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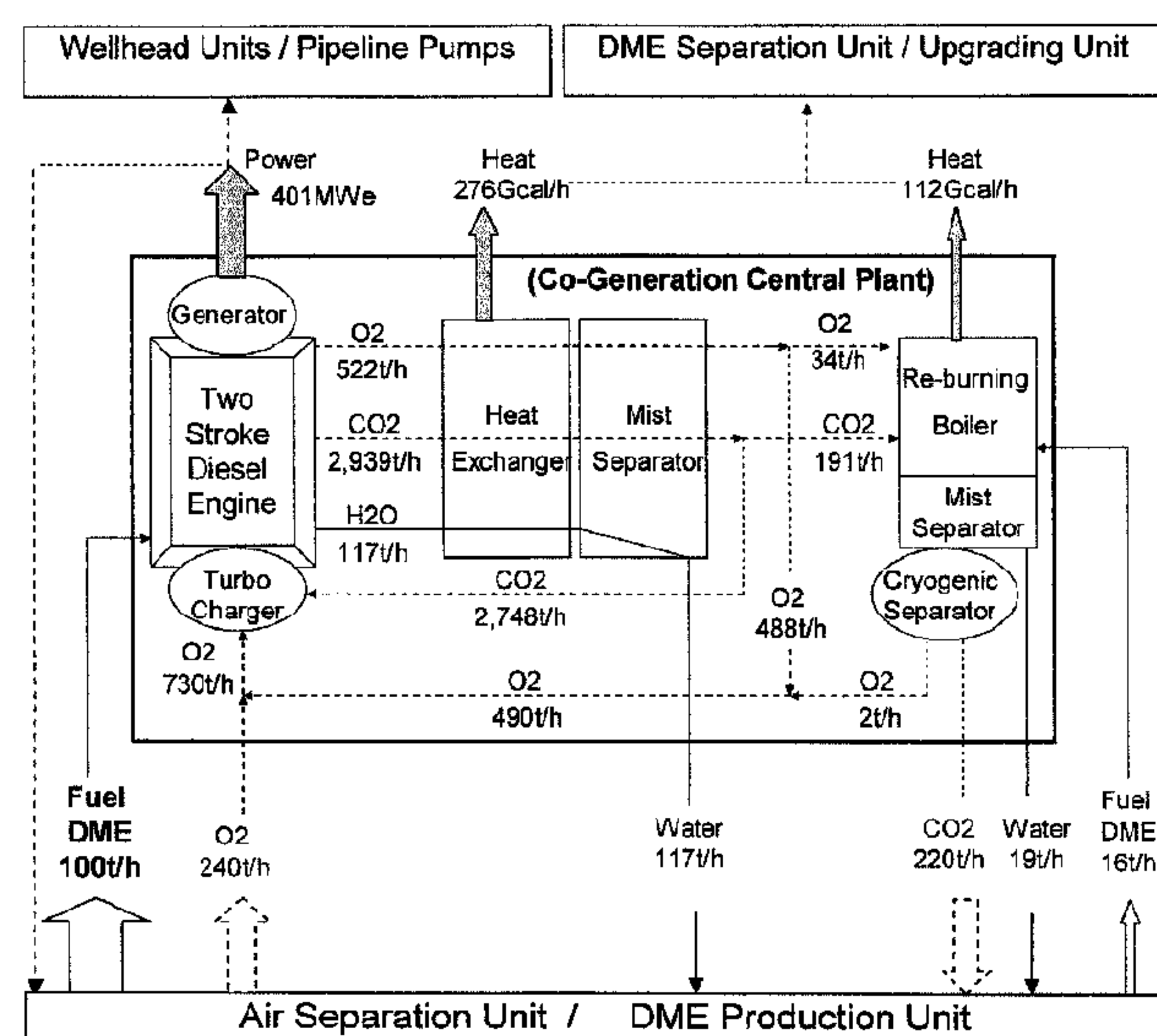
(72) Inventeurs/Inventors:
IGNASIAK, BOLESŁAW L., CA;
YAMAOKA, KEIJIRO, JP

(73) Propriétaires/Owners:
IGNASIAK, BOLESŁAW L., CA;
YAMAOKA, KEIJIRO, JP

(74) Agent: NA

(54) Titre : RECUPERATION IN SITU DE BITUME OU DE PETROLE LOURD PAR INJECTION DE DIMETHYL ETHER

(54) Title: IN-SITU RECOVERY OF BITUMEN OR HEAVY OIL BY INJECTION OF DI-METHYL ETHER



**Di-Methyl Ether (DME) Fired O2-CO2 Drive Two-Stroke
Diesel Co-generation with Re-burning O2-CO2 Drive
Boiler and Cryogenic CO2 Capture**

(57) Abrégé/Abstract:

A method is provided for energy efficient, environmentally friendly, in-situ recovery of bitumen or heavy oil by injecting di-methyl ether (DME) into the reservoir. The method includes the steps of heating the reservoir utilizing the condensation and latent heats of injected DME liquids and/or vapours, mobilizing the bitumen/heavy oil by lowering its viscosity, dissolving the water and some of the components of the bitumen/heavy oil in the DME, recovering from the reservoir the mixture of bitumen and DME containing the dissolved components of the bitumen, separating the DME from the mixture by depressurization followed by pressurizing, heating and re-injecting the recovered DME, into the reservoir.

