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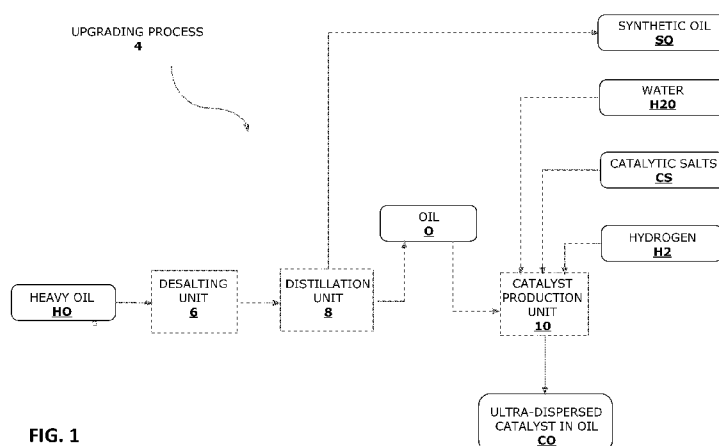


FIG. 1

(57) Abstract: A catalyst preparation unit for producing an activated hydrocarbon-catalyst mixture. The catalyst preparation unit includes one or more catalyst reactant input conduits; a hydrocarbon input conduit; a water input conduit; one or more catalyst reactant mixing and conveyance systems for receiving and mixing catalyst reactants from the catalyst component input conduits and water provided by the water input conduit to provide one or more catalyst reactant solutions; one or more hydrocarbon mixing and conveyance systems for receiving and mixing the catalyst reactant solutions and hydrocarbons provided by the hydrocarbon input conduit to produce a hydrocarbon-catalyst reactant mixture; at least one reactor located downstream of the mixers, for receiving and activating the hydrocarbon-catalyst reactant mixture, thereby producing the activated hydrocarbon catalyst mixture; a gas/liquid separator located downstream of the reactor, for removing vapors and gas from the activated hydrocarbon-catalyst mixture; and an output conduit for transporting the activated hydrocarbon-catalyst mixture away from the catalyst preparation unit.



CATALYST PREPARATION UNIT FOR USE IN PROCESSING OF HEAVY HYDROCARBONS

FIELD OF THE INVENTION

[0001] The invention relates to the field of processing of hydrocarbons and provides a catalyst preparation unit for producing a mixture of activated catalyst for this purpose.

BACKGROUND OF THE INVENTION

[0002] The use of catalysts in the processing of hydrocarbons is well known. Catalysts enable hydrocarbon processing reactions, such as hydro-treating, hydrocracking, steam cracking or upgrading reactions, to proceed more efficiently under various reaction conditions with the result that the overall efficiency and economics of a process are enhanced. Different catalysts are more effective in certain reactions than others and, as a result, significant research is conducted into the design of catalysts in order to continue to improve the efficiencies of reactions. Many factors such as catalyst chemistry, particle size, support structure and the reaction chemistry to produce the catalyst are very important in determining the reaction efficiency and effectiveness as well as the economics of a particular catalyst.

[0003] Catalysts can be generally categorized as supported and unsupported catalysts. Supported catalysts are more widely used due to several advantages including the high surface area available to anchor active phases (usually metals) predominantly responsible for the catalytic activity on the support. One advantage of supported catalysts over unsupported catalysts is that no separation of catalysts from reactants and products is required from within or outside the reaction vessel.

[0004] While effective in many applications, supported catalysts are at a disadvantage when used with feedstocks that inevitably produce solid deposits within the porous network of the catalyst support. In such cases a progressive loss of catalyst performance due to pore plugging occurs, making larger quantities of catalysts required for a given process to maintain efficient reactions.

[0005] Unsupported catalysts are not physically supported on a solid matrix and therefore are less expensive to produce. In reactions where unsupported catalysts are soluble in the reaction media, difficulties in recovery of the catalysts from the product stream increase reaction or production costs because the catalysts must be replaced. There may also be a requirement for

the reactants to be subjected to costly separation processes. Frequently, unsupported metal based catalysts with equivalent particle sizes or diameters to supported catalysts offer lower surface area of catalytic active phases. However, unsupported catalysts with particle sizes below the micron range provide advantages over supported catalysts by increasing the surface area available of active sites for reaction and thus, may enable a reaction to proceed more efficiently as compared to a reaction utilizing a supported catalyst.

[0006] While there is no universal rule with respect to the superiority of one class of catalyst over another, in many systems, a primary consideration in choosing or designing a catalyst system is the potential trade-off between the reaction efficiency and costs of unsupported catalysts versus supported catalysts.

[0007] *In situ* upgrading of hydrocarbons directly in a reservoir has become more feasible with development of processes using a high heating capacity fluid extracted from the same produced crude oil. This heating fluid may also be used as the heat conductor for the nano-catalyst which is needed to promote the upgrading reactions at relatively low temperatures.

[0008] The option of using conventional (heterogeneous) upgrading catalysts, to process heavy crude oil produced in a reservoir or very close to the producing well has been investigated. One of the most significant improvements in this area has led to the possibility of applying the process well to well, and, as a result, smaller scale equipment can be used which will resist pressure. Because the upgrading reactions occur within the reservoir, the small amount of coke that could be produced would remain within the reservoir (Weissman, J.G. and R.V. Kessler, Downhole heavy crude oil hydroprocessing. Applied Catalysis A: General, 1996. 140(1): p. 1-16, incorporated herein by reference in entirety).

[0009] Catalytic upgrading near the producing well has been investigated in an upgrading process which includes placing a catalyst in the producing well through conventional injection techniques and heating the production zone using electric elements, and injecting hydrogen or synthesis gas in the producing well. In this way, the fluids coming from the *in situ* combustion are forced to pass through the reservoir matrix. Results from various experiments indicated a larger production of hydrogen and hydrocarbons in the case of the catalytic test in comparison with the non-catalytic test. An increase of 8 degrees API was also observed in the density of the catalytic product, and a reduction of around 50% m of sulfur (Weissman, J. et al., Down-hole catalytic upgrading of heavy crude oil. Energy & Fuels, 1996. 10(4): p. 883-889, incorporated herein by reference in entirety). However, the risk of contact between fluids from *in situ*

combustion and synthesis gas or hydrogen at a high temperature is an important challenge for the control of that process.

[00010] The abovementioned investigations did not provide solutions to major challenges of a real-world upgrading process. The problem of incorporating a catalyst through the porous media of the reservoir in conditions different to those of air injection, and avoiding the deactivation of the catalyst was not addressed. This last challenge involves the maintenance of an economic process while reducing coke formation that at the same time is the cause and consequence of catalyst deactivation.

[00011] As such, one of the existing main challenges is the rapid deactivation or poisoning of the catalyst due to the large amount of contaminants such as: asphaltenes, sulfur and metals (Galarraga, C.E. and P. Pereira-Almao, Hydrocracking of Athabasca bitumen using submicronic multimetallic catalysts at near in-reservoir conditions. Energy & Fuels, 2010, 24(4): p. 2383-2389, incorporated herein by reference in entirety). Another challenge involves the transport of heat to the reservoir in a conventional (non-electrical) and continuous manner, without incurring large costs of energy transfer and while ensuring production with a stable increase in quality and crude oil. *In situ* combustion produces upgraded products only at the end of its lifetime. At the same time, this process produces olefins in significant amounts when insufficient levels of hydrogen are present.

[00012] Hydrocracking of bitumen using a variety of ultra-dispersed catalysts based on metallic particles (nickel, cobalt, tungsten and molybdenum) nano or sub-micron particles has been described (U.S. Patents 8,551,907, 8,304,363, 8,298,982, 8,283,279, and 7,897,537 each of which is incorporated herein by reference in entirety).

[00013] These ultra-dispersed catalysts have been investigated under conditions similar to the conditions existing in the reservoirs of the Athabasca region of Alberta, Canada, with sand packing within a permeability range between about 1 to about 12 Darcies. The tests performed (with or without catalysts) were between about 270°C and about 380°C and between about 8 and about 210 hours for crude oil. With the catalyst contact and the hydrogen flowing continuously, it was confirmed that the ultra-dispersed catalysts increase conversion, reduce micro carbon residue, reduce coke formation, and increase desulfurization. It was also confirmed that upon increasing temperature, the conversion of the residue fraction of the crude oil increases and the quality of the hydrocarbon product is reproducibly improved in terms of density, viscosity, and sulfur levels (Luis Alejandro Coy, P.P.-A. Experimental Reactive

Simulation of a Hot Fluid Injection Process for In-Reservoir Upgrading. In World Heavy Oil congress 2014. New Orleans, LA, USA: DMG Energy Conferences; Galarrraga, C.E. and P. Pereira-Almao, Hydrocracking of Athabasca bitumen using submicronic multimetallic catalysts at near in-reservoir conditions. Energy & Fuels, 2010. 24(4): p. 2383-2389; Rendón, V., Experimental Evaluation of In Situ Upgrading by Continuous Injection of Submicronic Catalysts at Moderate Temperatures with Hydrogen Addition, in Schulich School of Engineering. 2011, University of Calgary: Calgary. p. 238, each of which is incorporated herein by reference in entirety).

[00014] The transportability of ultra-dispersed catalysts in vacuum gas oil (VGO) initially at a temperature close to 25 °C has been described. Most notably, the surfactant that could be used in the preparation of the ultra-dispersed catalysts does not decompose entirely under the tested conditions, and that it had a tendency to form emulsions within a packed bed (previously saturated with water), precipitating some particles causing blocking of the packing, especially at its entrance. In a later test studying the effect of formation water, it was found that retention of the catalyst at the surface of the sand is slightly higher (approx. 18%) than the injected amount, given the absence of water at the surface of the sand grains. It was also found that the metallic particles suspended in the fluid, within the packing, were dragged out of the system, whereas those previously retained in the bed were not significantly affected. Further experiments at higher temperature show that the flow of a hydrocarbon stream with nano-dispersed catalysts can easily propagate through a packed bed without negatively affecting the permeability of the packed bed (Zamani, A., B. Maini, and P. Pereira-Almao, Experimental study on transport of ultra-dispersed catalyst particles in porous media. Energy & Fuels, 2010. 24(9): p. 4980-4988; Zamani, A., B. Maini, and P. Pereira-Almao, Flow of nanodispersed catalyst particles through porous media: Effect of permeability and temperature. The Canadian Journal of Chemical Engineering, 2012, 90(2): p. 304-314, each of which is incorporated herein by reference in entirety).

[00015] Tests at higher temperature (150°C) with low concentration of ultra dispersed catalysts showed retention of the catalyst of at least 20%. At higher temperature 280°C or more no evidence of the catalyst at the exit of the packing was found. Thus retention is increased at high temperatures of at least 150°C. It is possible that hydrodemetalation reactions could be taking place at the highest temperatures indicated. Permeability reduction in the highest

temperature tests was 5 to 1.9 Darcies after the injection of over 60 porous volumes through the packing and submitting it to diverse reaction conditions, with and without nano catalysts (Rendón, V., Experimental Evaluation of In Situ Upgrading by Continuous Injection of Submicronic Catalysts at Moderate Temperatures with Hydrogen Addition, in Schulich School of Engineering. 2011, University of Calgary: Calgary. p. 238, incorporated herein by reference in entirety).

[00016] The result of these investigations indicate that it is possible to inject an emulsion made up of heavy hydrocarbons, hydrogen and ultra-dispersed catalysts into a reservoir without damaging the structure of the reservoir. Moreover, it was confirmed that it is possible to fill the packed bed with sub micron particles, and that once inside the reservoir, the packed bed turns into a “fixed bed” type reactor, which can improve hydrocarbon streams without further addition of catalysts by adding a small amount of hydrogen. One such example is found in Canadian patent 2,810,022, which is incorporated herein by reference in entirety.

[00017] With these recent advancements in hydrocarbon processing technology, it is now possible to develop systems for performing larger scale processing of hydrocarbons. As a result, a number of problems must be addressed to take full advantage of the technology. One such problem is a requirement for a catalyst preparation unit with sufficient flexibility to produce hydrocarbon processing catalysts efficiently and at relatively low cost.

SUMMARY OF THE INVENTION

[00018] In accordance with a first aspect of the invention, a catalyst preparation unit for producing an activated hydrocarbon-catalyst mixture is described, the catalyst preparation unit comprising: one or more catalyst reactant input conduits; a hydrocarbon input conduit; a water input conduit; one or more catalyst reactant mixing and conveyance systems for receiving and mixing catalyst reactants from the catalyst component input conduits and water provided by the water input conduit to provide one or more catalyst reactant solutions; one or more hydrocarbon mixing and conveyance systems for receiving and mixing the catalyst reactant solutions and hydrocarbons provided by the hydrocarbon input conduit to produce a hydrocarbon-catalyst reactant mixture; at least one reactor located downstream of the mixers, for receiving and activating the hydrocarbon-catalyst reactant mixture, thereby producing the activated hydrocarbon catalyst mixture; a gas/liquid separator located downstream of the reactor, for

removing vapors and gas from the activated hydrocarbon-catalyst mixture; and an output conduit for transporting the activated hydrocarbon-catalyst mixture away from the catalyst preparation unit.

[00019] In one embodiment, the catalyst reactant input conduits, and the catalyst reactant mixing and conveyance systems are chemically compatible with ammonium heptamolybdate, ammonium metatungstate, nickel acetate, cobalt acetate, ammonium sulfide and thiourea or any combination thereof.

[00020] In one embodiment, the catalyst reactant input conduits include three metal salt conduits and a sulfur source compound conduit.

[00021] In one embodiment, the catalyst reactant input conduits include two metal salt conduits and a sulfur source compound conduit.

[00022] In one embodiment, wherein the catalyst reactant input conduits include one metal salt conduit and a sulfur source compound conduit.

[00023] In a further embodiment, each of the catalyst reactant mixing and conveyance systems include a solution mixer for generating a catalyst reactant solution and a dosing pump for conveying specified volumes of the catalyst reactant solution to one of the hydrocarbon mixing and conveyance systems.

[00024] In one embodiment, each of the hydrocarbon mixing and conveyance systems comprises a centrifugal pump and an inline mixer, wherein the centrifugal pump is for drawing the hydrocarbons from outside of the catalyst preparation unit and conveying the hydrocarbons to the inline mixer for mixing with the catalyst reactant solution.

[00025] In one embodiment, two catalyst reactant mixing and conveyance systems and two hydrocarbon mixing and conveyance systems are provided, wherein one of the two catalyst reactant mixing and conveyance systems is configured to convey a solution of two different metal salts and a sulfur source compound and the other catalyst reactant mixing and conveyance system is configured to convey a third metal salt solution, and wherein one of the two hydrocarbon mixing and conveyance systems is configured to receive and mix the solution of the two different metal salts and the sulfur source compound with the hydrocarbons to produce a first hydrocarbon-catalyst mixture and convey the first hydrocarbon-catalyst reactant mixture to the reactor, and the other hydrocarbon mixing and conveyance system is configured to receive and mix the solution of the third metal salt with the hydrocarbons to produce a second

hydrocarbon-catalyst reactant mixture and convey the second hydrocarbon-catalyst reactant mixture to the reactor.

[00026] In one embodiment, the catalyst preparation unit includes three catalyst reactant mixing and conveyance systems, three hydrocarbon mixing and conveyance systems, and three reactors, wherein each of the three catalyst reactant mixing and conveyance systems is configured to convey a solution of a different metal salt and a sulfur source compound to a corresponding hydrocarbon mixing and conveyance system of the three hydrocarbon mixing and conveyance systems, thereby producing three different hydrocarbon-catalyst reactant mixtures and wherein each of the three hydrocarbon mixing and conveyance systems is further configured to convey its respective hydrocarbon-catalyst reactant mixture of the three different hydrocarbon-catalyst reactant mixtures to one of three corresponding reactors.

[00027] In one embodiment, reactor output from each of the three corresponding reactors is merged upstream of the gas/liquid separator.

[00028] In various embodiments, the catalyst preparation unit further includes a hydrogen input conduit for addition of hydrogen to the activated hydrocarbon-catalyst mixture in the output conduit.

[00029] In one embodiment, the hydrocarbon input conduit is configured for conveyance of heavy oil and in yet further embodiments, the heavy oil is a distillation residue from a heavy oil upgrading process with an API gravity of about 20° or less.

