, binary, etc.) used to store the information. The tables may be indexed by certain parameters where values between recorded values may be linearly and/or non-linearly interpolated to find values without performing additional and potentially compute-expensive coupled simulations for relatively minor changes in parameters. Additionally or alternatively to the a priori tabulation, at least some of the complex constraints may be computed using simulations in the coupled simulators.

[0063] Regardless of using simulations in response to input values and/or using interpolation via the tables resulting from a priori tabulation, input values (e.g., wind speed and direction, etc.) may be used to determine output values (e.g., noise, heat radiation, temperature, etc.).

[0064] As noted, an amount of noise (e.g., in dB) emitted from a burner or flare stack may be computed using a priori tabulation and/or simulation to establish whether a result is likely to violate any prescribed noise limits that may be defined by regulation or client policy. Although this is a relatively straightforward constraint to consider during a cleanup operation when a priori tabulation is available, the issue is defining the range of values necessary to generate the aforementioned table as throughputs and equipment types will vary. This issue may be remedied using coupled

simulations. Furthermore, in some embodiments, the a priori tabulation tables may be updated when new simulations are run using the coupled simulators.

[0065] The commercial process facility simulator may also provide information to provide radiation information at specific points. For instance, FIG. **8** shows an embodiment of an isopleth **440** that contains a representative map with a flare stack **442** at the center of the isopleth **440** that shows a contour map of radiation from the flare stack. The flare simulator of the commercial process facility simulator may generate the isopleth **440** using local environmental conditions (e.g., wind speed, wind direction, etc.). In some embodiments, these isopleths may be generated a priori using the process **420** of FIG. **7** using a variety of local environmental conditions. Using these isopleths, temperatures of exposed surfaces for any specific surfaces may be tracked and compared to a threshold value (e.g., defined by regulation, regulatory authorities, and/or customer needs).

[0066] Another constraint previously discussed may be dispersion of emissions. The constraint may be that a threshold mole fraction of emission concentrations is not exceeded from a given location. The dispersion of emissions may be shown using a map, similar to the isopleth **440**. Additionally or alternatively, the dispersion of emissions may be represented using an elevation map, such as the elevation map **450** of FIG. **9**. Such maps may be generated using a priori tabulation and/or coupled simulations using various operating conditions, such as wind speed, wind direction, etc.

[0067] The commercial process facility simulator may also be used to evaluate a quantity of assistance fluids for smokeless flare uses as a function of throughput and assign their associated cost to the objective function, F. Such quantities may be computed a priori as a function of composition and throughput and a reasonable cost assigned to better define the objective function, F.

[0068] To mitigate some of the aforementioned environmental emissions, the impact of appropriate shielding may be computed from the coupled simulators. Shielding elevates emission limits that may impact a priori tabulation. However, the cost of such shielding may be defined for the objective function, F.

[0069] Burner and flare operating time window issues may be at least partially addressed using a new keyword or argument in the wellbore clean-up simulator. For example, the keyword may be called SHUTIN to indicate when a wellbore operation (e.g., cleanup, production, etc.) is delayed, paused, and/or stopped. This may be implemented as an argument in another keyword (e.g., CHOKE) and/or as a dedicated keyword. The insertion of text 'SHUTIN' as an argument may be accompanied by the clock-time duration of the shut-in itself, after which wellbore operation (e.g., clean-up) will recommence. Table 1 below shows an embodiment of SHUTIN used as an argument in the CHOKE keyword.

TABLE-US-00001 TABLE 1 CHOKE keyword with SHUTIN argument 2 48 8 SHUTIN 4 64

[0070] In Table 1, there is an eight hour shut-in after two hours of flow with choke set at 48 (e.g., 48/64″). The wellbore clean-up job is then recommenced with four hours of flow with a choke set at 64 (e.g., 64/64 or 1″). If conforming to emission regulations, a specific job-clock keyword may be used, such as CLOCKDATE shown in Table 2.