Abstract

A method is provided for energy efficient, environmentally friendly, in-situ recovery of bitumen or heavy oil by injecting di-methyl ether (DME) into the reservoir. The method includes the steps of heating the reservoir utilizing the condensation and latent heats of injected DME liquids and/or vapours, mobilizing the bitumen/heavy oil by lowering its viscosity, dissolving the water and some of the components of the bitumen/heavy oil in the DME, recovering from the reservoir the mixture of bitumen and DME containing the dissolved components of the bitumen, separating the DME from the mixture by depressurization followed by pressurizing, heating and re-injecting the recovered DME, into the reservoir.

IN-SITU RECOVERY OF BITUMEN OR HEAVY OIL BY INJECTION OF DI-METHYL ETHER

DESCRIPTION

The present invention is directed to a process for efficient, environmentally friendly, in-situ recovery of bitumen or heavy oil by injecting pressurized, heated di-methyl ether (OME) into the reservoir using equipment comparable to that applied for steam assisted gravity drainage (SAGO) or cyclic steam stimulation (CSS), recovering the mobilized bitumen/heavy oil from the reservoir, separating the OME from the bitumen/heavy oil by depressurizing followed by pressurizing, heating and re-injecting the recovered OME into the reservoir.

Background of the Invention

Field of the invention: Nowadays most of the bitumen is recovered by mining the oil sands ore and separating the bitumen from the mined ore. Only a minor fraction of the Alberta deposits of bitumen can be economically recovered by mining. Over 80 wt of the bitumen and essentially all heavy oils have to be recovered by a variety of in-situ processes for which the common denominator is injection of steam into the reservoir to raise its temperature and lower the viscosity of the bitumen/heavy oil in order to deliver it to the surface, clean and pipeline the bitumen/heavy oil for processing/upgrading.

Description of Prior Art: Increasing demand for heavy oil and bitumen in particular resulted in developing, over the last twenty years, a commercial steam assisted gravity drainage (SAGO) technology for in-situ recovery of bitumen from Alberta oil sands deposits. The SAGO concept is based on horizontal well technology. The steam is injected into horizontally positioned steam dispersing pipe (injection well) placed in the center of a gravity drainage chamber. Sometimes, suitable additives, surfactants or collectors are also injected, in addition to steam, into the chamber. Product collection pipe is placed beneath the steam dispersing pipe, at the bottom of the gravity drainage chamber. The steam delivered into the gravity drainage chamber heats the oil sands ore, lowers the viscosity of the bitumen and converts into water. The liquefied bitumen and water mixture flows downward, enters the product collection pipe from which it is delivered to the surface (production well). The gravity drainage chamber has dimensions of approximately: length - 700 m; width - 150 m; height - 20 m. As a rule several chambers are constructed in close vicinity and operated to maximally utilize the heat delivered and optimize the production of bitumen. The temperature of steam supplied to the chambers usually exceeds 200°C. Typically over three volumes of steam are required to produce one volume of raw bitumen. The production well delivers one volume of bitumen per three volumes of water. The water recovered from the gravity drainage chamber is contaminated and requires treatment prior to recycling and steaming. About 80-90 wt of produced water can be recycled after treatment. Required make-up/fresh water amounts to about 0.5 volume for every volume of bitumen produced. The high mineral content, salty water that cannot be recycled has to be

condensation of injected steam. The water pumped out from the reservoir is contaminated and requires treatment prior to recycling and steaming. About 80-90 wt% of produced water can be recycled after treatment. Typically required make-up/fresh water amounts to about 0.5 volume for every volume of bitumen produced. The high mineral content, salty water that cannot be recycled has to be disposed. The gas from the production well is either treated and partially utilized or flared. Huge volumes of natural gas are required for generation of steam from the treated and make-up waters. Natural gas cost accounts for significant portion of the cost of producing 1 barrel of bitumen by SAGD technology. The consumption of natural gas by SAGD technology results in generation of ever increasing volumes of CO₂. Projected increase in bitumen production in Athabasca region to 5 million barrels per day using SAGD does not appear to be sustainable. There is growing evidence that Northern Alberta region cannot supply sufficient volumes of water and natural gas to maintain the rapid development of the oil sands industry. Disposal of the contaminated produced water becomes a major environmental problem. Collection and sequestration of CO₂, the gas that is considered to be the main cause of climate change, while technically proven, may increase the cost of oil sands processing to a point of making the oil sands industry economically unviable.

The inability of SAGD to meet the environmental and economic growth expectations of the oil sands industry has sparked development of a new generation of in-situ bitumen recovery technologies based on application of low boiling hydrocarbons – VAPEX (vapour recovery extraction) technologies. In general VAPEX technologies use the hardware developed by SAGD but either partially (hybrid processes) or totally (hydrocarbon processes) replace steam with selected hydrocarbons or a mixture of selected hydrocarbons. So far the development of the new generation of in-situ processes for bitumen/heavy oil recovery is limited to bench scale, continuous bench scale and pilot plant (field) testing and modelling. As a rule low boiling hydrocarbons are injected into the gravity drainage chamber in the form of vapours and/or liquids. The mixture of hydrocarbon vapours and/or liquids injected into the chamber delivers the latent and condensation heats to the perimeter of the chamber and mobilizes the bitumen. The flow of bitumen results from lowering its viscosity due to increase in temperature and from solubilisation of some components of the bitumen in the hydrocarbon solvents. The product composed of the components of bitumen dissolved in hydrocarbon-solvent is, after recovery from the production well, subjected to flash distillation; the hydrocarbon vapours are recovered, pressurized, and re-injected in the form of liquids and/or vapours into the chamber; the bitumen is utilized as required. Attempts are being made to eliminate the recycling of the low boiling hydrocarbons recovered from the production well by distilling them off from the bitumen/hydrocarbon mixture prior to the mixture leaving the gravity drainage chamber. This is accomplished by using heaters placed in the product collection pool and/or product collection pipes.