[00030] In various embodiments, the catalyst preparation unit is provided in modular form and configured for disengagement from a hydrocarbon processing facility, transport by a vehicle and engagement to another hydrocarbon processing facility.

[00031] In yet further embodiments, the catalyst preparation unit produces an activated hydrocarbon-catalyst mixture, the catalyst preparation unit comprising: a catalyst reactant input conduit; a hydrocarbon input conduit; a catalyst reactant and hydrocarbon mixing and conveyance system for receiving and mixing catalyst reactants from the catalyst reactant input conduit with hydrocarbons provided by the hydrocarbon input conduit to produce a catalyst reactant and hydrocarbon mixture; a reactor located downstream of the catalyst reactant and hydrocarbon mixing and conveyance system, for receiving and activating the hydrocarbon-catalyst reactant mixture, thereby producing the activated hydrocarbon catalyst mixture; a gas/liquid separator located downstream of the reactor, for removing vapors and gas from the

activated hydrocarbon-catalyst mixture; and an output conduit for transporting the activated hydrocarbon-catalyst mixture away from the catalyst preparation unit.

[00032] In a further embodiment, the catalyst reactant input conduit is configured for conveyance of a composite mixture of catalyst reactants in solid form.

[00033] In yet a further embodiment, the catalyst reactant input conduit and the catalyst reactant and hydrocarbon mixing and conveyance system are chemically compatible with ammonium heptamolybdate, ammonium metatungstate, nickel acetate, cobalt acetate, ammonium sulfide and thiourea or any combination thereof.

[00034] In a further embodiment, the catalyst reactant and hydrocarbon mixing and conveyance system comprises a mill for reducing the particle size of reactants, a high shear mixer downstream of the mill for further reducing the particle size of the reactants.

[00035] In one embodiment, the catalyst preparation unit further includes a centrifugal pump for conveying the hydrocarbon-catalyst reactant mixture to the reactor.

[00036] In yet another embodiment, the catalyst preparation unit further includes a hydrogen input conduit for addition of hydrogen to the activated hydrocarbon-catalyst mixture in the output conduit.

[00037] In one embodiment, the hydrocarbon input conduit is configured for conveyance of heavy oil and more specifically, in further embodiments, the heavy oil is a distillation residue from a heavy oil upgrading process with an API gravity of about 20° or less.

[00038] In another aspect, the invention describes a combination catalyst preparation unit for producing an activated hydrocarbon-catalyst mixture by either a mono-metallic catalyst preparation process or a composite salt feed process, the combination catalyst preparation unit comprising: the catalyst preparation unit as above for the mono-metallic catalyst preparation process; and the catalyst preparation unit as recited above for the composite salt feed process, wherein at least one of the three reactors used for the mono-metallic catalyst preparation process is shared by the catalyst preparation unit for the composite salt feed process; and the gas/liquid separator and the output conduit used for the mono-metallic catalyst preparation process are both shared by the catalyst preparation unit for the composite salt feed process.

[00039] In another embodiment, the catalyst preparation unit further includes a hydrogen input conduit for addition of hydrogen to the activated hydrocarbon-catalyst mixture in the output conduit.

[00040] Additionally, the hydrocarbon input conduit may be configured for conveyance of heavy oil and in further embodiments, wherein the heavy oil is a distillation residue from a heavy oil upgrading process with an API gravity of about 20° or less.

[00041] Further, the catalyst preparation unit may be provided in modular form and configured for disengagement from a hydrocarbon processing facility, transport by a vehicle and engagement to another hydrocarbon processing facility.

[00042] In another aspect, the invention describes an *in situ* hydrocarbon upgrading facility configured to process hydrocarbons by injection of a mixture of activated catalyst and hydrocarbons into a reservoir wherein the mixture of activated catalyst and hydrocarbons is generated using any of the catalyst preparation units as described herein. .

BRIEF DESCRIPTION OF THE DRAWINGS

[00043] Various objects, features and advantages of the invention will be apparent from the following description of particular embodiments of the invention, as illustrated in the accompanying drawings. Emphasis is placed upon illustrating the principles of various embodiments of the invention. Similar reference numerals indicate similar components.

Figure 1 is a block diagram showing an embodiment of a hydrocarbon upgrading process.

Figure 2A is the first part of a process flow diagram for a catalyst preparation unit that produces a mixture of an activated ultra-dispersed catalyst (UDC) in oil, according to a first process designated as Tri-metallic Catalyst Preparation.

Figure 2B is the second part of a two-part process flow diagram described in Figure 2A.

Figure 3A is the first part of a process flow diagram for a catalyst preparation unit that produces a mixture of an activated ultra-dispersed catalyst in oil, according to a second process designated as Salt Composite Feed Process.

Figure 3B is the second part of a two-part process flow diagram described for Figure 3A.

Figure 4A is the first part of a three-part process flow diagram for a catalyst preparation unit that produces a mixture of an activated ultra-dispersed catalyst in oil according to a third process designated as Mono-metallic Catalyst Preparation.

Figure 4B is the second part of the process flow diagram described for Figure 4A.

Figure 4C is the third part of the process flow diagram described for Figure 4A.

Figure 5A is the first part of a three-part process flow diagram for a catalyst preparation unit that produces a mixture of an activated ultra-dispersed catalyst in oil according to, either the second process described for Figure 3A or the third process described for Figure 4A.

Figure 5B is the second part of the process flow diagram described for Figure 5A.

Figure 5C is the third part of the process flow diagram described for Figure 5A.

DETAILED DESCRIPTION OF THE INVENTION

Introduction and Overview

[00044] A number of embodiments will now be described with reference to the Figures which illustrate process flow of example embodiments. Emphasis is placed on highlighting the various contributions of the components to the functionality of various aspects of the invention. A number of possible alternative features are introduced during the course of this description. It is to be understood that, according to the knowledge and judgment of persons skilled in the art, such alternative features may be substituted in various combinations to arrive at alternative embodiments of the present invention and that such alternative embodiments are within the scope of the invention. Wherever possible, similar reference numbers indicate similar features.

[00045] Embodiments of a catalyst preparation unit are described. The catalyst preparation unit is designed to produce a mixture of ultra-dispersed catalyst in oil for subsequent use in a hydrocarbon processing operation which will typically include significant *in situ* upgrading of heavy hydrocarbons in a reservoir to produce upgraded hydrocarbon products.

[00046] The definitions of various terms as provided herein are intended to provide guidance to the skilled reader with regards to the principles and scope of the invention and where appropriate define particular limits as reasonably understood by such a reader.

Definitions

[00047] As used herein, the term “heavy oil” refers to any liquid petroleum product with an API gravity value between 22.2° and 10°. API gravity is a scale developed by the American Petroleum Institute and represents a modification of the equation for determination of specific

gravity. API gravity and methods for its determination are well known to those skilled in the art of petroleum extraction. One example of a classification system of crude oil according to API gravity values is provided in Table 1 (www.petroleum.co.uk), incorporated herein by reference in entirety). Other classification systems may have different value ranges and possibly other categories such as “extra light” crude oil.

Table 1: Crude Oil API Gravity Classification

Crude Oil Classification	API Gravity Value
Light	31.1° or Higher
Medium	22.3° to 31°
Heavy	22.2° to 10°
Extra Heavy (Bitumen)	Lower than 10°

[00048] As used herein, the term “conduit” is used to describe any means for conveying solids or liquids within the catalyst preparation unit. Examples include, but are not limited to tubes or pipes which may be coupled to conveyance means driven by various types of liquid pumps or vacuum sources for conveyance of liquids, as well as gravity chutes or conveyor belts driven by mechanical means for conveyance of solids.

[00049] As used herein, the terms “downstream” and “upstream” are relative terms used to identify locations in a process with respect to one or more other locations. A downstream location with respect to another location is a position closer to the end of the process than the other location. An upstream location with respect to another location is a position closer to the beginning of the process than the other location. These terms are in common usage in the arts relating to process engineering and are well understood by those skilled in the art.

[00050] As used herein, the term “activated hydrocarbon-catalyst mixture” refers to a mixture of an active catalyst and hydrocarbons in liquid form. The catalyst is a metal-based catalyst designed for cracking of hydrocarbons. Examples include, but are not limited to, the catalysts described in 8,304,363, 8,298,982, 8,283,279, and 7,897,537 (each of which is incorporated herein by reference in entirety).

[00051] As used herein, the term “catalyst reactant mixing and conveyance system” refers to a system having any means for mixing a catalyst reactant with a liquid and for conveying the resulting mixture to a downstream processing component of the catalyst preparation unit. Equipment for mixing and conveyance of liquids is known to those with skill in the arts relating to process engineering and can be adapted to the catalyst preparation unit of the present invention without undue experimentation. As used herein, the similar term “hydrocarbon mixing and conveyance system” refers to a system having any means for mixing a liquid hydrocarbon with a liquid and for conveying the resulting mixture to a downstream processing component of the catalyst preparation unit. “Conveyance” in both definitions means may be provided by pumps or vacuum means. Equipment used for mixing and conveyance of liquid mixtures and hydrocarbon liquid mixtures is known to those with skill in the arts relating to process engineering and can be adapted to the catalyst preparation unit of the present invention without undue experimentation.

[00052] As used herein, the term “reactor” refers to a vessel wherein a chemical reaction takes place. Reactors may be provided with means for controlling temperature, pressure and other parameters for promotion of chemical reactions.

[00053] As used herein the term “sulfur source compound” is any compound that can be used to provide sulfur as a reactant in preparation of activated catalysts including, but not limited to the catalysts described in 8,304,363, 8,298,982, 8,283,279, and 7,897,537 (each incorporated herein by reference in entirety).

[00054] As used herein, the term “dosing pump” is any pump provided with a means for controlling the addition of a liquid to a process.

[00055] As used herein, the term “high-shear mixer” refers to an apparatus configured to disperse or transport one phase or ingredient (liquid, solid, gas) into a main continuous phase (liquid), with which it would normally be immiscible. A rotor or impeller, together with a stationary component known as a stator, or an array of rotors and stators, is used either in a tank containing the solution to be mixed, or in a pipe through which the solution passes, to create shear. A high-shear mixer can be used to create emulsions, suspensions, lyosols (gas dispersed in liquid), and granular products.

[00056] As used herein, the term “mill” refers to an apparatus for grinding solid material into particles of smaller sizes.

[00057] As used herein, the terms “hydrocarbon upgrading” and “upgrading” are synonymous and refer to processes for obtaining higher value products from a lower quality mixture of hydrocarbons, typically in liquid form and generally refer to processes that result in a higher API gravity product compared to a lower API gravity starting material.

Hydrocarbon Upgrading Processes

[00058] Embodiments of the catalyst preparation unit of the present invention are designed for operation as part of hydrocarbon upgrading processes, which may be an *in situ* process (i.e. where hydrocarbon processing occurs within a reservoir), or a surface-based upgrading process. In one example of a hydrocarbon upgrading process, a fraction of heavy oil is distilled to separate lower boiling point hydrocarbon products and the remaining less volatile fraction (lower API gravity) is further processed by the catalyst preparation unit. An ultra-dispersed catalyst in oil is the end-product of the further processing and this end product may be injected into a reservoir to produce a packed catalytic bed which promotes the ensuing *in situ* upgrading process. Components of an example of an upgrading process are described in general terms. The skilled person will understand the functions of these components and will thus understand the context of operation of the catalyst preparation unit of the present invention.

[00059] Shown in Figure 1 is an example of an upgrading process 4 for treating crude oil typically having been recovered from an oil reservoir. The crude oil may be comprised of a plurality of fractions including various fractions as described above. In the subject invention, the crude oil will typically have a higher proportion of heavy oil fractions and hence is described as a heavy oil **HO**. The heavy oil **HO** is first subjected to desalting in desalting unit 6. Generally, removal of salt and water are required to prevent corrosion in the processing units as well as preventing chemical interaction of the salts with the catalysts designed for the upgrading process. The desalting process is also provided to reduce most impurities and suspended sediments present in the crude oil sample. The desalted sample is then sent to a distillation unit 8 wherefrom two fractions are obtained; a synthetic oil fraction **SO** which is composed of products such as naptha, kerosene and other compounds with initial boiling points generally less than 250°C. Such compounds may be considered as “higher value products”. The remaining fraction is indicated as oil **O** in Figure 1 and will be comprised of those compounds

that are generally considered as heavy oil compounds and/or “lower value products”. In certain embodiments (not shown in Figure 1), the remaining fraction is further subjected to vacuum distillation to remove further compounds with initial boiling points generally lower than 450 °C. As is understood, various combinations of separation processes may be utilized to produce a desired oil **O** feed. In one embodiment, and for the purposes of description herein, the remaining oil is designated vacuum residue (API gravity less than 8) and is used to feed the catalyst preparation unit **10**. Inputs into the catalyst preparation unit **10** include water **H₂O**, catalytic salts **CS** and hydrogen **H₂** and the output from the catalyst preparation unit is an ultra-dispersed catalyst-in-oil mixture **CO**. In preferred embodiments, the particle sizes of the catalysts are in the sub-micron-particle or nano-particle range, in order to provide increased catalytic efficiency and longevity. Specific equipment used for desalting and distillation is known to the skilled person and can be readily adapted for use in this process without undue experimentation. Embodiments of the catalyst preparation unit **10** are described hereinbelow.

Catalyst Preparation Unit

[00060] A series of embodiments of a catalyst preparation unit will now be described. Each of these embodiments may use the vacuum residue described above with respect to the upgrading process of Figure 1, or heavy oil from different sources as the oil component to form the ultra-dispersed catalyst in oil.

[00061] The processes developed to produce embodiments of an ultra-dispersed catalyst are described in U.S. Patents 8,304,363, 8,298,982, 8,283,279, and 7,897,537 (each incorporated herein by reference in entirety). While the foregoing patents describe catalysts in the nano-particle size range, it is understood that it is not essential that the products and processes described herein are restricted in the subject application to the particle sizes described in these patents. Three distinct processes are described which are designated as (i) preparation of ultra-dispersed mono-, bi- or tri-metallic catalyst, (ii) salt composite feed, and (iii) preparation of ultra-dispersed mono-metallic catalyst.

[00062] These three process options are described herein as including three functional zones (as shown in Figures 2 to 5); (a) a mixing zone, (b) a catalyst activation zone, and (c) a separation zone. In general terms, the oil is mixed with the salts in the mixing zone and the mixture is conveyed to the catalyst activation zone where the metals are activated. Next, the activated metal/oil mixture is conveyed to the separation zone, where all gases and vapors are separated from the liquid. In one particular embodiment, which is applicable to each tri-metallic

catalyst preparation, salt composite feed, and mono-metallic catalyst preparation, the ultra-dispersed catalyst in oil is used for *in situ* catalytic upgrading as described in Canadian Patent 2,810,022 (incorporated herein by reference in entirety), hydrogen is mixed with the ultra-dispersed catalyst in oil and the resulting mixture is injected into the well according to known methods. The skilled person will recognize that the catalyst preparation unit of the invention need not be configured for immediate mixing with hydrogen in cases where it may be desirable to store the accumulated ultra-dispersed catalyst in oil for later injection into a well. The hydrogen can then be mixed outside of the catalyst preparation unit just prior to injection. In this case, the hydrogen input into the separation zone is omitted from the embodiments of the catalyst preparation unit described hereinbelow.

[00063] A number of conduits are employed throughout the catalyst preparation unit for conveyance of materials to and from different components of the catalyst preparation unit. The selection of and manner of making connections between various conduits and the components of the catalyst preparation unit are routine tasks for those with skill in the art of process engineering. Some of the factors to be considered in selecting conduit materials are chemical compatibility, pressures, flow rates and temperatures of fluids being conveyed.

Embodiment 1: Catalyst Preparation Unit for Preparation of Tri-metallic Catalyst

[00064] According to one embodiment of the present invention, a catalyst preparation unit is provided which is designed to prepare ultra-dispersed catalyst in oil according to a process designated herein as "preparation of tri-metallic catalyst." This embodiment of the catalyst preparation unit is shown in two parts (**100A** and **100B**) in Figures 2A and 2B, respectively. One particular example of a process for production of a trimetallic catalyst is the production of Ni-W(S)MoO₃ catalyst which is described in Example 4 of U.S. Patent 7,897,537 which is incorporated herein by reference in entirety. The present embodiment is an appropriate platform for producing this and other similar metal-based hydrocarbon processing catalysts.