TABLE-US-00002 TABLE 2 CLOCKDATE keyword #1 #2 #3 #4 20:30 2024 05 02

[0071] The arguments of CLOCKDATE may be defined using Table 3 below:

TABLE-US-00003 TABLE 3 CLOCKDATE keyword #1 #2 #3 #4 Clock Time 24 hr Year Month Day [hh:mm] [YYYY] [MM] [DD]

[0072] Using Tables 2 and 3 to interpret Table 1 shows that choke defines a shut-in starting at 10:30 pm (i.e., two hours after start of job 8:30 pm (20:30)). The job recommences on May 3 at 6:30 and lasts for four hours (after 8 hours of shut-in).

[0073] Wellbore and/or flow modules may be active during shut-in to monitor for gravity segregation and potential fluid ingress back into the near wellbore region. Upon wellbore clean-up recommencement after shut-in, fluid saturation profiles in the well and the near wellbore region may have changed, causing the wellbore clean-up simulator to re-initialize itself accordingly.

During shut-in will, by definition, yield zero flow (or emissions) at surface. However, the subsurface system may be in a state of flux with phase segregation, counter-current flow, ingress, and so on. In some embodiments, the shut-in keyword or other similar operation halts, pauses, or delays may be used when one of the constraints (either a priori computed or using couples simulations) is violated.

Managing Uncertainty

[0074] As previously noted in relation to block **340** of FIG. **4**, at least some of the uncertainties may be present in simulation and/or computations of the objective function, F. Such uncertainties may be defined in a keyword for the wellbore clean-up simulator, such as RESERVOIR. For instance, some of the uncertain parameters may include the productivity index (PI) or J of the producing layer, volume of fluid invading formation during drilling, depth of invasion, types of solids and depth invading formation, permeability of the zone, porosity of the zone, and/or other factors.

[0075] It may be difficult to ascertain which uncertain parameters are the most impactful to the objective function, F, identify their bounds, identify their distributions, and determine how to best sample over these distributions. Furthermore, the issue of sample size may become problematic for stand-alone applications. However, cloud computing resources of the cloud **274** may be employed to resolve such limitations.

[0076] The question of the appropriate number of samples used to define an the inherent uncertainty (to a manageable number) is reduced somewhat, though perhaps not completely eliminated through cloud computation. However, such balance between sample size and compute resources may still be desirable/necessary. Thus, a preliminary sensitivity analysis may be performed prior to any operational optimization. The total number of calls to the simulator, N, that is to be used in each trial in the optimization defined by Equation 1:

[00001] $N = \underset{k=1}{\overset{K}{.\text{Math.}}} (s_k .\text{Math.} U_k)$ (Equation1)

[0077] K is the total number of uncertainties for the wellbore clean-up problem and (s.sub.K|U.sub.k) are the number of samples necessary to define uncertainty U.sub.k. As N is a product, it can become large quickly if s.sub.k and K are not selected carefully even though cloud computing may make computations faster. The uncertainty may be declared for the cleanup operation in the wellbore clean-up simulator using a relevant keyword, such as RESERVOIR and CONSTPRODIDX. For example, Table 4 shows an embodiment of a keyword (e.g., CONSTPRODIDX and/or RESERVOIR) describing two producing zones.

TABLE-US-00004 TABLE 4 Uncertainty declaration in a keyword #1 #2 #3 #4 #5 #6 #7 #8 #9 #10 5780 6100 0.19 107 310 0.17 0 3.5 0.075 0.020679 6198 6589 0.20 95 320 0.21 0 3.5 0.075 0.021534

[0078] Arguments #1 and #2 are measured depths of top and bottom of completed reservoir zone with argument #3 being porosity. Argument #4 is permeability (k stated in mD). Argument #5 is initial reservoir pressure (Bar) with argument #6 representing initial water saturation, S.sub.W with argument #7 being salt concentration. Argument #8 is the parameter m in the relationship k=k.sub.0(ϕ).sup.m that may typically be a constant. Argument #9 is drilling time (in hours). The meaning of argument #10 may be dependent on whether a specific keyword (e.g., CONSTPRODIDX) is declared or not.