Attempts are also being made to separate from bitumen, in-situ, some of the coke precursors, namely the asphaltenes, so that the bitumen product should be more amenable to upgrading compared to bitumen generated by other processes that do not involve in-situ de-asphalting. For this purpose the N-Solv Process (1) applies propane or butanes - well known de-asphalting agents.

The new generation of proposed in-situ bitumen recovery processes, based on application of low boiling hydrocarbons or a mixture of hydrocarbons and steam, offers significant advantages compared to commercial SAGD technology. The new generation processes have the potential to reduce consumption and processing of water by 50-90%. The consumption of energy is expected to be reduced by up to 50%. The generation of CO₂, the main component of the green house gas (GHG), may be reduced by 50-90%. The bitumen production rates can be increased by 70% or more while the volumes of produced sand can be reduced. There is a potential for significantly reducing the operating and capital costs. The shortcomings/challenges facing the new generation of hydrocarbon based in-situ bitumen recovery processes are: uncertainties regarding losses of hydrocarbon solvents- so far the field trials show losses in the range of 10-25%; the need for using high purity solvents – specifically N-Solv process performance is hampered by presence of methane in the gravity drainage chamber; growing scarcity of low boiling hydrocarbons required for bitumen recovery and pipelining; high cost of low boiling hydrocarbons compared to bitumen cost; uncertainties regarding the ecological impact of low boiling hydrocarbons lost during in-situ operations and released to atmosphere.

It is the object of the present invention to provide a process for effective and environmentally friendly in-situ bitumen recovery that will encompass and surpass all advantages of the proposed hydrocarbon based in-situ bitumen recovery processes.

It is another object of the present invention to provide a process that will be freed of the shortcomings/challenges facing the new generation of hydrocarbon based in-situ bitumen recovery processes.

These and other objects of the present invention will be apparent from the following description of the preferred embodiments, the appended claims and from practice of the invention.

SUMMARY

The present invention provides an efficient method for injecting pressurized di-methyl ether (DME) liquids and/or vapours into the gravity drainage chamber, mobilizing the bitumen in the chamber by lowering its viscosity due to the latent and condensation

heats of the DME and the capacity of DME to act as solvent significantly more powerful compared to propane and butanes, draining the binary liquid product composed of DME/bitumen and DME/water solutions towards the product collection pool, accumulating the product in the collection pipe, delivering the product to the surface via the production well, separating the binary liquid, subjecting the DME/ water solution to flash distillation by depressurizing, separating the DME vapours, pressurizing the separated vapours and recycling the DME liquids and/or vapours and cleaning, pipelining and utilizing the DME/bitumen solution as required. The present invention, as summarized above and compared to prior art replaces costly and scarce hydrocarbons with DME, requires less energy, has the capability to remove some water from the gravity drainage chamber prior to raising its temperature, enhances the solubilisation and mobilization of bitumen by removing the water and the polar and other components of the bitumen which are not soluble in propane/butanes and thus increasing the porosity of the oil sands ore and the rate of penetration of DME vapours into the ore, reducing the viscosity of the generated DME/bitumen solution, using DME solvent costing less compared to liquefied petroleum gas (LPG) or condensate from which the hydrocarbon solvents are separated, using non-hydrocarbon solvent that can be readily manufactured, is widely accessible, environmentally benign, well known as excellent Diesel fuel and decomposes over relatively short period of time when released to atmosphere.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 presents changes in saturated vapour pressures of DME (di-methyl ether), propane and butane at different deposition depths and as a function of temperature.

Figure 2 presents changes in kinetic viscosities for selected bitumen/DME (di-methyl ether) blends as a function of temperature.

Figure 3 depicts the applicability of various bitumen recovery technologies depending on the depth of the reservoir containing the oil sands ore or heavy oil.

Figure 4 presents the schematics of DME fired O_2 - CO_2 drive two-stroke Diesel engine co-generation system with re-burning O_2 - CO_2 drive boiler and cryogenic CO_2 capture.

Figure 5 depicts the concept of Skin Electric Current Tracing (SECT) method for heating DME to be applied as solvent and diluent.

Figure 6 presents the schematics of the experimental set-up employed for extraction of oil sands ore with liquid DME.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The starting material used in the process of the present invention for in-situ recovery of bitumen or heavy oil from their reservoirs is the di-methyl ether (DME). DME has a chemical formula $\text{CH}_3 - \text{O} - \text{CH}_3$; it is produced commercially in many countries (2, 3). DME can be produced by gasification of coals, bio-mass or other solid fossil fuels followed by subjecting the generated gas to water shift reaction and reacting the generated syngas in a catalytic ebullated bed to form the DME. DME can also be produced from natural gas (methane) via auto-thermal reaction (3) that requires steam, oxygen and utilizes CO_2 that is recycled in the process.