[00065] Turning now to Figure 2A, which shows part **100A** of the catalyst preparation unit, it is seen that material inputs into this part **100A** of the catalyst preparation unit include an oil **O** (which may be a heavy oil fraction or vacuum distillation residue or similar sample), three different metal salts (**MS-1**, **MS-2** and **MS-3**), water **H₂O** and one or more compounds providing a reactant source of sulfur **S**.

[00066] In certain embodiments, the metal salts used to prepare the catalyst include salts of one group VIIIB non-noble metal, and two group VIB metals, as described in U.S. Patents

8,304,363, 8,298,982, 8,283,279, and 7,897,537, each of which is incorporated herein by reference in entirety. In certain embodiments, the two group VIB metals are molybdenum and tungsten and the group VIIIB metal is nickel or cobalt. In certain embodiments, metal salt 1 **MS-1** is ammonium heptamolybdate, metal salt 2 **MS-2** is ammonium metatungstate and metal salt 3 **MS-3** is nickel acetate. In certain embodiments, the source of sulfur **S** is ammonium sulfide or thiourea.

[00067] The oil **O** is drawn into the catalyst preparation unit **100A** by a centrifugal pump **112** located in the mixing zone **110** of the catalyst preparation unit **100A**. All of the processing steps described hereinbelow with respect to Figure 2A occur within the mixing zone **110**. The centrifugal pump **112** then sends the oil to a first mixer **126** for mixing of metal salt 1 **MS-1** and metal salt 2 **MS-2** with the oil **O** and to a second mixer **130** for mixing of metal salt 3 **MS-3** with the oil **O**.

[00068] In each case, the metal salts **MS-1**, **MS-2** and **MS-3** are conveyed to solution mixers where they are mixed with water to form solutions. The water **H₂O** is conveyed to the mixers from outside of the catalyst preparation unit. Metal salt 1 **MS-1** and metal salt 2 **MS-2** are both conveyed by respective conduits to the metal salt 1, 2 solution mixer **118**. After mixing to form a solution of both of these metal salts, the solution is stored in a tank **120**. Metal salt 3 **MS-3** is mixed in a batch mode with water in metal salt 3 solution mixer **114** until all salts are dissolved, and then the resulting solution is stored in tank **116**. The solution mixture of tank **120** which contains the mixture of metal salt 1 **MS-1** and **MS-2** is in fluid communication with a dosing pump **124** which draws specified volumes of solution from tank **120** and conveys these volumes to mixer **126**. Likewise, the solution mixture of tank **116** containing the solution of metal salt 3 **MS-3** is in fluid communication with another dosing pump **128** which draws specified volumes of solution from tank **116** and conveys these volumes to mixer **130**. In this embodiment and in embodiment 3 described hereinbelow, the combination of a given solution mixer, tank and dosing pump (such as mixer **118**, tank **120**, and dosing pump **124**) is referred to as a "catalyst reactant mixing and conveyance system."

[00069] The external sulfur source compound **S** in solution form is drawn into the mixing zone **110** by another dosing pump **122**. This dosing pump **122** conveys specified volumes of the sulfur source solution to the line connecting tank **120** with dosing pump **124**. Thus the solution conveyed to inline mixer **126** from dosing pump **124** also includes the sulfur source compound **S**.

[00070] Inline mixer **126** receives and mixes the oil **O** and the solution containing metal salt 1, metal salt 2, and the sulfur source compound. The resulting mixture is conveyed away from inline mixer **126** to the catalyst activation zone **170** which is shown in Figure 2B as part of the catalyst preparation unit part **100B**. Inline mixer **130** receives and mixes the oil **O** and the solution containing metal salt 3 **MS-3**. Advantageously, the latter step is performed as close as possible to the reactor vessel which will be described hereinbelow. The resulting mixture is conveyed away from inline mixer **130** and joins the downstream conveyance of the output from inline mixer **126** to the catalyst activation zone **170**. Downstream of the point of joining output of the inline mixers **126** and **130**, the mixture being conveyed to the catalyst activation zone **170** includes an emulsion of oil **O**, water, metal salt 1 **MS-1**, metal salt 2, **MS-1**, metal salt 3 **MS-3** and the sulfur source compound **S**. Specific conditions and mole fractions of metals used in an example embodiment appropriate for *in situ* catalytic upgrading will be described in the examples provided hereinbelow. It is to be noted that in this embodiment, inline mixers **126** and **130** are referred to as “hydrocarbon mixing and conveyance systems.” Similar inline mixers described in additional embodiments hereinbelow are other examples of hydrocarbon mixing and conveyance systems.

[00071] Turning now to Figure 2B, which is a continuation of the process of Figure 2A, the second part **100B** of the catalyst production unit is shown. The emulsion mixture which includes oil **O**, the three metal salts **MS-1**, **MS-2**, and **MS-3**, the sulfur source compound **S** and water **H₂O** is conveyed to a reactor **172** in the catalyst activation zone **170** which heats the emulsion mixture to vaporize the water and generate the ultra-dispersed catalyst. The emulsion mixture enters the top of the reactor **172** and exits the bottom of the reactor **172**, where it is conveyed to the separation zone **180** of the second part **100B** of the catalyst preparation unit. The separation zone **180** includes a gas/liquid separator **182** whose function is to remove gas and water vapor **G** to provide ultra-dispersed catalyst in oil **CO**. After this step, the product is conveyed to dosing pump **184** where mixing with hydrogen **H₂** (from outside of the catalyst preparation unit) is controlled. With the addition of hydrogen **H₂**, the ultra-dispersed catalyst in oil is ready for injection into a well in an *in situ* catalytic upgrading process. The skilled person will recognize that in alternative embodiments, the ultra-dispersed catalyst in oil **CO** may be used in other hydrocarbon recovery processes which do not require the presence of hydrogen. In such alternative embodiments, the hydrogen source and input line would be omitted from the process flow shown in Figure 2B. This also applies to other embodiments described hereinbelow.

[00072] It is also understood that the embodiment as described above may be utilized to formulate bi-metallic catalysts where one of the metal salts 1 or 2 may be omitted such that the salt at 126 contains only one metal salt such that a bi-metallic catalyst is formed in the catalyst activation zone 170.

Embodiment 2: Catalyst Preparation Unit for a Salt Composite Feed Process

[00073] According to another embodiment of the present invention, a catalyst preparation unit is provided which is designed to prepare ultra-dispersed catalyst in oil according to a process designated herein as “salt composite feed.” In a manner similar to Figures 2A and 2B, the present embodiment of the catalyst preparation unit is shown in two parts (**200A** and **200B**) in Figures 3A and 3B, respectively.

[00074] Turning now to Figure 3A, there is shown a mixing zone **210** in part **200A** of the catalyst preparation unit. It is seen that material inputs include an oil **O** (which may be a heavy oil fraction or vacuum distillation residue or similar sample), and a mixture of three different metal salts, each in solid form and one or more compounds providing a reactant source of sulfur. This mixture is referred to as a “metal salt composite” **MS-C**.

[00075] The metal salt composite **MS-C** is conveyed to a mill **234** whose function is to grind the solids to reduce particle sizes to at least within the micrometer range (typically 5- 100 microns). Unlike the tri-metallic catalyst preparation described with respect to Figures 2A and 2B, the present process does not require addition of water for preparing aqueous metal salt solutions prior to mixing with the oil. The reduced particle size metal salt composite **MS-C** emerging from the mill **234** is conveyed to a salt solution mixer **236** where it is mixed directly with the oil **O**. When uniformly mixed, the mixture is conveyed to a high shear mixer **238** which further reduces the size of particles suspended in the oil **O**.

[00076] Following sufficient mixing in the shear mixer **238**, the mixture is conveyed to the reactor **272** in the catalyst activation zone **270** which is shown in Figure 3B.

[00077] Figure 3B is a continuation of the process of Figure 3A. The mixture containing oil **O**, the three metal salts **MS-1**, **MS-2** and **MS-3**, and the sulfur source compound **S** is conveyed to a reactor **272** in the catalyst activation zone **270** which heats the emulsion mixture to generate the ultra-dispersed catalyst. The emulsion mixture enters the top of the reactor **272** and exits the bottom of the reactor **272**. It is then conveyed to the separation zone **280** of the second part **200B** of the catalyst preparation unit. The separation zone **280** includes a gas/liquid

separator **282** whose function is to remove gas and water vapor **G** to provide ultra-dispersed catalyst (UDC) in oil **CO**. After this step, the product is conveyed to dosing pump **284** where mixing with hydrogen **H2** (from outside of the catalyst preparation unit) is controlled. With the addition of hydrogen the ultra-dispersed catalyst in oil is ready for injection into a well in an *in situ* catalytic upgrading process. As described above for Figures 2A and 2B, the skilled person will recognize that in alternative embodiments, the ultra-dispersed catalyst in oil **CO** may be used in other hydrocarbon recovery processes which do not require the presence of hydrogen, as described above with respect to embodiment 1.

[00078] As noted above, water is not added in this process because a solid metal salt composite is employed. In cases where it can be reasonably ensured that the amount of water in the source oil **O** and in the metal salt composite is negligible, it may be possible to omit the liquid/gas separator from the catalyst preparation unit. Such an alternative embodiment is also within the scope of the invention.

[00079] Similarly, as with embodiment 1, a mono- or bi-metallic catalyst may be synthesized with the embodiment as described in embodiment 2 by altering the number of metal salts within the metal salt composite as appropriate.

Embodiment 3: Catalyst Preparation Unit for a Mono-metallic Catalyst Preparation Process

[00080] According to another embodiment of the present invention, a catalyst preparation unit is provided which is designed to prepare ultra-dispersed catalyst in oil according to a process designated herein as “mono-metallic catalyst preparation.” In a manner similar to Figures 2A and 2B as well as Figures 3A and 3B, the present embodiment of the catalyst preparation unit is shown in three parts (**300A** and **300B** and **300C**) in Figures 4A, 4B and 4C, respectively. This embodiment provides a mixture of three different mono-metallic catalyst compounds by separate reactions of three different metal salt compounds with a sulfur source compound. However, the skilled person will recognize that alternative embodiments are possible wherein only one, only two or more than three metal salts are used to generate distinct mono-metallic catalyst compounds. Therefore, alternative embodiments are contemplated wherein fewer or more catalyst reactant mixing and conveyance systems are included in the catalyst preparation unit and these alternative embodiments are also within the scope of the invention because the catalyst preparation unit of embodiment 3 may be modified appropriately to arrive at such alternative embodiments without undue experimentation.

[00081] In Figure 4A, there is shown a mixing zone **310** in part **300A** of the catalyst preparation unit. It is seen that material inputs include metal salts 1, 2 and 3 (**MS-1**, **MS-2** and **MS-3**), a sulfur source compound **S**, and water **H₂O**. Each of the metal salts is separately mixed with water to form a solution, conveyed to its own solution tank and pumped downstream by its own dosing pump. Accordingly, metal salt 1 **MS-1** is conveyed to salt solution mixer **318** where it is mixed with water to form a solution and then sent to tank **320** where it is drawn downstream by dosing pump **324**. Likewise, metal salt 2 **MS-2** is conveyed to salt solution mixer **325**, mixed with water, sent to tank **327** and drawn to dosing pump **329**. Metal salt 3 **MS-3** is conveyed to salt solution mixer **314**, mixed with water, sent to tank **316** and drawn downstream by dosing pump **328**.

[00082] The sulfur source compound **S** is conveyed by dosing pump **322** to the downstream lines from each of the tanks **316**, **320** and **327** to add the sulfur source compound to each of the metal salt solutions prior to entrance into each of the individual metal salt dosing pumps **324**, **328** and **329**. The downstream conveyance of these metal salt and sulfur source compound mixtures leads to a series of corresponding inline mixers **344**, **346** and **342** which are shown in Figure 4B.

[00083] In Figure 4B, which is a continuation of Figure 4A, it is seen that the output from each of dosing pumps **324**, **328** and **329** is conveyed to corresponding inline mixers **344**, **346** and **342** (which are also located in the mixing zone **310**) where the metal salt and sulfur mixtures are further mixed with oil **O** conveyed by centrifugal pump **340**. After sufficient mixing of the complete reaction mixtures in each of the inline mixers **344**, **346** and **342**, they are conveyed to the catalyst activation zone **370** and to corresponding reactors **374**, **376** and **372** which are shown in Figure 4C.

[00084] In Figure 4C, which is a continuation of Figure 4B, it can be seen that the three individual reaction mixtures conveyed from inline mixers **342**, **344** and **346** are conveyed to corresponding reactors **372**, **374** and **376**. The reactors heat the three mixtures and generate individual mixtures of mono-metallic ultra-dispersed catalysts in oil, as for embodiments 1 and 2. The output of these three reactors **372**, **374** and **376** is merged downstream and sent to the separation zone **380** where it enters gas/liquid separator **382**. Subsequent downstream processing is the same as described for embodiments 1 and 2 with the output from the gas/liquid separator **382** conveyed to dosing pump **384** where mixing with hydrogen **H₂** (from outside of the catalyst preparation unit) is controlled. Vapor and gas **G** is removed and ultra-dispersed catalyst in oil **CO** is obtained.

[00085] With the addition of hydrogen the ultra-dispersed catalyst in oil is ready for injection into a well in an *in situ* catalytic upgrading process. As described above, the skilled person will recognize that in alternative embodiments, the ultra-dispersed catalyst in oil **CO** may be used in other hydrocarbon recovery processes which do not require the presence of hydrogen.

Embodiment 4: Combination Catalyst Preparation Unit Configured for Composite Salt Feed and for Mono-Metallic Catalyst Preparation

[00086] It is recognized that it is advantageous to provide a catalyst preparation unit with means for conducting more than one process from among the processes described above. Therefore, a fourth embodiment of the catalyst preparation unit is configured to generate ultra-dispersed catalyst in oil by either the composite salt feed process or by the mono-metallic catalyst preparation process. Accordingly, certain unique components of embodiments 2 and 3 are included in this combination unit, while other components which are common to both of these embodiments are shared.

[00087] In a manner similar to Figures 4A, 4B and 4C, the present embodiment of the catalyst preparation unit is shown in three parts (**400A** and **400B** and **400C**) in Figures 5A, 5B and 5C, respectively.

[00088] Firstly, the components of the catalyst preparation unit responsible for the composite salt feed process will be described, followed by a description of the components responsible for the mono-metallic catalyst preparation process.

[00089] Turning now to Figure 5A, there is shown a mixing zone **410** in part **400A** of the catalyst preparation unit. It is seen that material inputs include an oil **O** (which may be a heavy oil fraction or vacuum distillation residue or similar sample), and a mixture of three different metal salts, each in solid form and one or more compounds providing a reactant source of sulfur. This mixture is referred to as a "metal salt composite" **MS-C**.

[00090] The metal salt composite **MS-C** is conveyed to the mixing zone **410** and to a mill **434** whose function is to grind the solids to reduce particle sizes to at least within the micrometer range (typically 5- 100 microns). The composite feed process does not require addition of water for preparing aqueous metal salt solutions prior to mixing with the oil. The metal salt composite **MS-C** emerging from the mill **434** is conveyed to a salt solution mixer **436** where it is mixed directly with the oil **O**. When uniformly mixed, the mixture is conveyed to a high shear mixer **438** which further reduces the size of particles suspended in the oil **O**.

[00091] Following sufficient mixing in the shear mixer **438**, the mixture is conveyed to each of the reactors **472**, **474** and **476** in the catalyst activation zone **470** which is shown in Figure 5C. In the reactors **472**, **474** and **476**, the reaction mixture is heated to generate the ultra-dispersed catalyst in oil, which is subsequently conveyed out of the catalyst activation zone and into the separation zone **480** where vapor and gas **G** is separated. Subsequent downstream processing is the same as described for the embodiments described above with the output from the gas/liquid separator **482** conveyed to dosing pump **484** where mixing with hydrogen **H2** (from outside of the catalyst preparation unit) is controlled. With the addition of hydrogen the ultra-dispersed catalyst in oil **CO** is ready for injection into a well in an *in situ* catalytic upgrading process.

[00092] Returning now to Figure 5A, the components responsible for the mono-metallic catalyst preparation process will now be described.