[0079] In the example with the specific keyword declared, argument #10 represents productivity index (PI) of the zone (stated in Sm.sup.3/d/bar). Using conventional $-delimited declarations for uncertainties we specify two such declaration for PI for both layers, as shown in Table 5 below:

TABLE-US-00005 TABLE 5 Uncertainty declaration in a keyword #1 #2 #3 #4 #5 #6 #7 #8 #9 #10 5780 6100 0.19 107 310 0.17 0 3.5 0.075 $PIL1$ 6198 6589 0.20 95 320 0.21 0 3.5 0.075 $PIL2$

[0080] According to Table 5, the PI for zone 1 (5780 to 6100 m) is declared as $PIL1$ which is sampled at three equally probable points: Uk=1, with 3 samples {0:020; 0:022; 0:024}. PI for zone

2 (6198 to 6589 m) is declared as $PIL2$, sampled at three equally probable points: Uk=2, with 3 samples {0:019; 0:021; 0:023}. Using Equation 1, we have K=2 thus N=9. In other words, a single trial of the wellbore clean-up simulator will require 9 separate (but perhaps parallel) calls to the wellbore clean-up simulator simulation engine. We then obtain values for μ and σ. If there are further uncertainties, such as samples for ϕ, then Equation 1 soon results in an explosion of samples per trial. For example, 2 additional independent samples for ϕ for both zones, then N=36 as K=4, so sK=[3 3 2 2] for k=1-4. In other words, a single trial will require 36 separate (but perhaps parallel) calls of the wellbore clean-up simulator in order to compute with uncertainties. Although uniform grid sampling may be used, non-uniform grid sampling may be instead and/or also used. Indeed, many uncertain parameters may be better addressed using non-uniform sampling schemes. Moreover, all uncertainty samples are to be drawn over the uncertainty space using grid sampling or otherwise.

Minimizing CO.SUB.2 .Emissions

[0081] As previously noted, the objective function, F, may include minimizing CO_2 emissions in identifying a wellbore clean-up choke schedule. CO_2 emissions may be simulated using the commercial process facility simulator and the wellbore clean-up simulator for different situations. For instance, the wellbore clean-up simulator may simulate wellbore invasion and associated damage along with multi-phase fluid flow as a function of surface choke settings, downhole pressure, and saturations. In other words, the wellbore clean-up simulator may model the behavior of fluids in the wellbore as a function of the choke schedule. The commercial process facility simulator may model surface and/or subsurface facilities to compute CO_2 emissions for a given input fluid stream as a function of time. For instance, the commercial process facility simulator may be used to derive information about energy consumption of equipment in terms of equivalent CO_2 emissions, emissions emanating from gas flaring, and/or emissions emanating from burning of liquid hydrocarbon. Additional emissions considerations may be tracked, such as those related to transportation of equipment to the wellhead, set-up, testing, and/or other information. For instance, such information may be estimated (based on number of loads/vehicles/trip lengths), simulated (based on number of loads/vehicles/trip lengths), tracked, and/or manually input to the plurality of simulators.

[0082] To consider CO_2, the level of CO_2 emissions is used from the simulators as the objective function, F, as performed in block **308** of FIG. **3**. As previously noted, this level of CO_2 emissions may be tied to the choke schedule developed to assist evacuation of clean-up fluids from the wellbore. However, additional and/or alternative parameters may be controlled and/or used to determine a level of CO_2 emissions during the clean-up job.