At temperatures above -25.1°C DME occurs as a gas that can be readily liquefied at moderate pressures and temperatures below 127°C . DME has exceptionally high cetane number estimated at 55-60 compared to quality hydrocarbon based Diesel oil (45-53). It performs very well when fired in Diesel engines and its application at low temperatures is free of problems typical of hydrocarbon based Diesel oil. DME suppresses corrosion, does not contain any sulphur or nitrogen and, therefore, the products of DME combustion in nitrogen free atmosphere do not contain any sulphur and nitrogen oxides (SO_x and NO_x). DME reduces Diesel engines emissions by 95% as compared with conventional Diesel fuel.

Some DME properties relevant to its application for in-situ recovery of bitumen are presented in Table 1 and compared to those of propane. Propane is considered by prior art to be the most promising hydrocarbon solvent for in-situ recovery of bitumen. In terms of boiling temperatures, gravity of liquids, gas gravities, critical temperatures and critical pressures the differences between DME and propane are insignificant. The major difference that results from structural make-up of both solvents (ether versus hydrocarbon) is the capability of DME to dissolve water and polar compounds. This results from hydrophobic – hydrophilic character of DME. Propane, a highly hydrophobic compound, does not show any capability for water dissolution. Propane, butanes and pentanes ($\text{C}_3\text{-C}_5$), have been well known for their capabilities to precipitate some polar compounds from bitumen solutions and are applied as de-asphalting agents. According to Hagight (4) application of $\text{C}_3\text{-C}_5$ as solvents for in-situ bitumen recovery causes precipitation of asphaltenic fraction that often results in severe damage to the formation thus leading to significant drop in bitumen production.

The capability of DME to dissolve water and polar compounds indicates that injecting DME into the gravity drainage chamber shall remove the water and polar compounds, in addition to oily components, from the oil sands ore. Removal of water and polar compounds should increase the porosity of the oil sands ore, make it more accessible

to DME vapours, facilitate the heat transfer and mobilization of the bitumen, and reduce the viscosity of the solution composed of bitumen and DME. The capability of DME to remove the water from high water content bitumen ore, at reservoir temperature and prior to commencement of heating, shall allow for additional savings of energy.

The important advantage of the present invention is that DME can be generated at low production cost, from non-petroleum, solid fossil fuels (2, 3). There is a consensus among DME producers that subject to availability of inexpensive low rank solid fossil fuel DME market price shall be significantly lower compared to conventional Diesel fuel, liquefied petroleum gas (LPG) and condensate. Japanese DME process developers estimate that the production cost of DME synthesized directly from coal gasification gas can be as low as US\$ 100/tonne (4). In 2011 market prices for propane/butanes and bitumen were in the range of Can.\$ 560-920/metric ton and Can.\$ 390/metric ton, respectively.

Propane recommended by prior art for in-situ recovery would have to be, according to prior art (1), high purity, methane free propane. The cost of propane separation would further increase its cost. Propane and butanes are typically the products of natural gas processing. Limited availability of propane, butanes and condensate in Northern Alberta is of considerable concern to the oil sands industry and impedes its growth.

The other major advantage of the present invention is that DME has the capacity to recover from the deposit the whole bitumen including the asphaltenic fraction composed mainly of polar components namely, asphaltenes, some resins and some high molecular weight aromatics – the asphaltenic fraction. Using any of the existing de-asphalting procedures the asphaltenic fraction can be separated from the DME recovered bitumen and subjected to co-processing (5) yielding distillable oils in quantities essentially equivalent to the mass of the separated asphaltenic fraction. The de-asphalted fraction can be efficiently processed using conventional upgrading technologies. This approach, based on utilization of the asphaltenic fraction, results in increasing the yield of primary distillable oils by about 25 wt%, per barrel of bitumen, as compared to conventional bitumen upgrading technologies where the asphaltenic fraction is either rejected, gasified or converted into undesirable, high sulfur content coke. Primary distillable oils produced by co-processing (5) would be, according to Alberta Energy, exempted from royalty payments.

The propane based in-situ recovery of bitumen leaves in the reservoir some organics of which, reportedly (1) about 60-70 wt% are asphaltenes. However, in the recovered bitumen there still remains up to 40 wt% of the original asphaltenes plus unspecified content of resins and high molecular weight aromatics – of which some are also coke precursors. These coke precursors, unless they are separated by de-asphalting process prior to upgrading, will generate coke and impede the upgrading process. Therefore, the

propane assisted bitumen recovery generates product that still requires de-asphalting. The hydrogen rich (~8.5 wt% H) asphaltenic fraction left in the reservoir when propane is used for bitumen recovery is irreversibly lost and cannot be utilized for generation of distillable oils (5) or hydrogen.

The other major advantage of the present invention is that at set pressure the application of DME for in-situ bitumen recovery allows to operate at higher temperatures as compared to propane (Fig. 1). Within the pressure range of 1-2 MPa, most likely to be maintained in the gravity drainage chamber, the DME will generate temperatures about 20°C higher compared to propane. Consequently, the DME will lower the viscosity of the binary liquid in the chamber significantly more compared to propane. Furthermore, if the operating temperature in the chamber reaches 97°C, the heat of propane condensation cannot be transferred to the perimeter of the chamber due to propane critical temperature, Table 1. By contrast, DME can effectively transfer the heat of condensation at temperatures up to 126°C.

The other major advantage of the present invention is that DME delivered by a pipeline from its production facility to in-situ bitumen production site can also be utilized as a quality Diesel fuel for Diesel vehicles as well as for electric power and heat generation. Such utilization of DME will eliminate the need for pipelining natural gas that is required for SAGD.