[00093] In Figure 5A, it is seen that material inputs for the mono-metallic catalyst preparation process include metal salts 1, 2 and 3 (**MS-1**, **MS-2** and **MS-3**) a sulfur source compound **S**, and water **H2O**. Each of the metal salts is separately mixed with water to form a solution, conveyed to its own solution tank and pumped downstream by its own dosing pump. Accordingly, metal salt 1 **MS-1** is conveyed to salt solution mixer **448** where it is mixed with water to form a solution and then sent to tank **450** where it is drawn downstream by dosing pump **452**. Likewise, metal salt 2 **MS-2** is conveyed to salt solution mixer **454**, mixed with water, sent to tank **456** and drawn to dosing pump **458**. Metal salt 3 **MS-3** is conveyed to salt solution mixer **414**, mixed with water, sent to tank **416** and drawn downstream by dosing pump **428**.

[00094] The sulfur source compound **S** is conveyed by dosing pump **422** to the downstream lines from each of the tanks **450**, **454** and **416** to add the sulfur source compound to each of the metal salt solutions prior to entrance into each of the individual metal salt dosing pumps **452**, **458** and **428**. The downstream conveyance of these metal salt and sulfur source compound **S** mixtures leads to a series of corresponding inline mixers **444**, **442** and **446** which are shown in Figure 5B.

[00095] In Figure 5B, which is a continuation of Figure 5A, it is seen that the output from each of dosing pumps **452**, **458** and **428** is conveyed to corresponding inline mixers **444**, **442** and **446** (which are also located in the mixing zone **410**) where the metal salt and sulfur mixtures are further mixed with oil **O** conveyed by centrifugal pump **440**. After sufficient mixing of the complete reaction mixtures in each of the inline mixers **444**, **442** and **446**, they are

conveyed to the catalyst activation zone **470** and to corresponding reactors **472**, **474** and **476** which are shown in Figure 5C.

[00096] In Figure 5C, which is a continuation of Figure 5B, it can be seen that the three individual reaction mixtures conveyed from inline mixers **444**, **442** and **446** are conveyed to corresponding reactors **472**, **474** and **476**. The reactors heat the three mixtures and generate individual mixtures of mono-metallic ultra-dispersed catalysts in oil. The output of these three reactors **472**, **474** and **476** is merged downstream and sent to the separation zone **480** where it enters gas/liquid separator **482**. Subsequent downstream processing is the same as described for the other embodiments with the output from the gas/liquid separator **482** conveyed to dosing pump **484** where mixing with hydrogen (from outside of the catalyst preparation unit) is controlled. Thus it is seen that all components of the catalyst activation zone **470** and the separation zone **480** are shared between the two processes. With the addition of hydrogen the ultra-dispersed catalyst in oil is ready for injection into a well in an *in situ* catalytic upgrading process.

Examples

[00097] The foregoing description will be more fully understood with reference to the following examples. These examples are, however, exemplary of methods of using certain aspects of the present invention and are not intended to impose limits on the scope of the invention as defined by the appended claims.

[00098] In each of the examples, metal salt 1 is ammonium heptamolybdate, metal salt 2 is ammonium metatungstate, metal salt 3 is nickel acetate, the sulfur source compound is ammonium sulfide or thiourea and the oil is vacuum residue from a distillation process, which is hereinafter simply referred to as "vacuum residue." In each example, the amount of hydrogen to be mixed with the ultra-dispersed catalyst in oil prior to injection in an *in situ* upgrading process is 120 Scc/gr/h of vacuum residue. The vacuum residue being fed to the catalyst preparation unit should not exceed about 240°C. The stream of ultra-dispersed catalyst in oil should be no lower than about 280 °C prior to injection into a well for *in situ* catalytic upgrading of hydrocarbons.

Example 1: Preparation of Ultra-Dispersed Trimetallic Catalyst in Oil for use in In Situ Catalytic Upgrading

[00099] In this process, which can be performed by a catalyst preparation unit with features similar to those of Embodiment 1 described above, the total amount of water used for the preparation of the salt solutions should be around 2% wt of the feed (vacuum residue). This value is set to ensure a minimum amount of water in which the salts can be completely dissolved (at ambient temperature) to meet the reactor vapor requirement, and to ensure the formation of a stable suspension (vacuum residue/salt solution) with a minimum bubble size dispersion. In this example and subsequent examples, Metal salt 1 is ammonium heptamolybdate, metal salt 2 is ammonium metatungstate, metal salt 3 is nickel acetate, the sulfur source compound is ammonium sulfide or thiourea and the oil is vacuum residue from a distillation process.

[000100] The amount of salt in solution also depends on the feed and desired target concentration. In certain embodiments, for a representative *in situ* catalytic upgrading process, a total catalyst (metal) concentration of 720 ppm is added. The amount of each metal required is calculated by the following relationships:

$$(1) \text{ Mole fraction of Ni: } \text{Ni}/(\text{Ni} + \text{Mo} + \text{W}) = 0.3$$

$$(2) \text{ Relationship of Ni to Ni+W: } \text{Ni}/(\text{Ni} + \text{W}) = 0.653$$

$$(3) \text{ Relationship of Ni to Ni+Mo: } \text{Ni}/(\text{Ni} + \text{Mo}) = 0.36$$

$$(4) \text{ Relationship of Mo to W: } \text{Mo}/\text{W} = 3$$

[000101] The amount of ammonium sulfide (or thiourea) is determined based on the stoichiometry of sulfured nickel, molybdenum, and tungsten compounds. This would be a mole of sulfur per mole of nickel and two moles of sulfur per mole of molybdenum and tungsten. However, in this option (as it was tested in the laboratory) a relation of three moles of sulfur per mole of molybdenum and tungsten was used. This way the ammonium sulfide is only added to the stream of the solution of metal salts 1 and 2.

[000102] While mixing with the vacuum residue the water should remain in liquid form so that a stable suspension can be formed before entering the reactor. For this reason a maximum temperature in the vacuum residue entering the unit is set at 240°C and a maximum pressure in the unit is set at 4000 KPa. Once the salt solutions are prepared and mixed with vacuum residue the solutions enter the catalyst activation zone and enter the reactor. Representative conditions include heating of the emulsion to 370°C. By the time the fluid reaches this temperature, the water should be completely vaporized and the catalyst should be active and

ultra-dispersed as nano particles in the vacuum residue. A given volume of liquid should remain in the reactor between about 2.4 to about 2.6 min to allow sufficient time for binding of the metal ions to the hydrocarbons. The liquid should enter the reactor from the top and exit through the bottom to avoid the accumulation of metals in the bottom of the reactor.

[000103] Since the direction of the flow is from top to bottom in a reactor that has the form of a vertical tube and vaporization is occurring, avoidance of slug flow is desirable and obtained by keeping the velocity lower than 0.09 m/s and the volume of vapor inside the reactor under 50% vol.

[000104] The vapor-liquid stream that exits the reactor then enters the separation zone and is conveyed to a gas-liquid separator. This separator should be close to the reactor and should be insulated in order to avoid heat loss. The vapours and gases produced should be tested and treated if necessary before sending it to the atmosphere or any other facility. The liquid from the separator is mixed with hydrogen and then injected to the well as described in Canadian Patent 2,810,022, which is incorporated herein by reference in entirety.

[000105] *Example 2: Salt Composite Feed Process Conditions for Producing Ultra-Dispersed Catalyst for In Situ Catalytic Upgrading*

[000106] In this process, which can be performed by a catalyst preparation unit with features similar to those of Embodiment 2 described above, the salt solutions are substituted with a composite which includes all of the required metal salts and a sulfur source compound. The molar relationships of the metals are the same as described in Example 1.

[000107] The salt composite enters a mill to reduce any big particle within it to a powder size in the range of 50 to 100 μm . This composite then is mixed directly with vacuum residue in a tank with a high shear mixer. As in described in Example 1, the composite/oil are mixed in a batch mode.

[000108] The reactor in the catalyst activation zone in this example should provide conditions similar to those described in Example 1. Since water is not added to the process, the velocity requirement for the preparation may vary.

[000109] The amount of vapor produced in the reactor may be negligible without the addition of water. In such a case, the use of a gas/liquid separator in the process is optional.

Example 3: Preparation of Ultra-Dispersed Monometallic Catalyst in Oil for use in In Situ Catalytic Upgrading

[000110] In this example, the vacuum residue entering the unit is divided into three streams to be mixed with three salt solutions.

[000111] In a manner similar to that described for Example 1 and Embodiment 1, the solutions are prepared mixing the metal salts and water. The operation is carried out in a batch mode for a period of time, to ensure the complete dissolutions of the salts in each case. Subsequently, each solution is sent to a corresponding tank, to be later mixed with ammonium sulfide or thiourea. The resulting solutions are then mixed with vacuum residue separately. The total amount of water used for the preparation of the salt solutions is around 2% by weight of the feed (vacuum residue).

[000112] The molar relationships and amounts of the metals are the same as in Example 1. The amount of ammonium sulfide (or thiourea) is determined based on the stoichiometry of sulfured nickel, molybdenum, and tungsten compounds. Once determined, each stream of ammonium sulfide (or thiourea) is then mixed with the corresponding water-salt solution.

[000113] The conditions for the vacuum residue/water mixing are the same as in Example 1 (maximum temperature in the vacuum residue entering the unit 240°C and a maximum pressure in the unit is set at 4000 KPa). Once the salt solutions are prepared and mixed with vacuum residue, each separate stream (three in total) enter different reactors under conditions described in Example 1.

[000114] The vapor-liquid streams that exit the reactors are then mixed, and enter the gas-liquid separator in the separation zone. This gas/liquid separator should be close to the reactors and should be insulated in order to avoid heat loss. The vapors and gasses produced should be tested and treated if necessary before sending it to the atmosphere or any other facility. The liquid from the separator is mixed with hydrogen and then injected to the well as described in Canadian Patent 2,810,022, which is incorporated herein by reference in entirety.

Equivalents and Scope

[000115] Although the present invention has been described and illustrated with respect to preferred embodiments and preferred uses thereof, it is not to be so limited since modifications and changes can be made therein which are within the full, intended scope of the invention as understood by those skilled in the art. Each of the references cited herein is incorporated herein by reference in entirety.

CLAIMS

1. A catalyst preparation unit for producing an activated hydrocarbon-catalyst mixture, the catalyst preparation unit comprising:
 - i) one or more catalyst reactant input conduits;
 - ii) a hydrocarbon input conduit;
 - iii) a water input conduit;
 - iv) one or more catalyst reactant mixing and conveyance systems for receiving and mixing catalyst reactants from the catalyst component input conduits and water provided by the water input conduit to provide one or more catalyst reactant solutions;
 - v) one or more hydrocarbon mixing and conveyance systems for receiving and mixing the catalyst reactant solutions and hydrocarbons provided by the hydrocarbon input conduit to produce a hydrocarbon-catalyst reactant mixture;
 - vi) at least one reactor located downstream of the mixers, for receiving and activating the hydrocarbon-catalyst reactant mixture, thereby producing the activated hydrocarbon catalyst mixture;
 - vii) a gas/liquid separator located downstream of the reactor, for removing vapors and gas from the activated hydrocarbon-catalyst mixture; and
 - viii) an output conduit for transporting the activated hydrocarbon-catalyst mixture away from the catalyst preparation unit.
2. The catalyst preparation unit of claim 1, wherein catalyst reactant input conduits, and the catalyst reactant mixing and conveyance systems are chemically compatible with ammonium heptamolybdate, ammonium metatungstate, nickel acetate, cobalt acetate, ammonium sulfide and thiourea or any combination thereof.
3. The catalyst preparation unit of claim 1 or claim 2, wherein the catalyst reactant input conduits include three metal salt conduits and a sulfur source compound conduit.
4. The catalyst preparation unit of claim 1 or claim 2, wherein the catalyst reactant input conduits include two metal salt conduits and a sulfur source compound conduit.

5. The catalyst preparation unit of claim 1 or claim 2, wherein the catalyst reactant input conduits include one metal salt conduit and a sulfur source compound conduit.

6. The catalyst preparation unit of any one of claims 1 to 5, wherein each of the catalyst reactant mixing and conveyance systems include a solution mixer for generating a catalyst reactant solution and a dosing pump for conveying specified volumes of the catalyst reactant solution to one of the hydrocarbon mixing and conveyance systems.

7. The catalyst preparation unit of claim 6, wherein each of the hydrocarbon mixing and conveyance systems comprises a centrifugal pump and an inline mixer, wherein the centrifugal pump is for drawing the hydrocarbons from outside of the catalyst preparation unit and conveying the hydrocarbons to the inline mixer for mixing with the catalyst reactant solution.

8. The catalyst preparation unit of any one of claims 1 to 7 comprising two catalyst reactant mixing and conveyance systems and two hydrocarbon mixing and conveyance systems, wherein

one of the two catalyst reactant mixing and conveyance systems is configured to convey a solution of two different metal salts and a sulfur source compound and the other catalyst reactant mixing and conveyance system is configured to convey a third metal salt solution, and

wherein one of the two hydrocarbon mixing and conveyance systems is configured to receive and mix the solution of the two different metal salts and the sulfur source compound with the hydrocarbons to produce a first hydrocarbon-catalyst mixture and convey the first hydrocarbon-catalyst reactant mixture to the reactor, and the other hydrocarbon mixing and conveyance system is configured to receive and mix the solution of the third metal salt with the hydrocarbons to produce a second hydrocarbon-catalyst reactant mixture and convey the second hydrocarbon-catalyst reactant mixture to the reactor.

9. The catalyst preparation unit of any one of claims 1 to 7 comprising three catalyst reactant mixing and conveyance systems, three hydrocarbon mixing and conveyance systems, and three reactors, wherein

each of the three catalyst reactant mixing and conveyance systems is configured to convey a solution of a different metal salt and a sulfur source compound to a corresponding hydrocarbon mixing and conveyance system of the three hydrocarbon

mixing and conveyance systems, thereby producing three different hydrocarbon-catalyst reactant mixtures and wherein

Each of the three hydrocarbon mixing and conveyance systems is further configured to convey its respective hydrocarbon-catalyst reactant mixture of the three different hydrocarbon-catalyst reactant mixtures to one of three corresponding reactors.

10. The catalyst preparation unit of claim 9, wherein reactor output from each of the three corresponding reactors is merged upstream of the gas/liquid separator.

11. The catalyst preparation unit of any one of claims 1 to 10, further comprising a hydrogen input conduit for addition of hydrogen to the activated hydrocarbon-catalyst mixture in the output conduit.

12. The catalyst preparation unit of any one of claims 1 to 11, wherein the hydrocarbon input conduit is configured for conveyance of heavy oil.

13. The catalyst preparation unit of claim 12 wherein the heavy oil is a distillation residue from a heavy oil upgrading process with an API gravity of about 20° or less.

14. The catalyst preparation unit of any one of claims 1 to 13 which is provided in modular form and configured for disengagement from a hydrocarbon processing facility, transport by a vehicle and engagement to another hydrocarbon processing facility.