[0083] CO_2 emissions may be calculated for particular designs, choke schedules, and/or other parameters using the foregoing techniques. For instance, FIG. **10** shows a graph **470** that represents data points for different trials/simulations that are plotted along axis **472** with resulting clean-up quality along axis **474**. The axis **474** represents a quality of clean-up that is a ratio of hydrocarbons to the total wellbore fluid volume. The trial points along the axis **472** may also be plotted against axis **476** that corresponds to a level of CO_2 emissions. Thus, selection of various parameters (e.g., choke schedule) may at least partially factor into how much CO_2 is emitted. As the trial index changes, the clean-up quality generally increases while the amount of CO_2 emitted is more sporadic though generally increasing as well. In one embodiment, the trials/results may be filtered over both goals where one design/trial settings may be selected that minimizes the emission of CO_2 while achieving a reasonable level/threshold of clean-up quality. Additionally or alternatively, an objective measure may be augmented to implicitly account for both competing goals explicitly using a multi-objective solution as discussed below.

[0084] Using the trial data, the trial index, clean-up quality, job time (hours) and CO_2 emissions (tons) may be stored in a ranked-order table. For instance, Table 6 below may represent an example of trials run using real-world numbers, simulation, emulation, and/or any other suitable

techniques.

TABLE-US-00006 TABLE 6 Ranked-order table showing trial index, clean-up quality, job time, and CO_2 emissions for multiple trials.

Trial	Clean-up Quality	Job Time	CO_2 Emission
93	100.0	33.6	131,921
88	99.9	31.2	134,145
71	99.5	36.5	129,843
50	99.0	34.3	127,064
17	98.0	29.5	119,037
12	97.0	33.8	116,582
14	96.0	36.6	115,709
24	95.0	26.9	116,766
. . .	. . .	. . .	. . .
6	82.0	40.2	114,227

[0085] As previously noted, the level of CO_2 emissions may be extracted for any wellbore clean-up optimizations using one or more suitable techniques: pre-computation and tabulation of all outputs, coupled simulation, and partial pre-computation and tabulation of outputs that are all addressed separately in the following sections.

Pre-Compute and Tabulation of all Outputs

[0086] In this approach, a more extensive pre-job computation may be performed using the commercial process facility simulator since the wellbore clean-up simulator may not yield equivalent CO_2 emissions of any facilities without the commercial process facility simulator. The commercial process facility simulator may be used to perform a pre-job computation, such as is similar to the process **420** of FIG. **7**. The pre-job computations may cover a range of hydrocarbon flow rates and energy usage of the equipment configuration. The tables used to store the results may be a multi-dimensional table that includes likely CO_2 emission per unit of hydrocarbon liquids produced, likely CO_2 emission per unit of hydrocarbon gases produced, likely CO_2 emission associated with energy consumption of facilities (may be function of fluid throughput), variations of emissions for different equipment configurations, and/or other suitable parameters. The resulting table may include parameters derived from outputs of the wellbore clean-up simulator, such as surface rates, upstream choke pressure, etc. With these pre-generated tables with the expansive outputs, the objective function determination may be performed without explicit calls to the commercial process facility simulator during run time.

[0087] The length of how long the pre-computation would take to complete would be a function of granularity of the sampling of the input one or more sets(S) of parameters (e.g., block **422**). For instance, S may represent a set of all possible liquid flowrates (Q_{oil}, $Q_{cushion}$, Q_{mud}, $Q_{filtrate}$, etc.), volumetric flow rate of gas, pressure (e.g., at surface choke outlet), temperature, facility energy requirements by clean-up job, and/or any other properties associated with a clean-up job that may impact CO_2 emissions (e.g., transportation of equipment, removal of solids and surface clean-up, etc.). As may be appreciated, as the granularity of S increases (e.g., more samples), the consumption of computing resources may increase. Thus, a balance may be struck between high compute resource requirements for large numbers of samples and diminished solution accuracy due to sampling that is too sparse.