The other major advantage of the present invention is the application, at the central bitumen processing facility, of two-stroke DME fired Diesel engines. The engines are capable of utilizing oxygen and recycling the flue gas to increase thermal efficiency and separation of CO₂. They will generate electric power and heat that can be utilized in the central facility for a variety of applications. Two-stroke Diesel engines are expected to simplify the operations of the in-situ bitumen recovery plants and lower their capital costs.

The other major advantage of the present invention is the reduction in kinematic viscosities of blends composed of bitumen and DME liquids (Fig. 2). At temperatures over 50°C and pressures over 1 MPa the viscosity of the blend composed of 75 wt% bitumen and 25 wt% DME would be less than 7 cSt. Increasing the content of DME in the blend to 30 wt% would reduce the viscosity to below 3 cSt. Reducing the content of DME in the blend to 20 wt% would result in viscosity of about 12 cSt or less. It is, therefore, expected that removal of blends composed of 80-85 wt% of bitumen and 20-15 wt% DME from the gravity drainage chamber operating at depth over 130 m, temperatures over 50°C and pressures of more than 1 MPa shall be very effective.

The other major advantage of the present invention is the potential of DME to substitute for the condensate (C3-C8 hydrocarbons) required for pipelining of bitumen or heavy oil.

The content of condensate in either bitumen/condensate or heavy oil/condensate blend has to be adjusted in such a way that the kinematic viscosity of the blend shall be about 250 cSt or less. Within the temperature range of 10-50°C bitumen/DME blend containing 10-15 wt% DME would satisfy this requirement. The pressure generated by saturated DME vapours at temperatures up to 50°C will be about 1.0 MPa. Typically the pipelines are designed to withstand pressures significantly higher than that. Additional advantage of DME as a substitute for the condensate is that DME content in DME/bitumen solution below approximately 45wt% will not result in precipitation of bitumen components. Propane and butanes will spark a precipitation under such conditions. Precipitation increases the pressure drop thus reducing pipeline economy and is believed to be the source of plugging the flow lines at downstream bitumen processing/upgrading facilities.

The other major advantage of the present invention is the capability of DME to be applied for in-situ recovery of the bitumen from relatively shallow to the deepest Alberta reservoirs (Fig. 3). The pressure in Alberta oil sands reservoirs increases by about 0.75 MPa per every 100 m of depth. It is believed that the oil sands ores do not occur at depths exceeding 700 m (600 m for Athabasca deposit). At 700 m the pressure in the reservoir is about 5.37 MPa. Surface mining of the oil sands ore can be economically practised to a depth of about 70-75 m. SAGD system does not operate smoothly at saturated steam pressures lower than 1.0-1.1 MPa. That indicates that it is unsafe to carry out SAGD operations at depths less than 130 m. To eliminate the possibility of blow-outs, SAGD operations are carried out, as a rule, at depth significantly more than 130m. Cold injection of propane, butanes and DME could be carried out, due to low pressure of saturated vapours of these compounds, at depth less than 130 m. Specifically, operations with propane could be carried out at depths of about 90 m down to about 570 m. Operations with butane could be, theoretically, carried out at depth 20-30 m down to about 500 m. Application of DME for in-situ bitumen recovery can be carried out over the range of 50-700 m which in terms of pressure is equivalent to 1.15-5.37MPa. It therefore appears that as compared with the most promising hydrocarbons, DME has significant advantage for in-situ recovery of bitumen from oil sands and carbonate deposits that cannot be recovered by mining.

Another important advantage of the present invention was unravelled recently based on results of the capital and operating costs estimates for SAGD plant carried out by General Electric and Halliburton Corporation. General Electric (6) estimated the cost of replacing the steam-generation, water-treatment and natural-gas-combustion components of the SAGD plant and concluded: "As much as 80% of the capital cost and 65% of the operating cost associated with facility development and operation is dedicated to treatment of produced water". Halliburton estimate for such replacement is 65% reduction in operating cost (8). NALCO's published estimate (9) for SAGD

operating cost associated with steam generation, water treatment and gas consumption by boiler amounts to 60-70%.

The DME Process replaces the steam generation, water treatment and natural gas combustion components of the SAGD plant. In addition, the DME plant has the capacity to recover approximately 80% more bitumen compared to equivalent SAGD plant.