15. A catalyst preparation unit for producing an activated hydrocarbon-catalyst mixture, the catalyst preparation unit comprising:

- a) a catalyst reactant input conduit;
- b) a hydrocarbon input conduit;
- c) a catalyst reactant and hydrocarbon mixing and conveyance system for receiving and mixing catalyst reactants from the catalyst reactant input conduit with hydrocarbons provided by the hydrocarbon input conduit to produce a catalyst reactant and hydrocarbon mixture;
- d) a reactor located downstream of the catalyst reactant and hydrocarbon mixing and conveyance system, for receiving and activating the hydrocarbon-catalyst reactant mixture, thereby producing the activated hydrocarbon catalyst mixture;
- e) a gas/liquid separator located downstream of the reactor, for removing vapors and gas from the activated hydrocarbon-catalyst mixture; and

- f) an output conduit for transporting the activated hydrocarbon-catalyst mixture away from the catalyst preparation unit.
16. The catalyst preparation unit of claim 15, wherein the catalyst reactant input conduit is configured for conveyance of a composite mixture of catalyst reactants in solid form.
17. The catalyst preparation unit of claim 15 or 16, wherein catalyst reactant input conduit and the catalyst reactant and hydrocarbon mixing and conveyance system are chemically compatible with ammonium heptamolybdate, ammonium metatungstate, nickel acetate, cobalt acetate, ammonium sulfide and thiourea or any combination thereof.
18. The catalyst preparation unit of claim 17, wherein the catalyst reactant and hydrocarbon mixing and conveyance system comprises a mill for reducing the particle size of reactants, a high shear mixer downstream of the mill for further reducing the particle size of the reactants.
19. The catalyst preparation unit of claim 18, further comprising a centrifugal pump for conveying the hydrocarbon-catalyst reactant mixture to the reactor.
20. The catalyst preparation unit of any one of claims 15 to 19, further comprising a hydrogen input conduit for addition of hydrogen to the activated hydrocarbon-catalyst mixture in the output conduit.
21. The catalyst preparation unit of any one of claims 15 to 20, wherein the hydrocarbon input conduit is configured for conveyance of heavy oil.
22. The catalyst preparation unit of claim 21 wherein the heavy oil is a distillation residue from a heavy oil upgrading process with an API gravity of about 20° or less.
23. A combination catalyst preparation unit for producing an activated hydrocarbon-catalyst mixture by either a mono-metallic catalyst preparation process or a composite salt feed process, the combination catalyst preparation unit comprising:
- a) the catalyst preparation unit as recited in claim 9 for the mono-metallic catalyst preparation process; and
 - b) the catalyst preparation unit as recited in claim 19 for the composite salt feed process, wherein
 - (1) at least one of the three reactors used for the mono-metallic catalyst preparation process is shared by the catalyst preparation unit for the composite salt feed process; and

(2) the gas/liquid separator and the output conduit used for the mono-metallic catalyst preparation process are both shared by the catalyst preparation unit for the composite salt feed process.

24. The catalyst preparation unit of any one of claims 23, further comprising a hydrogen input conduit for addition of hydrogen to the activated hydrocarbon-catalyst mixture in the output conduit.

25. The catalyst preparation unit of claim 23 or 24, wherein the hydrocarbon input conduit is configured for conveyance of heavy oil.

26. The catalyst preparation unit of claim 25 wherein the heavy oil is a distillation residue from a heavy oil upgrading process with an API gravity of about 20° or less.

27. The catalyst preparation unit of any one of claims 23 to 26 which is provided in modular form and configured for disengagement from a hydrocarbon processing facility, transport by a vehicle and engagement to another hydrocarbon processing facility.

28. An *in situ* hydrocarbon upgrading facility configured to process hydrocarbons by injection of a mixture of activated catalyst and hydrocarbons into a reservoir wherein the mixture of activated catalyst and hydrocarbons is generated using the catalyst preparation unit of any one of claims 1 to 27.