Coupled Simulators

[0088] In place of and/or in addition to pre-computing a relatively large number of outputs, the wellbore clean-up simulator and the commercial process facility simulator may function together in a coupled configuration (i.e., coupling their codes together) as previously discussed in relation to FIG. **5**. To achieve such a flexible and accurate prediction of CO_2 emissions in both hydrocarbon flaring, burning, and equipment energy function, the simulators may be coupled. For instance, the wellbore clean-up simulator may have the flowrates of each phase first computed as functions of choke settings/adjustments. The flowrates, pressures, and temperatures are then passed from the wellbore clean-up simulator to the commercial process facility simulator. Using that data, the commercial process facility simulator then extracts the CO_2 emissions. Fluid flow rates and required condition changes through surface equipment (and related mechanical efficiencies) enable the commercial process facility simulator to calculate CO_2 equivalent emissions.

Partial Pre-Computation (Hybrid)

[0089] In some embodiments, it may be impossible or impractical to couple the codes of the wellbore clean-up simulator and the commercial process facility simulator due to the complexity

and/or compatibility of the information exchanged between the simulators. To at least partially alleviate such issues, a hybrid approach may be adopted where some parameters are pre-computed while others are evaluated by the commercial process facility simulator on demand. Thus, when a computation is particularly expensive (e.g., time-wise and/or resource-wise), it may be omitted from pre-computation and instead be performed on-demand similar to the complex restraints discussed previously. For instance, when performing CO_2 emission computation, the commercial process facility simulator may function similarly to the coupled simulators previously discussed except that the commercial process facility simulator may determine the liquid flowrates without considering pressure, temperature, energy requirements, and/or any other aspects that may impact facility operations. In other words, the simulations may be restricted to volumetric flowrates and/or their corresponding CO_2 emissions. These values may be stored in tables to be later used to determine flow rates and/or CO_2 emissions from other measurements. At this later time, outputs of the wellbore clean-up simulator may be determined and used to find outputs of the wellbore clean-up simulator. These outputs along with the looked up flowrates values (and/or corresponding CO_2 emissions) are used in the commercial process facility simulator to determine the overall CO_2 emissions. For instance, in some embodiments, the commercial process facility emulator may determine CO_2 emissions attributable to flowrates and storing such data in the table(s). Later, the commercial process facility emulator may obtain outputs from the wellbore clean-up simulator to determine additional CO_2 emissions from those outputs. The two CO_2 emissions may then be added together to determine the overall CO_2 emissions. Additionally or alternatively, the pre-computed parameters may be intermediate measurements (e.g., flowrates, etc.) with CO_2 emissions being computed alongside the CO_2 emissions calculations based on the outputs of the wellbore clean-up simulator.

Multi-Objective Optimization

[0090] As previously noted, two goals of maximizing wellbore clean-up and minimizing the total CO_2 emissions result in a multi-objective optimization problem. For the purposes of discussion, let the original measure for wellbore clean-up be defined as function $f_1(X)$, where X represents the set of n control variables in the problem. Also, $f_2(X)$ is defined as the second measure for CO_2 emissions.

[0091] One method for managing the dual objective problem includes implicitly treating both goals into a single objective or by eliminating one goal in preference of the other by constraint assignment. In the former, the measures may be standardized and combined using weights, such as that shown in the following equation:

[00002] $$\min F(X) = w_1 \bar{f_1}(X) + w_2 f_2(X), \quad \text{(Equation 2)}$$

where w_1 is the weight for the wellbore clean-up function f_1, w_2 is the weight for the wellbore clean-up function f_2, and $f_1(X) = -f_1(X)$ as a minimization of the wellbore clean-up goal.

[0092] The advantage of this approach is that it provides a simple way to combine multiple objectives, and any suitable nonlinear optimization procedure can be applied to the combined objective for solution, as it could to any one objective alone (e.g., $f_1(X)$ previously). The disadvantage, however, is that the weights may not be well understood, and indeed, the linear combination may not ensure full discovery of the Pareto Front. As shown in FIG. **11**, a graph **480** includes a Pareto Front **482** that defines the set of all optimal (non-dominated) solutions that are indicative of the trade-off between each sub-objective. Hence, the advantage in solution procedure is at the cost of a potentially less well developed, and therefore less well understood, Pareto Front. Conversion of one goal to a constraint may help identify a better Pareto Front when anticipated to be non-convex in form. However, the relegation of goals, their preferential ordering and level stipulation is far from trivial, especially when considering many goals.