Another very important advantage of the present invention is that DME can be applied for both, in-situ bitumen recovery and as a diluent for bitumen pipelining. Application of DME eliminates the demand for heat to produce steam and reduces the electric power consumption, as compared to propane, by a factor of two. Numerous in-situ DME based bitumen recovery plants in the Athabasca area could be supplied with power by one central co-generating plant. Such central power plant with flue gas recycling would use DME fired O_2/CO_2 drive two-stroke Diesel co-generation engine with DME re-burning O_2/CO_2 drive boiler and cryogenic CO_2 capture system (Fig. 4). The oxygen required for such plant could be produced on site or could be supplied by pipeline from the plant generating oxygen for coal gasification facility. Pure CO_2 generated by central co-generating plant would be suitable for EOR (enhanced oil recovery), CBMR (coal bed methane recovery) and its capture would not present any technical challenge. The central power and heat co-generation plant would not be effective in providing the individual DME based bitumen recovery plants with the heat required to raise the temperature of DME injected into the gravity drainage chambers. Such heat could be provided by application of the Skin Electric Current Tracing (SECT) method (Fig. 5). SECT has been successfully applied all over the world for heating pipes/pipelines to temperatures as high as 160°C. Provision of heat using the SECT method would further simplify the operation of the individual DME based in-situ bitumen recovery plants. The plants would be supplied with DME and electric power only. Under such circumstances there would be no need to locate the power and heat co-generation plant in bitumen producing region. The power and heat cogeneration plant (Fig. 4) could be constructed as one of the components of the integrated coal gasification, DME synthesis, co-processing and bitumen up-grading central facility. The heat generated by co-generation plant would be fully utilized by the integrated facility. The DME based in-situ bitumen recovery plants would pipeline the DME/bitumen dilbits freed of particulates directly to the central integrated facility for separating, processing and re-cycling of the recovered DME. That would further simplify the operation and reduce the capital and operating costs of the bitumen recovery plants and the whole integrated facility. The in-situ DME based bitumen recovery plants would not emit any CO_2 , volatile organic hydrocarbons (VOC's), SO_x and NO_x ; they would not require natural gas, natural gas pipeline, condensate, condensate gas pipeline, oxygen pipeline, CO_2 pipeline and the auxiliary equipment associated with natural gas combustion, generation of heat and steam, water treatment, separation and disposal of CO_2 .

Having described the foregoing features and advantages of the present invention the following examples are provided by way of illustration, but not by limitation.

Example 1:

Extraction of oil sands ore with liquid DME at ambient temperature

The starting material used was oil sands ore containing 12.1wt% moisture on as received basis and 11.8 wt% of di-chloro methane (CH_2Cl_2) extractable material, on dry basis.

The set-up used for extraction with liquid DME is presented in Fig. 6. The set-up included cylinder A containing liquid DME under nitrogen. Cylinder A was supplied with nitrogen at a flow rate that resulted in discharging 50 ml per min. of liquid DME from cylinder A. The DME discharged from cylinder A was passed through a compacted layer of oil sands ore placed in tube B and the liquid effluents containing the DME, the bitumen, extracted materials and water were introduced into vessel C. Vessel C was connected via pressure release valve (PRV) with vessel D that was immersed in liquid CO_2 and vented to atmosphere.

The experiment was carried out as follows. About 1,000 (+/- 1) g of oil sands ore was placed and compacted in tube B and the set-up was assembled. The nitrogen flow regulator (FR) valve was adjusted in such a way that liquid DME was flown through the layer of the oil sands ore at a rate of about 50 ml per minute at ambient temperature ($18\text{-}20^\circ\text{C}$) while the pressure in the set-up was maintained, using PRV valve, at 0.6 MPa. The flow was maintained for three (3) hours that resulted in about 8 L of liquid DME passing through the oil sands ore layer. Subsequently the flow of DME was terminated using FR and FR1, the pressure in vessel C was reduced to atmospheric pressure and tube B was separated. The residual solids were removed from the tube and vented for a few minutes until the DME evaporated. The DME free solids were blended, placed in a tightly closed glass jar and subjected to moisture determination followed by extraction with di-chloro methane (CH_2Cl_2). The results of analyses show that the moisture content of the treated oil sands ore was reduced from 12.1 wt% to 2.4 wt%, a reduction of close to 80 %. The content of the CH_2Cl_2 extractable material was reduced from 11.8 wt% to 4.1 wt%, a reduction of about 65 wt%.

Example 2:

Extraction of oil sands ore with liquid DME at temperature of 50°C

The same starting material (see Example 1) was used.

The set-up used for extraction was the same as employed in Example I and presented in Fig. 6 except that tube B was placed inside of a hinged heater maintaining the temperature of 50 (+/- 2)^oC and the PRV valve was set to maintain a pressure of 1.2 MPa. in the set-up.

The results of analyses of oil sands ore extracted with liquid DME at 50^oC showed that the moisture content of the treated product was reduced from 12.1 wt% to 0.3 wt%, a reduction of approximately 97-98%. The content of CH₂Cl₂ extractable material was reduced from 11.8 wt% to 0.2 wt%, a reduction of over 98%.

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CLAIMS

What is claimed is:

1. A method for in-situ primary recovery of bitumen or heavy oils from their reservoirs by application of Di- Methyl Ether (DME), comprising the steps of:
 - a) injecting DME via a horizontal injection well into a gravity drainage chamber or an underground formation containing oil sands or carbonate bitumen or heavy oils;
 - b) generating the energy required for DME-based recovery of bitumen or heavy oils by employing a co-generation DME-fired O_2/CO_2 drive 2-stroke Diesel engine equipped with DME re-burning O_2/CO_2 drive boiler and cryogenic CO_2 capture technology;
 - c) generating the heat required for converting DME injected into the bitumen chamber or heavy oils formation into vapors by application of immersion Skin Electric Current Tracing (SECT) - type heaters adapted for usage of DME;
 - d) utilizing the condensation and latent heats of DME vapors and liquids for heating the chamber and the capacity of DME to act as solvent; draining the binary liquid products composed of DME, dissolved components of bitumen or heavy oil and water towards the collection pipe;
 - e) eliminating the recycling of excessive volumes of the DME from the collection pool and product pipe/well by distilling them off using said immersion SECT- type heaters;
 - f) accumulating the product in the collection pipe, delivering the product to the surface plant via the production well for separating;
 - g) depressurizing the separated DME/water solution at surface plant and recovering the DME vapors, pressurizing and recycling said DME vapors together with the make-up DME for bitumen recovery; surface-disposing of the water;
 - h) pipelining from the DME- based bitumen or heavy oil recovery plant the separated binary liquids to the central processing facility;
2. The method according to claim 1, step a), wherein the pressurized DME is injected at a pressure ranging from 0.45- 5.37 MPa;
3. The method according to claim 1, step a) wherein the DME occurs in the form of liquid only or vapor only or any mixture of liquid and vapor;
4. The method according to claim 1, step a), wherein additives, surfactants or collectors are also injected into the gravity drainage chamber either by blending into DME or direct injection into the chamber.
5. The method according to claim 1, steps a), b) and c), wherein DME temperature in the chamber is less than $127^{\circ}C$.