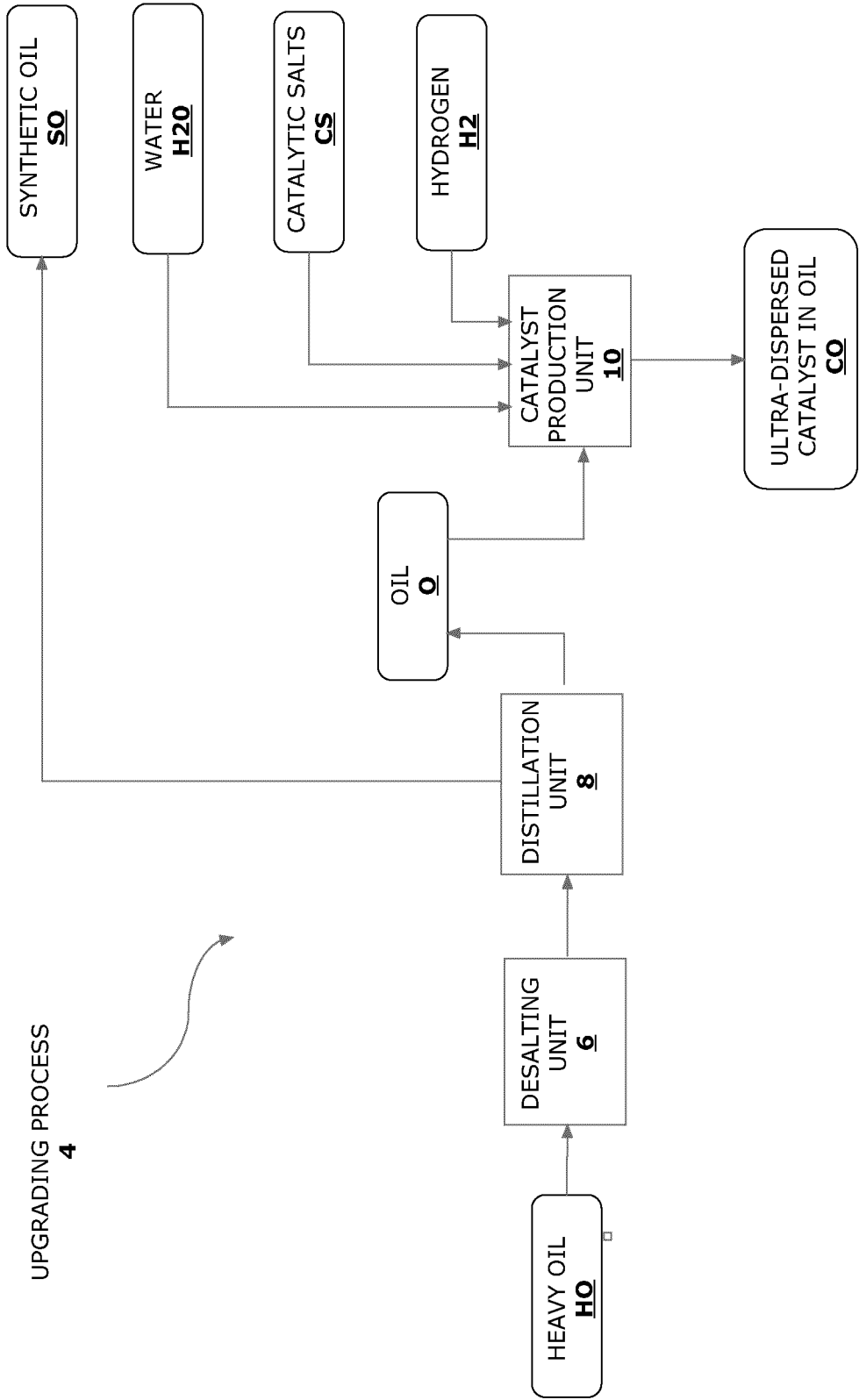


FIG. 1

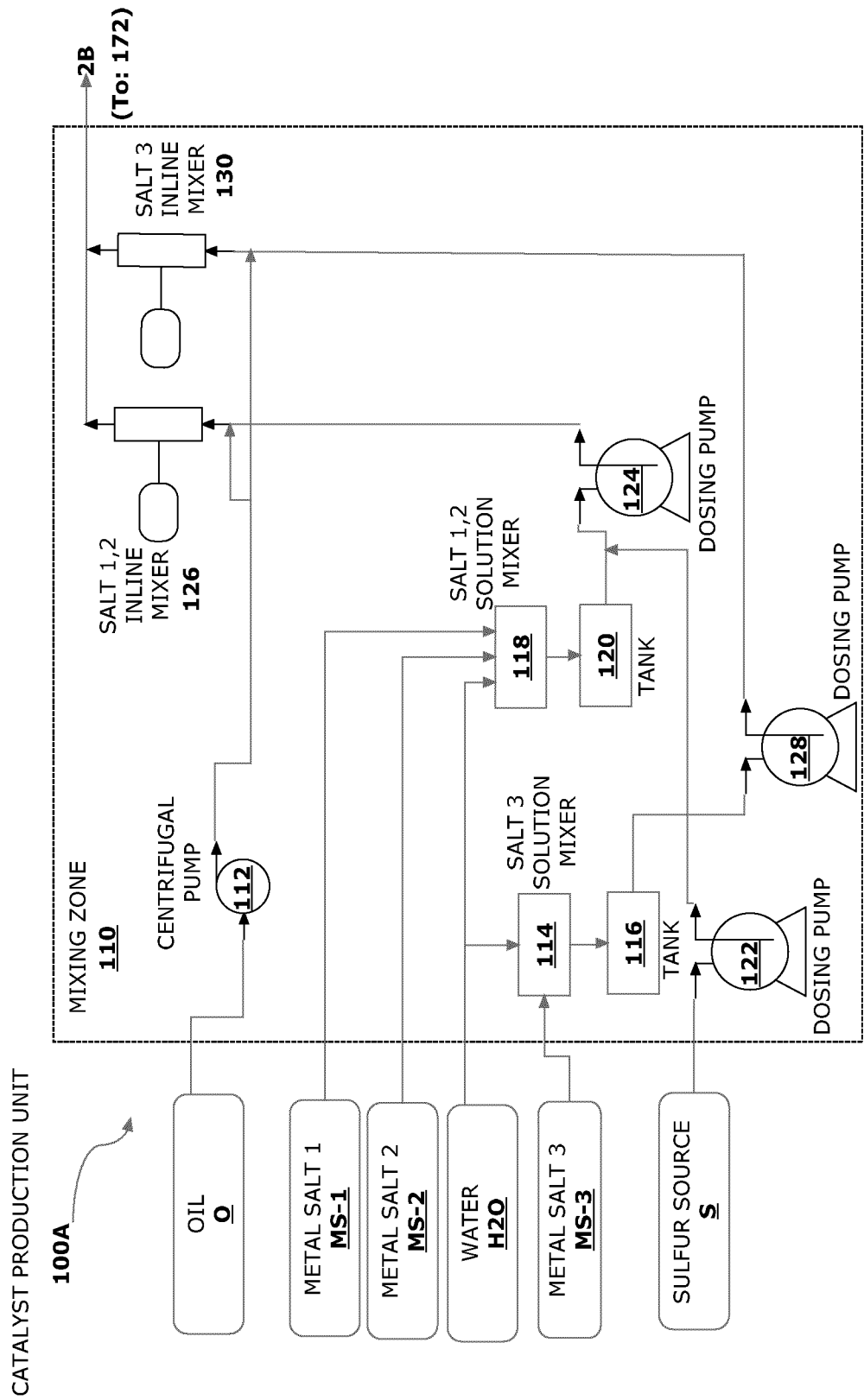


FIG. 2A

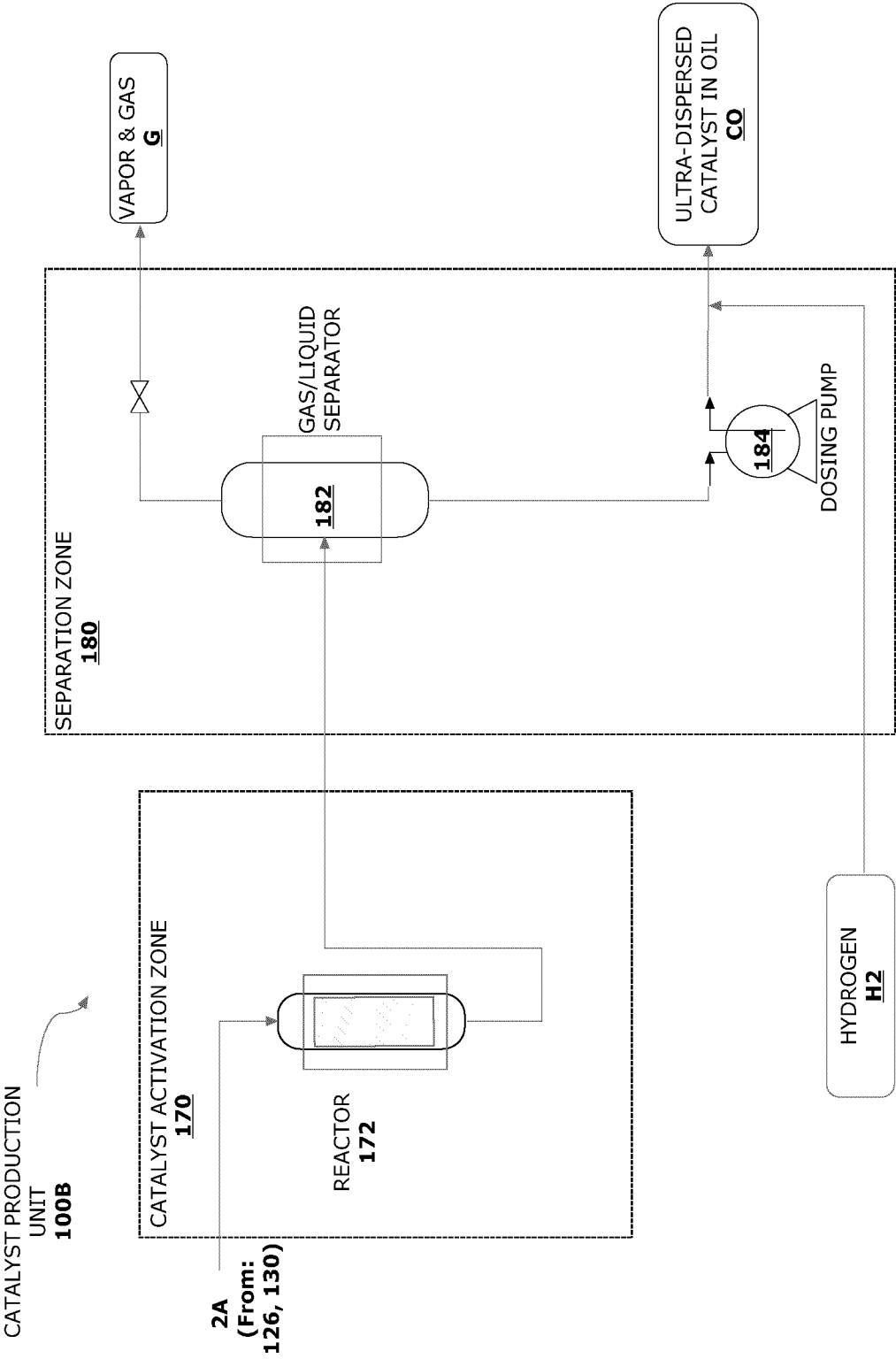


FIG. 2B

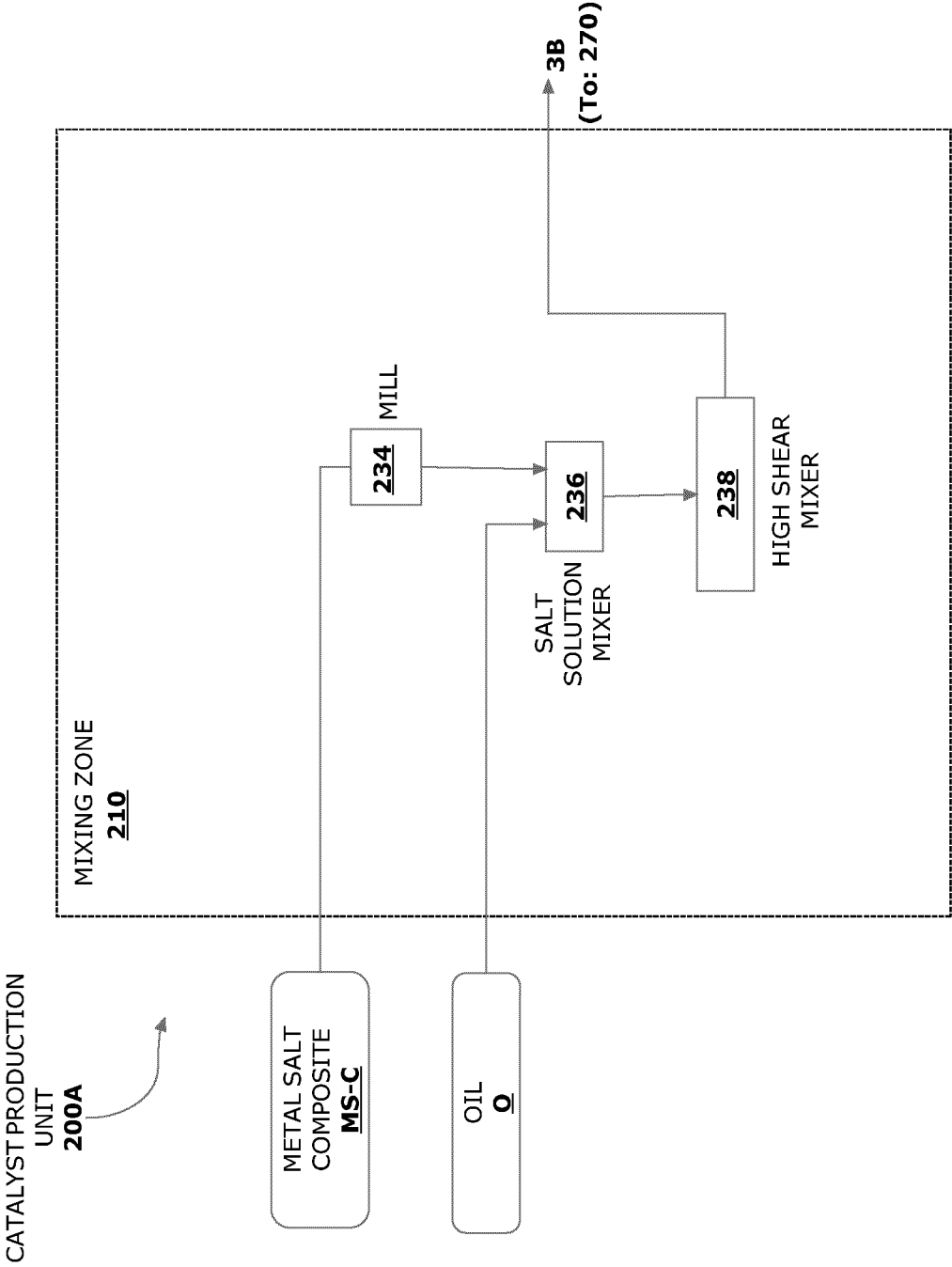


FIG. 3A

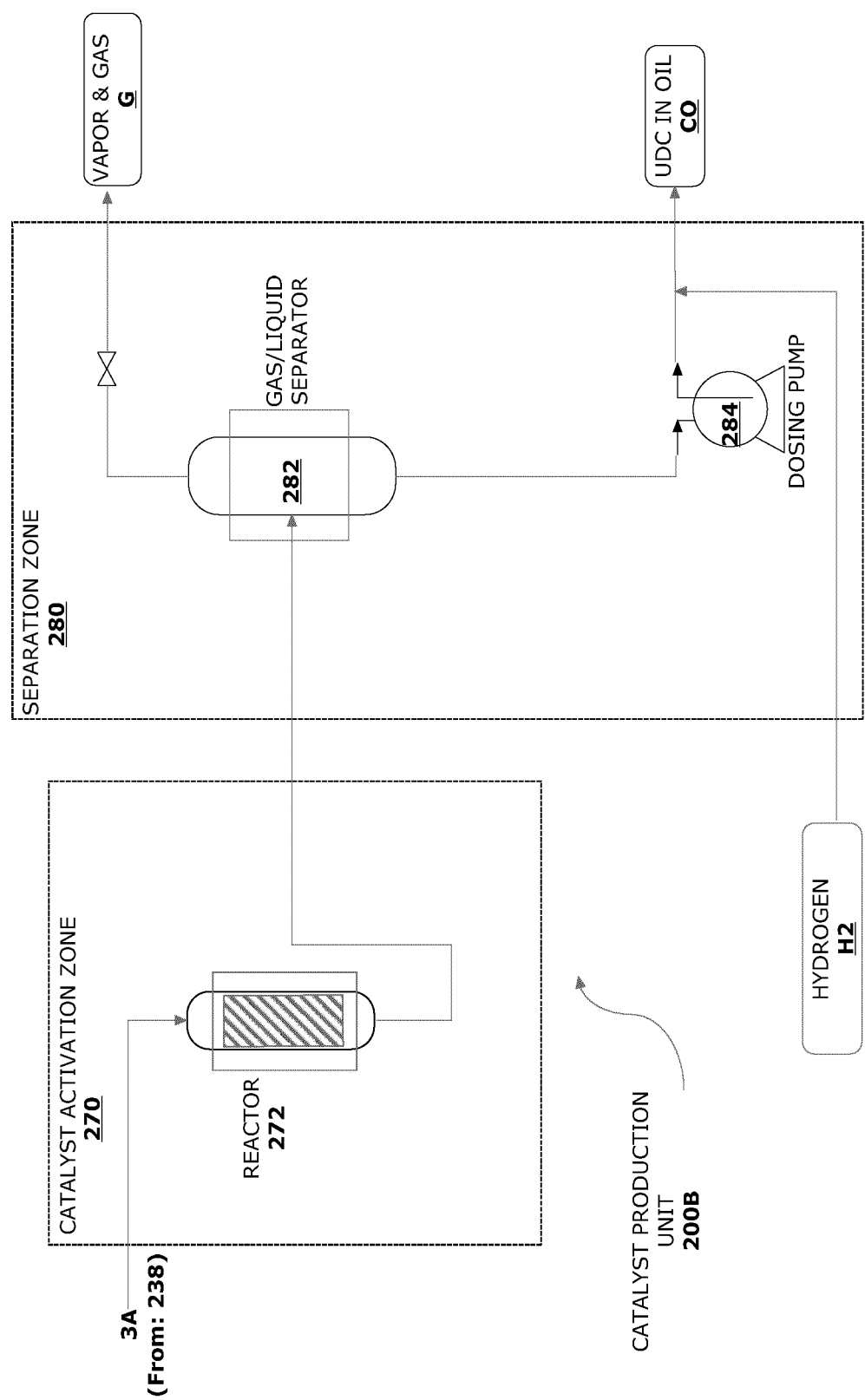


FIG. 3B

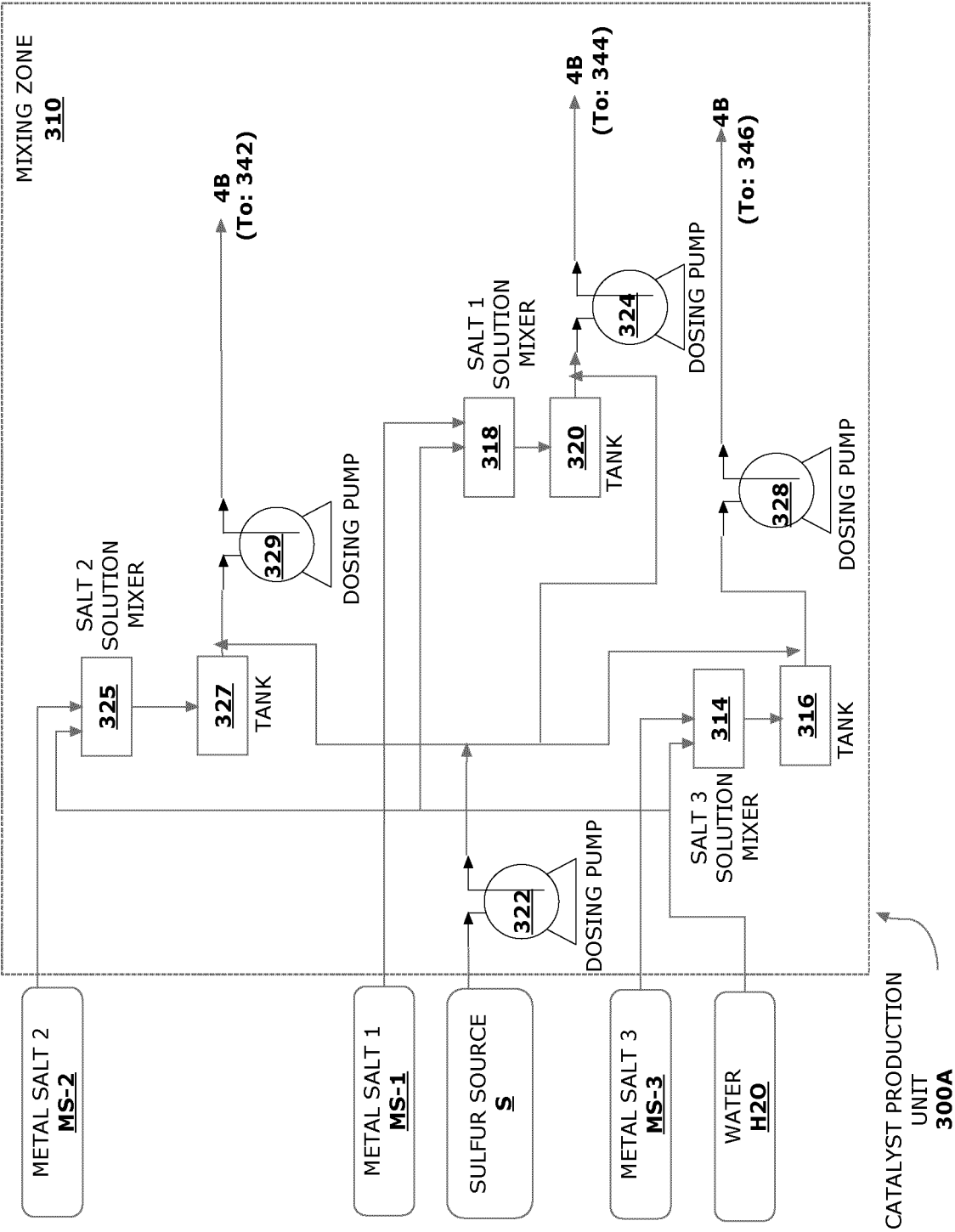


FIG. 4A

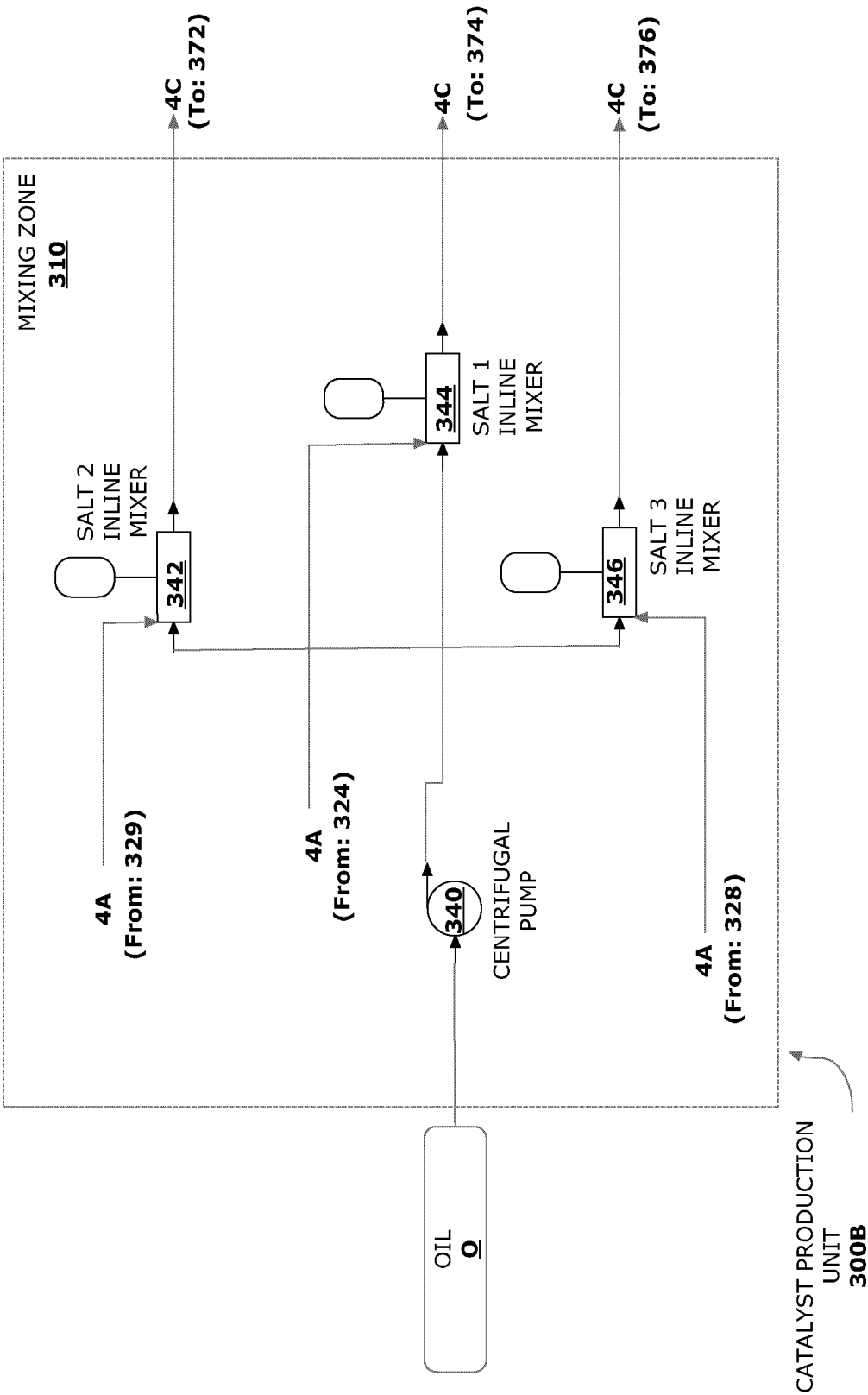


FIG. 4B

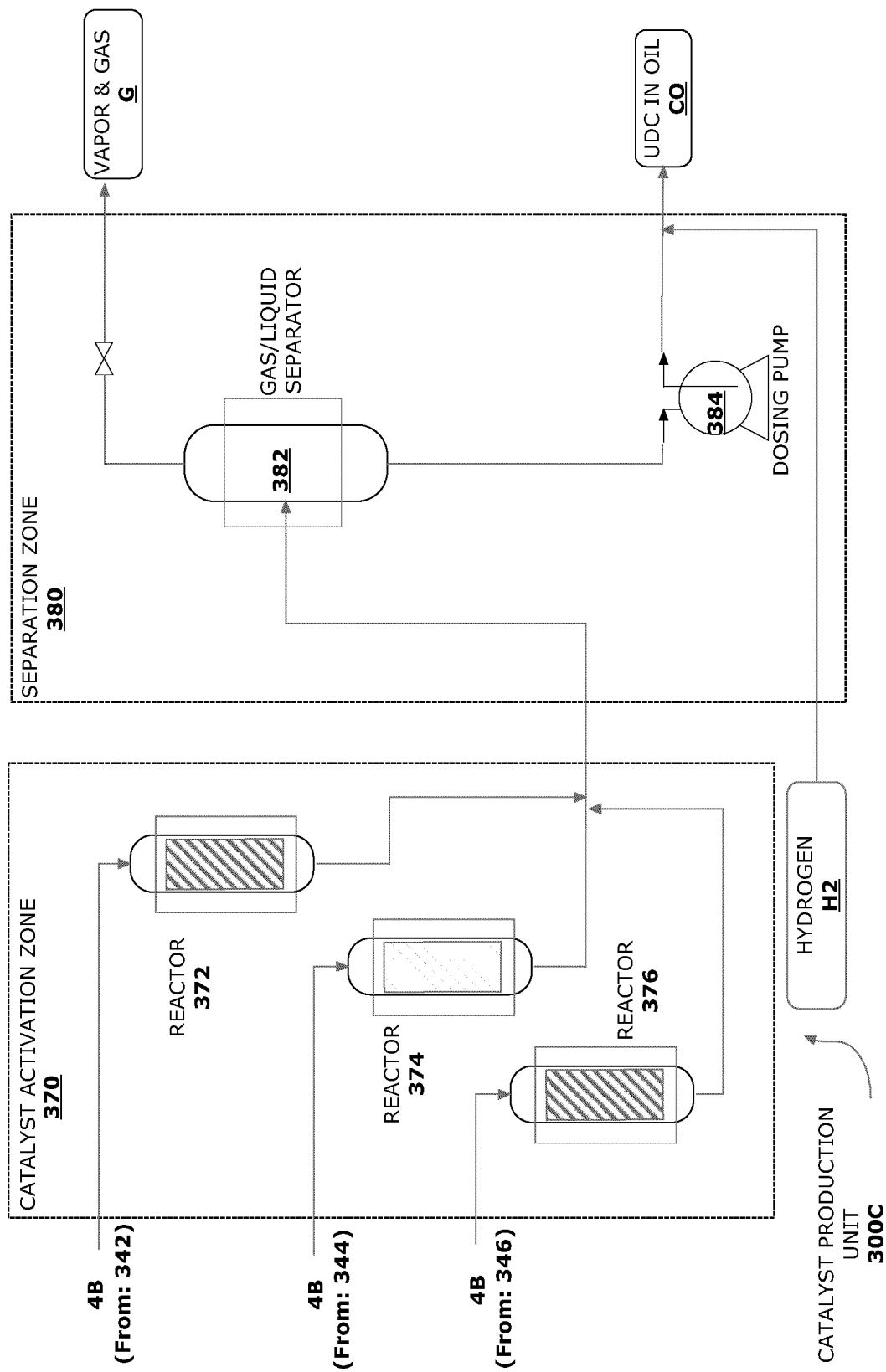


FIG. 4C

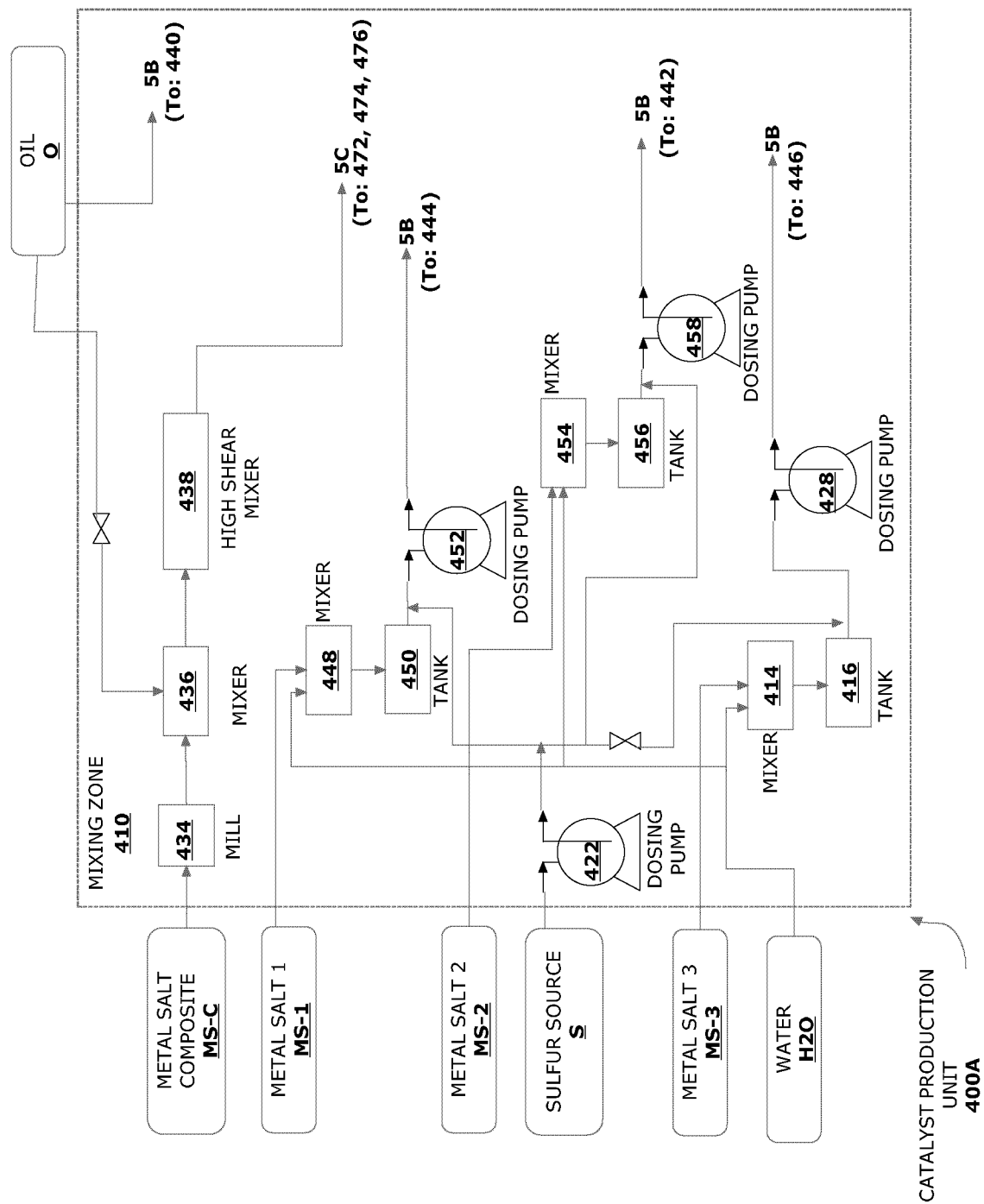


FIG. 5A

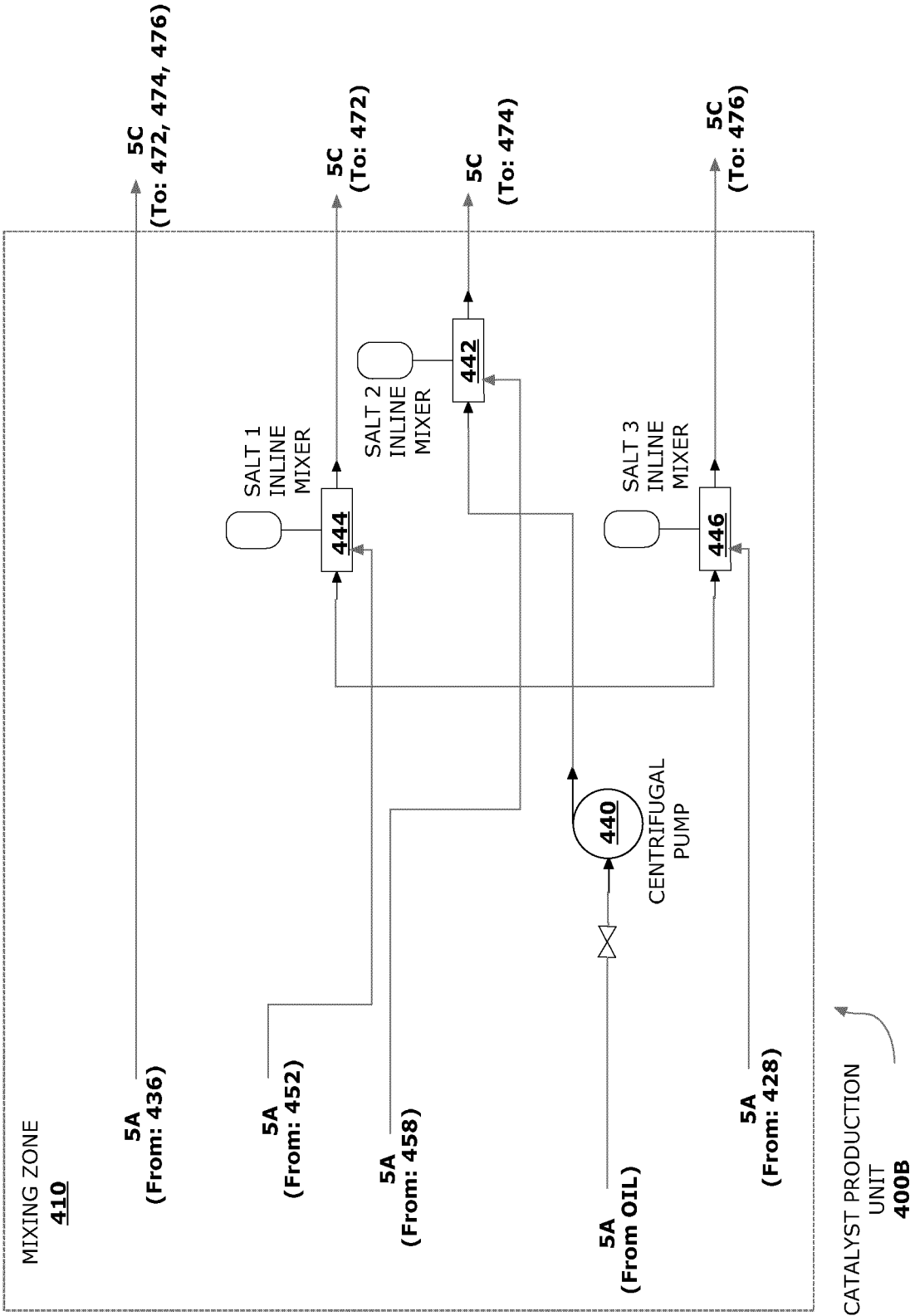


FIG. 5B

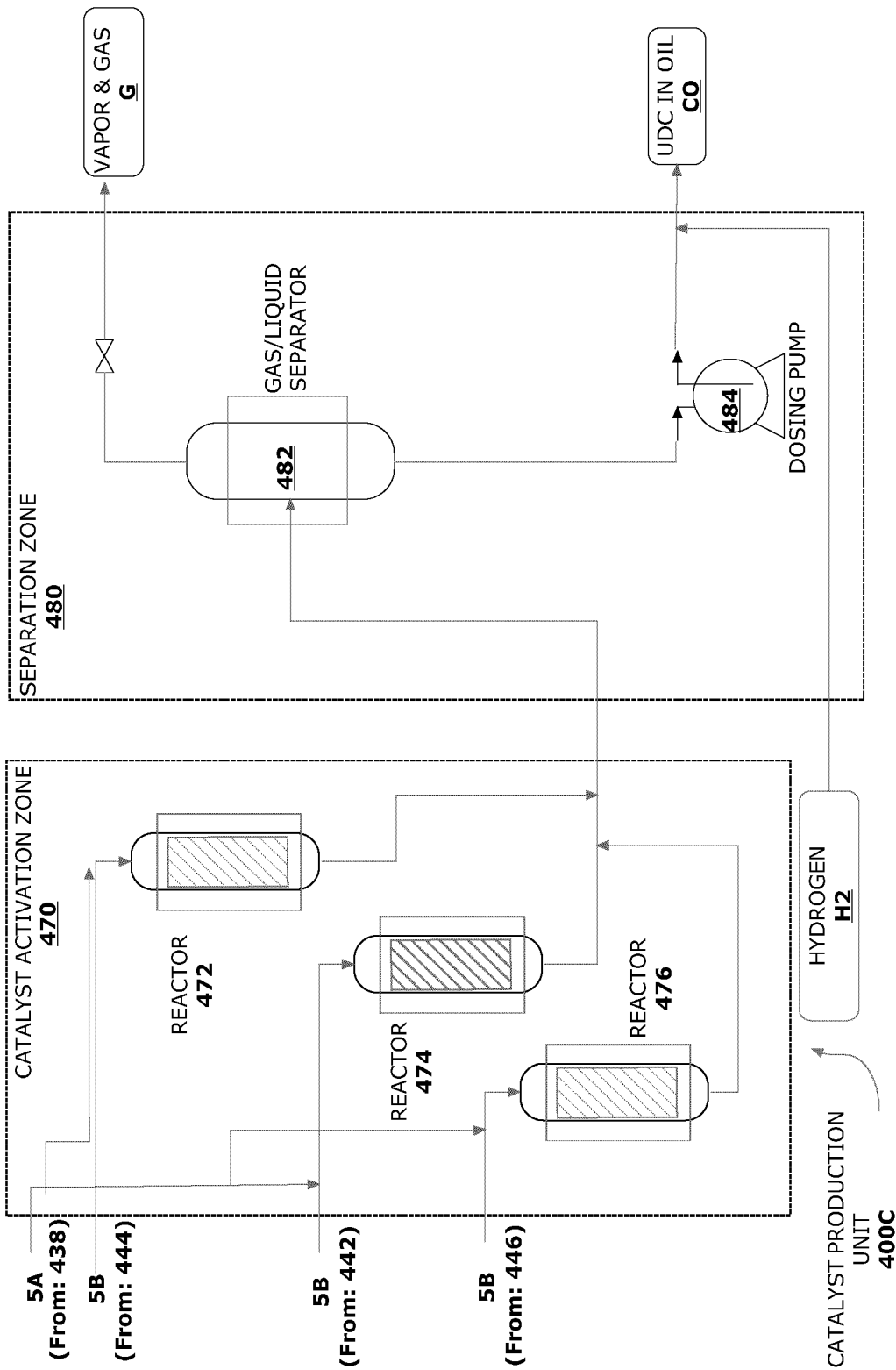


FIG. 5C

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2016/050399

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **B01J 37/00** (2006.01), **C10G 49/02** (2006.01), **E21B 43/22** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: B01J 37/00 (2006.01), C10G 49/02 (2006.01), E21B 43/22 (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Documents cited in the documents listed in C, and in the Description

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Canadian Patents Database; INTELLECT; Questel Orbit; Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages			Relevant to claim No.
X,Y	US 7,897,537 B2	(PEREIRA-ALMAO ET AL)	01 March 2011 (01-03-2011)	1 – 27
X,Y	US 8,283,279 B2	(PEREIRA-ALMAO ET AL)	09 October 2012 (09-10-2012)	1 – 27
X,Y	US 8,298,982 B2	(PEREIRA-ALMAO ET AL)	30 October 2012 (30-10-2012)	1 – 27
X,Y	US 8,304,363 B2	(PEREIRA-ALMAO ET AL)	06 November 2012 (06-11-2012)	1 – 27
X,Y	US 8,551,907 B2	(PEREIRA ET AL)	08 October 2013 (08-10-2013)	1 – 27
X,Y	CA 2,810,022 A1	(PEREIRA-ALMAO ET AL)	30 November 2013 (30-11-2013)	28

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* “A” “E” “L” “O” “P”	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance earlier application or patent but published on or after the international filing date document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	“T” “X” “Y” “&”	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art document member of the same patent family
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Date of the actual completion of the international search
30 May 2016 (30-05-2016)Date of mailing of the international search report
22 June 2016 (22-06-2016)Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer

Ravi Philar (819) 639-8530

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2016/050399

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US7897537B2	01 March 2011 (01-03-2011)	US2007161505A1 CA2630365C US2011105315A1 US8283279B2 US2011105308A1 US8298982B2 US2011105307A1 US8304363B2 WO2007059621A1	12 July 2007 (12-07-2007) 16 March 2010 (16-03-2010) 05 May 2011 (05-05-2011) 09 October 2012 (09-10-2012) 05 May 2011 (05-05-2011) 30 October 2012 (30-10-2012) 05 May 2011 (05-05-2011) 06 November 2012 (06-11-2012) 31 May 2007 (31-05-2007)