[0093] The second approach is to consider both objectives explicitly. Without loss, we define the

multi-objective optimization problem as follows:

[00003] $\min F(X) = \min([\bar{f}_1(X), f_2(X)]$,   (Equation3)

where each subjective is treated separately by the optimization procedure intended for that purpose. As shown in FIG. **11**, a multi-objective optimization scheme will aim to determine the collection of non-dominated solutions (empty squares) that identify the Pareto Front **482**. In the FIG. **11**, both sub-objectives are to be minimized. Thus, the extreme points of the Pareto Front **482** indicate the optimal value of one measure at the cost of the other. Along the Pareto Front **482**, there is a trade-off between both objectives. The dominated/sub-optimal solutions appear above the Pareto Front and are typically undesirable. For the present problem however, if the full clean-up is necessary, the degradation of f.sub.2(x) may warrant dominated solutions within a tolerable range of the Pareto Front **482**.

Reducing CO.sub.2 Emissions with Facility Design

[0094] To reduce CO.sub.2 emissions, the facility may be redesigned to reduce/minimize CO.sub.2 emissions for optimization of a wellbore clean-up without (excessively) compromising clean-up quality. For instance, system **500** of FIG. **12** may illustrate a facility that uses a Boudouard reaction to reduce CO.sub.2 emissions. The Boudouard reaction is defined as 2CO⇌CO.sub.2+C. The system **500** receives air **502** and hydrocarbons **504**. The hydrocarbons **504** and air **502** are mixed in a mixer **505** and passed to a partially oxidized burner **506**. The partially oxidized burner **506** burns the hydrocarbons **504** and produces syngas **508** that is passed to a heat exchanger **510** and/or air cooler **512** to cool the syngas **508** that is then passed to a collector **514** that collects carbon as soot that drops from the cooled syngas **508** as soot. The heat exchanger **510** may be stationed prior to the air cooler **512** to keep a flare flame **518** in a flare stack **520** similar as possible to a flaring process without the reduced CO.sub.2 emissions due to the collector **514**. The system **500** may also use a trim feed **522** for air **502** and/or hydrocarbons **504** to bypass the partially oxidized burner **506** to enable additional flare temperature control for the flare stack **520**. In other words, the partially oxidized burner **506**, heat exchanger **510**, air cooler **512**, and/or collector **514** removes at least some carbon content from flue gas as solid soot **516**. For instance, if 100 mols of carbon is in the hydrocarbons **504** and b is the amount of mols of carbon in the soot **516**, the flare stack **520** may output **100**-*b* mols of carbon as CO.sub.2.

[0095] FIG. **13** shows a system **600** that is another embodiment (or more detailed embodiment) of the system **500**. The system **600** functions similar to the functions discussed in relation to the system **500** of FIG. **12**. The system **600** also shows a nozzle and throat **602** that may at least partially determine how much soot **516** is dropped out of the syngas **508** in the collector **514**. For instance, with one setting (e.g., throat diameter of 24″ and nozzle diameter of 18″), a first percentage (10%) of CO.sub.2 emissions may be reduced while another setting (e.g., throat diameter of 36″ and nozzle diameter of 24″) may cause reduction by a second percentage (e.g., 20%) by changing the mixture in the partially oxidized burner **506**. The trim feed **522** may also include a cold trim feed **604** and a hot trim feed **606**. Likewise, the collector **514** may include a dropout chamber **608** where carbon laydown **610** results in the soot **516**.