6. The method according to claim 1, step d), wherein utilizing the condensation and latent heats of DME vapors and liquids is employed for heating of a plurality of gravity drainage chambers.
7. The method according to claim 1, steps d), e) and f) wherein the viscosity of the binary liquid composed of DME/bitumen or DME/heavy oils collected in the product pool and well pipes is adjusted by evaporating DME using immersion heaters.
8. The method according to claim 7, wherein the kinematic viscosity of the recovered binary liquids composed of DME/bitumen or DME/heavy oil is about 250 cSt or less.
9. The method according to claim 1, steps g) and h), wherein the binary liquids composed of DME/bitumen or DME/heavy oil delivered to the central integrated facility are freed of DME and partially upgraded.
10. The method according to claim 1, step h) wherein the separated binary liquid composed of DME/bitumen or DME/heavy oils are transported from central integrated facility to selected destination.
11. The method according to claim 9, wherein the DME vapors recovered in the central integrated facility from binary liquids are combined with make-up DME, pressurized and the liquid DME is recycled for bitumen recovery.
12. The method according to claim 11, wherein the liquid DME, instead of being recycled for bitumen recovery is utilized as super-clean Diesel fuel for electric power and heat generation or as transportation fuel in Diesel engine equipped vehicles.
13. The method according to claim 11, wherein the liquid DME, due to very low pressure of its saturated vapors, is utilized for in-situ recovery of bitumen from shallow or thin bitumen deposits that otherwise cannot be exploited.
14. The method according to claim 1, and one or more of steps a-h), wherein the bitumen recovery plants are supplied with DME and electric power from the central processing facility by integrating DME production with partial upgrading of bitumen and eliminating GHG emissions, discontinuing by-products generation and the need for natural gas and condensate supply, the need for pipelines delivering natural gas, condensate and oxygen and the need for auxiliary equipment associated with natural gas combustion, heat generation, process water treatment and disposal.