US8283279B2	09 October 2012 (09-10-2012)	US2011105315A1 CA2630365C US2007161505A1 US7897537B2 US2011105308A1 US8298982B2 US2011105307A1 US8304363B2 WO2007059621A1	05 May 2011 (05-05-2011) 16 March 2010 (16-03-2010) 12 July 2007 (12-07-2007) 01 March 2011 (01-03-2011) 05 May 2011 (05-05-2011) 30 October 2012 (30-10-2012) 05 May 2011 (05-05-2011) 06 November 2012 (06-11-2012) 31 May 2007 (31-05-2007)
US8298982B2	30 October 2012 (30-10-2012)	US2011105308A1 CA2630365C US2007161505A1 US7897537B2 US2011105315A1 US8283279B2 US2011105307A1 US8304363B2 WO2007059621A1	05 May 2011 (05-05-2011) 16 March 2010 (16-03-2010) 12 July 2007 (12-07-2007) 01 March 2011 05 May 2011 (05-05-2011) 09 October 2012 (09-10-2012) 05 May 2011 (05-05-2011) 06 November 2012 (06-11-2012) 31 May 2007 (31-05-2007)
US8304363B2	06 November 2012 (06-11-2012)	US2011105307A1 CA2630365C US2007161505A1 US7897537B2 US2011105315A1 US8283279B2 US2011105308A1 US8298982B2 WO2007059621A1	05 May 2011 (05-05-2011) 16 March 2010 (16-03-2010) 12 July 2007 (12-07-2007) 01 March 2011 (01-03-2011) 05 May 2011 (05-05-2011) 09 October 2012 (09-10-2012) 05 May 2011 (05-05-2011) 30 October 2012 (30-10-2012) 31 May 2007 (31-05-2007)
US8551907B2	08 October 2013 (08-10-2013)	US2011068045A1 BRPI0804269A2 CA2639777C EP2113304A3 US2012252660A1 US8815765B2 US2009023965A1	24 March 2011 (24-03-2011) 23 August 2011 (23-08-2011) 22 April 2014 (22-04-2014) 10 March 2010 (10-03-2010) 04 October 2012 (04-10-2012) 26 August 2014 (26-08-2014) 22 January 2009 (22-01-2009)
CA2810022A1	30 November 2013 (30-11-2013)	CA2810022A1 CA2864788A1 CA2928272A1 CN104619947A CO7200244A2 MX2014014193A US2015114636A1 WO2013177683A1	30 November 2013 (30-11-2013) 30 November 2013 (30-11-2013) 30 November 2013 (30-11-2013) 13 May 2015 (13-05-2015) 27 February 2015 (27-02-2015) 11 May 2015 (11-05-2015) 30 April 2015 (30-04-2015) 05 December 2013 (05-12-2013)

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

To: HICKS, ANDREW R. c/o Hicks & Associates 300 - 709 Main Street CANMORE, Alberta Canada, T1W 2B2

Date of mailing <i>(day/month/year)</i>	22 June 2016 (22-06-2016)
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Applicant's or agent's file reference HA-P1458PCT	FOR FURTHER ACTION See paragraph 2 below
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International application No. PCT/CA2016/050399	International filing date <i>(day/month/year)</i> 07 April 2016 (07-04-2016)	Priority date <i>(day/month/year)</i> 07 April 2015 (07-04-2015)
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International Patent Classification (IPC) or both national classification and IPC IPC: B01J 37/00 (2006.01), C10G 49/02 (2006.01), E21B 43/22 (2006.01)

Applicant PC-CUPS LTD.