[0096] The techniques presented and claimed herein are referenced and applied to material objects and concrete examples of a practical nature that demonstrably improve the present technical field and, as such, are not abstract, intangible, or purely theoretical. Moreover, although various actions are discussed as part of processes in a specific order, at least some of the actions may be performed in different orders. Additionally, at least some of the actions may be performed by one or more processors **256** of suitable computing devices. Further, if any claims appended to the end of this specification contain one or more elements designated as "means for [perform]ing [a function] . . . " or "step for [perform]ing [a function] . . . ," it is intended that such elements are to be interpreted under 35 U.S.C. § 112 (f). However, for any claims containing elements designated in any other manner, it is intended that such elements are not to be interpreted under 35 U.S.C. § 112 (f).

Claims

1. A system, comprising: a mixer configured to mix air and hydrocarbons; a burner configured to receive the mixed air and hydrocarbons and to generate syngas; a cooling system configured to receive the syngas and to cool the syngas to form cooled syngas; a collector configured to collect carbon from the cooled syngas as soot; and a flare stack configured to receive the cooled syngas and to burn off at least part of the cooled syngas.

2. The system of claim 1, comprising one or more processors configured to implement coupled simulators to simulate CO_2 emissions for at least part of a wellbore clean-up.

3. The system of claim 1, wherein the mixer comprises a nozzle.

4. The system of claim 1, wherein the mixer comprises a throat and nozzle configured to mix the air and hydrocarbons.

5. The system of claim 1, wherein the cooling system comprises a heat exchanger.

6. The system of claim 1, wherein the cooling system comprises an air cooler configured to cool the syngas.

7. The system of claim 1, wherein the cooling system comprises: a heat exchanger coupled to the burner configured to receive the syngas from the burner; and an air cooler coupled to the heat exchanger and the collector.

8. The system of claim 1, comprising a cool trim path to pass at least some hydrocarbons to the cooling system bypassing the burner.

9. The system of claim 1, comprising a hot trim path to pass the syngas from the cooling system to the flare stack.

10. The system of claim 1, wherein due to the dropping of carbon as soot, the hydrocarbons comprises more carbon than an output of the flare stack by the amount of carbon in the soot.

11. A method, comprising: receiving one or more sets of parameters related to an operation corresponding to a wellbore; at a first time, simulating at least a portion of the operation using the one or more sets of parameters to determine CO_2 emissions during the operation; recording pertinent results from the simulation; storing results comprising the CO_2 emissions for the operation in a table; at a second time, retrieving the determined CO_2 emissions from the table; and using the determined CO_2 emissions to control the operation.

12. The method of claim 11, wherein the operation comprises a cleanup operation of the wellbore.

13. The method of claim 11, wherein the one or more sets of parameters comprise real-world conditions of the wellbore.

14. The method of claim 11, wherein simulating the operation using the one or more sets of parameters comprises simulating the operation using a plurality of coupled simulators.

15. The method of claim 14, wherein the plurality of coupled simulators comprises a commercial process facility simulator.

16. The method of claim 14, wherein the plurality of coupled simulators comprises a wellbore clean-up simulator.

17. The method of claim 14, comprising determining, using a commercial process facility simulator, additional CO_2 emissions at the second time using outputs of a wellbore cleanup simulator.

18. A system, comprising: a throat and nozzle system configured to mix air and hydrocarbons; a burner configured to receive the mixed air and hydrocarbons from the throat and nozzle system and to generate syngas; an air cooler configured to receive the syngas and to cool the syngas to form cooled syngas; a collector configured to collect carbon from the cooled syngas as soot; a flare stack configured to receive the cooled syngas and to burn off at least part of the cooled syngas; and a heat exchanger located between the air cooler and the collector to control a temperature of the flare stack.

19. The system of claim 18, wherein a diameter of the throat and nozzle system at least partially controls an amount of carbon in the soot collected in the collector from the hydrocarbons.

20. The system of claim 18, comprising a trim system comprising: a cool trim path configured to enable at least some of the hydrocarbons to bypass the burner; and a hot trim path configured to enable at least some of the syngas to bypass the air cooler and the collector to the flare stack.