1. This opinion contains indications relating to the following items: ☒ Box No. I Basis of the opinion ☐ Box No. II Priority ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability ☐ Box No. IV Lack of unity of invention ☒ Box No. V Reasoned statement under Rule 43<i>bis</i>.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement ☐ Box No. VI Certain documents cited ☐ Box No. VII Certain defects in the international application ☒ Box No. VIII Certain observations on the international application 2. FURTHER ACTION If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1<i>bis</i> (b) that written opinions of this International Searching Authority will not be so considered. If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later. For further options, see Form PCT/ISA/220.

Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Date of completion of this opinion 21 June 2016 (21-06-2016)	Authorized officer Ravi Philar (819) 639-8530
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WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/CA2016/050399

Box No. I

Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:

- ☒ the international application in the language in which it was filed.
- ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a))

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing:

- a. ☐ forming part of the international application as filed:
- ☐ in the form of an Annex C/ST.25 text file.
 - ☐ on paper or in the form of an image file.
- b. ☐ furnished together with the international application under PCT Rule 13*ter*.1(a) for the purposes of international search only in the form of an Annex C/ST.25 text file.
- c. ☐ furnished subsequent to the international filing date for the purposes of international search only:
- ☐ in the form of an Annex C/ST.25 text file (Rule 13*ter*.1(a)).
 - ☐ on paper or in the form of an image file (Rule 13*ter*.1(b) and Administrative Instructions, Section 713).

4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

Box No. V	Reasoned statement under Rule 43bis.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement									
1. Statement	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%; vertical-align: top;">Novelty (N)</td> <td style="width: 40%; vertical-align: top;"> Claims <u>None</u> Claims <u>1 - 28</u> </td> <td style="width: 30%; vertical-align: top; text-align: right;"> YES NO </td> </tr> <tr> <td style="vertical-align: top;">Inventive step (IS)</td> <td style="vertical-align: top;"> Claims <u>None</u> Claims <u>1 - 28</u> </td> <td style="vertical-align: top; text-align: right;"> YES NO </td> </tr> <tr> <td style="vertical-align: top;">Industrial applicability (IA)</td> <td style="vertical-align: top;"> Claims <u>1 - 28</u> Claims <u>None</u> </td> <td style="vertical-align: top; text-align: right;"> YES NO </td> </tr> </table>	Novelty (N)	Claims <u>None</u> Claims <u>1 - 28</u>	YES NO	Inventive step (IS)	Claims <u>None</u> Claims <u>1 - 28</u>	YES NO	Industrial applicability (IA)	Claims <u>1 - 28</u> Claims <u>None</u>	YES NO
Novelty (N)	Claims <u>None</u> Claims <u>1 - 28</u>	YES NO								
Inventive step (IS)	Claims <u>None</u> Claims <u>1 - 28</u>	YES NO								
Industrial applicability (IA)	Claims <u>1 - 28</u> Claims <u>None</u>	YES NO								
2. Citations and explanations:	D1 = US 7,897,537 B2 (PEREIRA-ALMAO ET AL) 01 March 2011 (01-03-2011) D2 = US 8,283,279 B2 (PEREIRA-ALMAO ET AL) 09 October 2012 (09-10-2012) D3 = US 8,298,982 B2 (PEREIRA-ALMAO ET AL) 30 October 2012 (30-10-2012) D4 = US 8,304,363 B2 (PEREIRA-ALMAO ET AL) 06 November 2012 (06-11-2012) D5 = US 8,551,907 B2 (PEREIRA ET AL) 08 October 2013 (08-10-2013) D6 = CA 2,810,022 C (PEREIRA-ALMAO ET AL) 30 November 2013 (30-11-2013) Claims 1 - 27 are not novel and therefore do not comply with PCT Article 33(2). Each of documents D1 - D5 (entire documents) discloses the subject matter of Claims 1 – 27 (Col.1 – 8; examples; claims). The present Description cites each of D1 to D5 and unequivocally incorporates these documents in their entirety to clearly underline that the subject matter of these claims is presented in D1 to D5. Sections of the present Description are verbatim excerpts of the descriptions found in D1 to D5. Therefore, claims 1 - 27 are not novel. Claim 28 is not novel and therefore does not comply with PCT Article 33(2). D6 discloses the subject matter of Claim 28 (page 1 – 34; abstract; claims) by describing a method of introducing hydrogen and an ultradispersed catalyst together with the injection of a hot fluid into a production well to further promote hydrocarbon upgrading. The present Description cites D6 and unequivocally incorporates this document in its entirety to clearly underline that the subject matter of this claims is presented in D6 (see page 5, 25 and 26 of present Description). Therefore, claim 28 is not novel. The lack of novelty of Claims 1 – 28 is further underlined by repeated assertions in the present Description to the effect that a specific equipment or process step is, for example, “ known to those with skill in the arts relating to process engineering and can be adapted to the catalyst preparation unit of the present invention without undue experimentation”.(paragraph 00051). Claims 1 - 28 do not involve an inventive step and therefore do not comply with PCT Article 33(3). Given the above novelty objections, claims 1 - 28 do not involve an inventive step. The subject matter of claims 1 - 28 is considered to be industrially applicable and thus complies with the requirements of PCT Article 33(4).									

Box No. VIII Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

Independent Claims 1, 15, 23 and 28 do not comply with PCT Article 6. These claims are not clear. The term “activated” is neither clear nor comprehensible from the description. It is further unclear as to what specific characteristics are endowed in the catalyst, and what treatment steps are prescribed in order to render said catalyst to become “activated”, especially as it pertains to step (vi) in Claim 1.

Claim 2 does not comply with PCT Article 6. This claim is not clear. The term “chemically compatible” is not clear from the description either regarding its significance, or its purpose.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter I of the Patent Cooperation Treaty)

(PCT Rule 44bis)

Applicant's or agent's file reference HA-P1458PCT	FOR FURTHER ACTION	See item 4 below
International application No. PCT/CA2016/050399	International filing date (<i>day/month/year</i>) 07 April 2016 (07.04.2016)	Priority date (<i>day/month/year</i>) 07 April 2015 (07.04.2015)
International Patent Classification (8th edition unless older edition indicated) See relevant information in Form PCT/ISA/237		
Applicant PC-CUPS LTD.		

1.	This international preliminary report on patentability (Chapter I) is issued by the International Bureau on behalf of the International Searching Authority under Rule 44 bis.1(a).																								
2.	This REPORT consists of a total of 5 sheets, including this cover sheet.																								
In the attached sheets, any reference to the written opinion of the International Searching Authority should be read as a reference to the international preliminary report on patentability (Chapter I) instead.																									
3.	This report contains indications relating to the following items: <table style="width: 100%;"> <tr> <td style="width: 5%; text-align: center;">☒</td> <td style="width: 25%;">Box No. I</td> <td style="width: 70%;">Basis of the report</td> </tr> <tr> <td style="text-align: center;">☐</td> <td>Box No. II</td> <td>Priority</td> </tr> <tr> <td style="text-align: center;">☐</td> <td>Box No. III</td> <td>Non-establishment of opinion with regard to novelty, inventive step and industrial applicability</td> </tr> <tr> <td style="text-align: center;">☐</td> <td>Box No. IV</td> <td>Lack of unity of invention</td> </tr> <tr> <td style="text-align: center;">☒</td> <td>Box No. V</td> <td>Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement</td> </tr> <tr> <td style="text-align: center;">☐</td> <td>Box No. VI</td> <td>Certain documents cited</td> </tr> <tr> <td style="text-align: center;">☐</td> <td>Box No. VII</td> <td>Certain defects in the international application</td> </tr> <tr> <td style="text-align: center;">☒</td> <td>Box No. VIII</td> <td>Certain observations on the international application</td> </tr> </table>	☒	Box No. I	Basis of the report	☐	Box No. II	Priority	☐	Box No. III	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability	☐	Box No. IV	Lack of unity of invention	☒	Box No. V	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement	☐	Box No. VI	Certain documents cited	☐	Box No. VII	Certain defects in the international application	☒	Box No. VIII	Certain observations on the international application
☒	Box No. I	Basis of the report																							
☐	Box No. II	Priority																							
☐	Box No. III	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability																							
☐	Box No. IV	Lack of unity of invention																							
☒	Box No. V	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement																							
☐	Box No. VI	Certain documents cited																							
☐	Box No. VII	Certain defects in the international application																							
☒	Box No. VIII	Certain observations on the international application																							
4.	The International Bureau will communicate this report to designated Offices in accordance with Rules 44bis.3(c) and 93bis.1 but not, except where the applicant makes an express request under Article 23(2), before the expiration of 30 months from the priority date (Rule 44bis .2).																								

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No. +41 22 338 82 70	Date of issuance of this report 10 October 2017 (10.10.2017) Authorized officer Athina Nickitas-Etienne e-mail: pct.team4@wipo.int
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PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

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Date of mailing <i>(day/month/year)</i>	22 June 2016 (22-06-2016)
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Applicant's or agent's file reference HA-P1458PCT
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FOR FURTHER ACTION See paragraph 2 below
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International application No. PCT/CA2016/050399	International filing date <i>(day/month/year)</i> 07 April 2016 (07-04-2016)	Priority date <i>(day/month/year)</i> 07 April 2015 (07-04-2015)
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International Patent Classification (IPC) or both national classification and IPC IPC: B01J 37/00 (2006.01), C10G 49/02 (2006.01), E21B 43/22 (2006.01)

Applicant PC-CUPS LTD.

1. This opinion contains indications relating to the following items: ☒ Box No. I Basis of the opinion ☐ Box No. II Priority ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability ☐ Box No. IV Lack of unity of invention ☒ Box No. V Reasoned statement under Rule 43<i>bis</i>.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement ☐ Box No. VI Certain documents cited ☐ Box No. VII Certain defects in the international application ☒ Box No. VIII Certain observations on the international application 2. FURTHER ACTION If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1<i>bis</i> (b) that written opinions of this International Searching Authority will not be so considered. If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later. For further options, see Form PCT/ISA/220.

Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Date of completion of this opinion 21 June 2016 (21-06-2016)	Authorized officer Ravi Philar (819) 639-8530
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Box No. I

Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:
 - ☒ the international application in the language in which it was filed.
 - ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).
2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a))
3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing:
 - a. ☐ forming part of the international application as filed:
 - ☐ in the form of an Annex C/ST.25 text file.
 - ☐ on paper or in the form of an image file.
 - b. ☐ furnished together with the international application under PCT Rule 13*ter*.1(a) for the purposes of international search only in the form of an Annex C/ST.25 text file.
 - c. ☐ furnished subsequent to the international filing date for the purposes of international search only:
 - ☐ in the form of an Annex C/ST.25 text file (Rule 13*ter*.1(a)).
 - ☐ on paper or in the form of an image file (Rule 13*ter*.1(b) and Administrative Instructions, Section 713).
4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.
5. Additional comments:

Box No. V	Reasoned statement under Rule 43bis.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement									
1. Statement	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%; vertical-align: top;">Novelty (N)</td> <td style="width: 40%; vertical-align: top;"> Claims <u>None</u> Claims <u>1 - 28</u> </td> <td style="width: 30%; vertical-align: top; text-align: right;"> YES NO </td> </tr> <tr> <td style="vertical-align: top;">Inventive step (IS)</td> <td style="vertical-align: top;"> Claims <u>None</u> Claims <u>1 - 28</u> </td> <td style="vertical-align: top; text-align: right;"> YES NO </td> </tr> <tr> <td style="vertical-align: top;">Industrial applicability (IA)</td> <td style="vertical-align: top;"> Claims <u>1 - 28</u> Claims <u>None</u> </td> <td style="vertical-align: top; text-align: right;"> YES NO </td> </tr> </table>	Novelty (N)	Claims <u>None</u> Claims <u>1 - 28</u>	YES NO	Inventive step (IS)	Claims <u>None</u> Claims <u>1 - 28</u>	YES NO	Industrial applicability (IA)	Claims <u>1 - 28</u> Claims <u>None</u>	YES NO
Novelty (N)	Claims <u>None</u> Claims <u>1 - 28</u>	YES NO								
Inventive step (IS)	Claims <u>None</u> Claims <u>1 - 28</u>	YES NO								
Industrial applicability (IA)	Claims <u>1 - 28</u> Claims <u>None</u>	YES NO								
2. Citations and explanations:	D1 = US 7,897,537 B2 (PEREIRA-ALMAO ET AL) 01 March 2011 (01-03-2011) D2 = US 8,283,279 B2 (PEREIRA-ALMAO ET AL) 09 October 2012 (09-10-2012) D3 = US 8,298,982 B2 (PEREIRA-ALMAO ET AL) 30 October 2012 (30-10-2012) D4 = US 8,304,363 B2 (PEREIRA-ALMAO ET AL) 06 November 2012 (06-11-2012) D5 = US 8,551,907 B2 (PEREIRA ET AL) 08 October 2013 (08-10-2013) D6 = CA 2,810,022 C (PEREIRA-ALMAO ET AL) 30 November 2013 (30-11-2013) Claims 1 - 27 are not novel and therefore do not comply with PCT Article 33(2). Each of documents D1 - D5 (entire documents) discloses the subject matter of Claims 1 – 27 (Col.1 – 8; examples; claims). The present Description cites each of D1 to D5 and unequivocally incorporates these documents in their entirety to clearly underline that the subject matter of these claims is presented in D1 to D5. Sections of the present Description are verbatim excerpts of the descriptions found in D1 to D5. Therefore, claims 1 - 27 are not novel. Claim 28 is not novel and therefore does not comply with PCT Article 33(2). D6 discloses the subject matter of Claim 28 (page 1 – 34; abstract; claims) by describing a method of introducing hydrogen and an ultradispersed catalyst together with the injection of a hot fluid into a production well to further promote hydrocarbon upgrading. The present Description cites D6 and unequivocally incorporates this document in its entirety to clearly underline that the subject matter of this claims is presented in D6 (see page 5, 25 and 26 of present Description). Therefore, claim 28 is not novel. The lack of novelty of Claims 1 – 28 is further underlined by repeated assertions in the present Description to the effect that a specific equipment or process step is, for example, “ known to those with skill in the arts relating to process engineering and can be adapted to the catalyst preparation unit of the present invention without undue experimentation”.(paragraph 00051). Claims 1 - 28 do not involve an inventive step and therefore do not comply with PCT Article 33(3). Given the above novelty objections, claims 1 - 28 do not involve an inventive step. The subject matter of claims 1 - 28 is considered to be industrially applicable and thus complies with the requirements of PCT Article 33(4).									

Box No. VIII Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

Independent Claims 1, 15, 23 and 28 do not comply with PCT Article 6. These claims are not clear. The term “activated” is neither clear nor comprehensible from the description. It is further unclear as to what specific characteristics are endowed in the catalyst, and what treatment steps are prescribed in order to render said catalyst to become “activated”, especially as it pertains to step (vi) in Claim 1.

Claim 2 does not comply with PCT Article 6. This claim is not clear. The term “chemically compatible” is not clear from the description either regarding its significance, or its purpose.