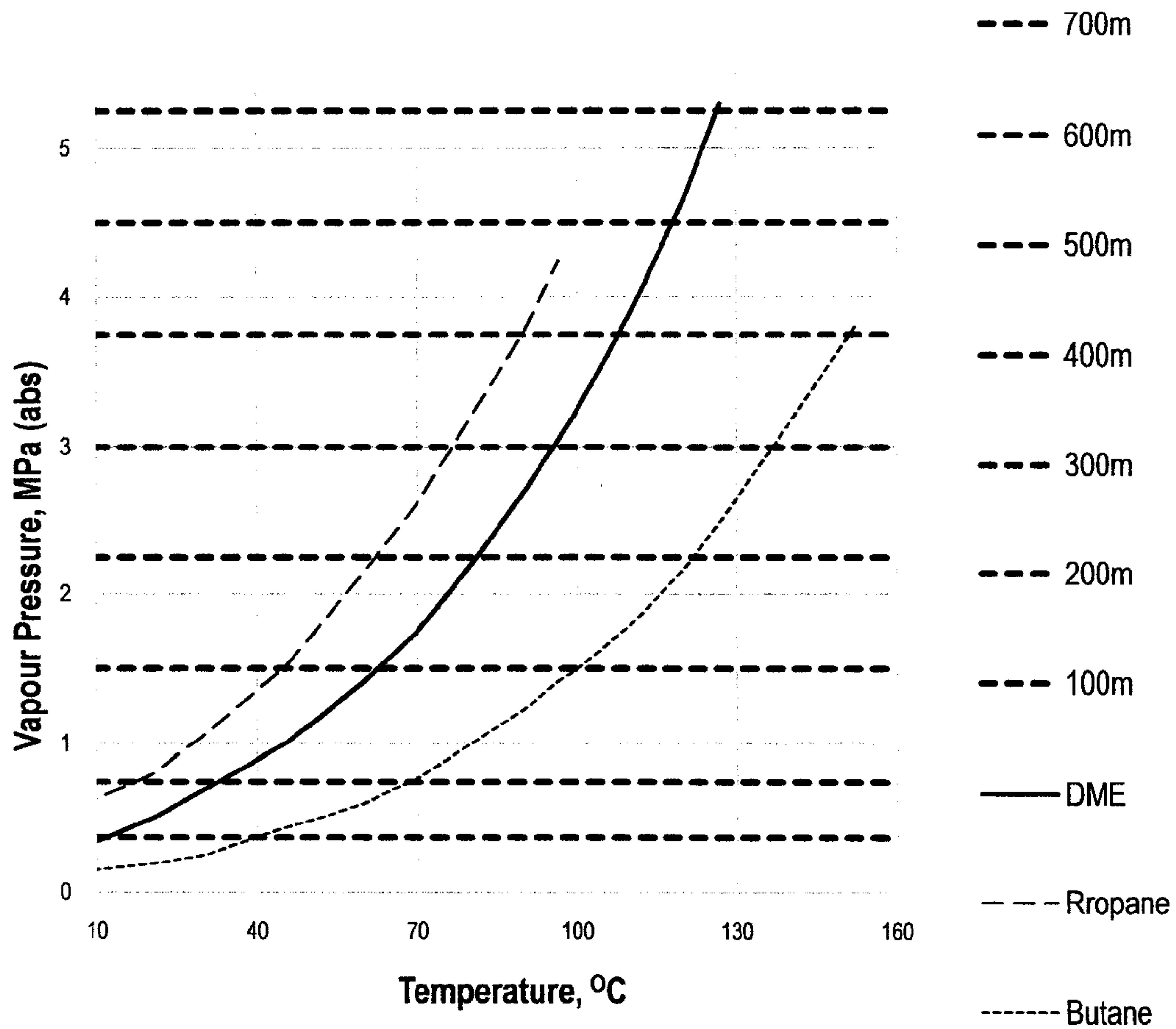


Figure 1. Saturated DME/Propane/Butane Vapours Pressures and Reservoir Depth Versus Vapours Temperatures

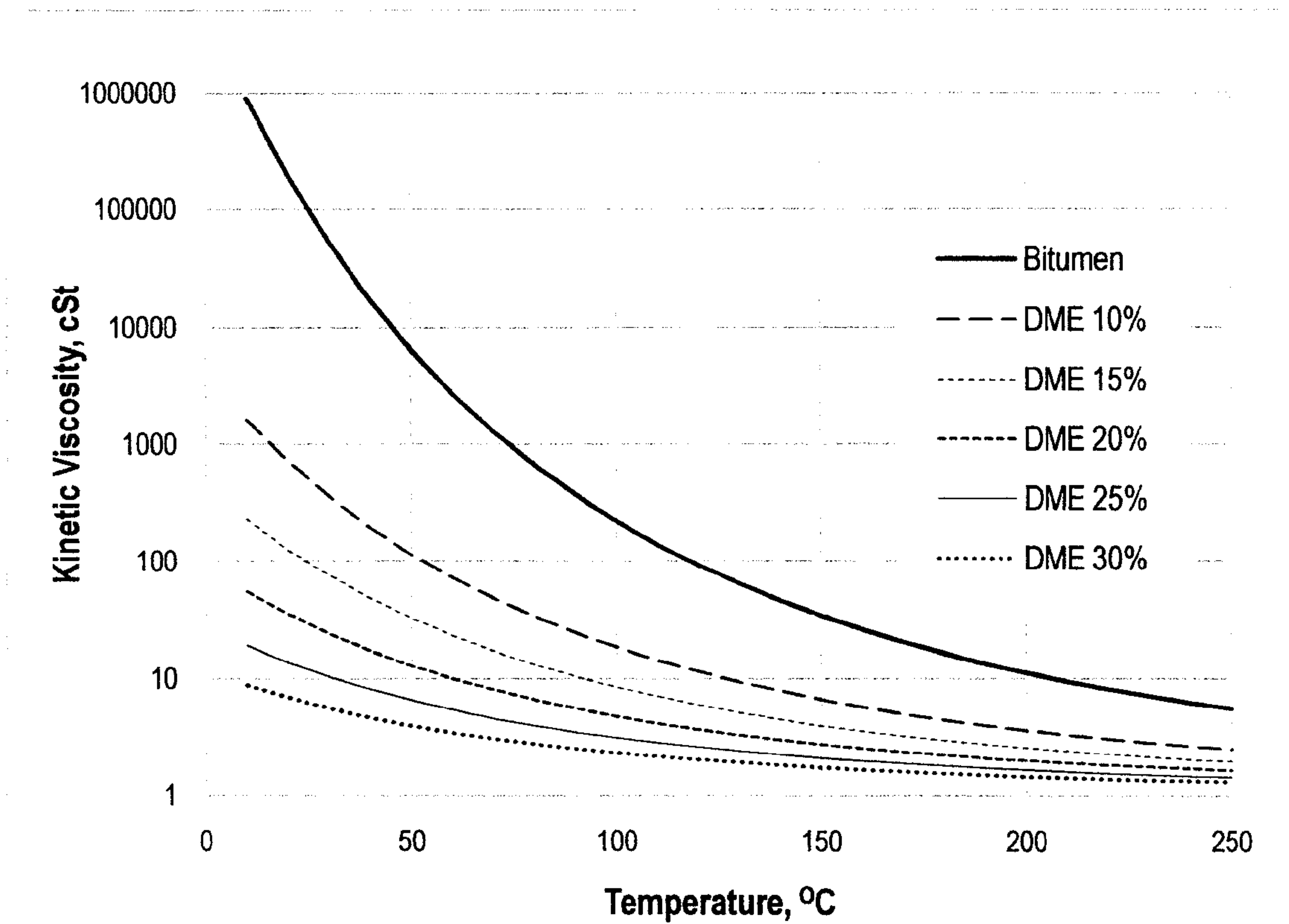


Figure 2. Kinetic Viscosities of Athabasca Bitumen Dissolved in DME as a Function of Temperature

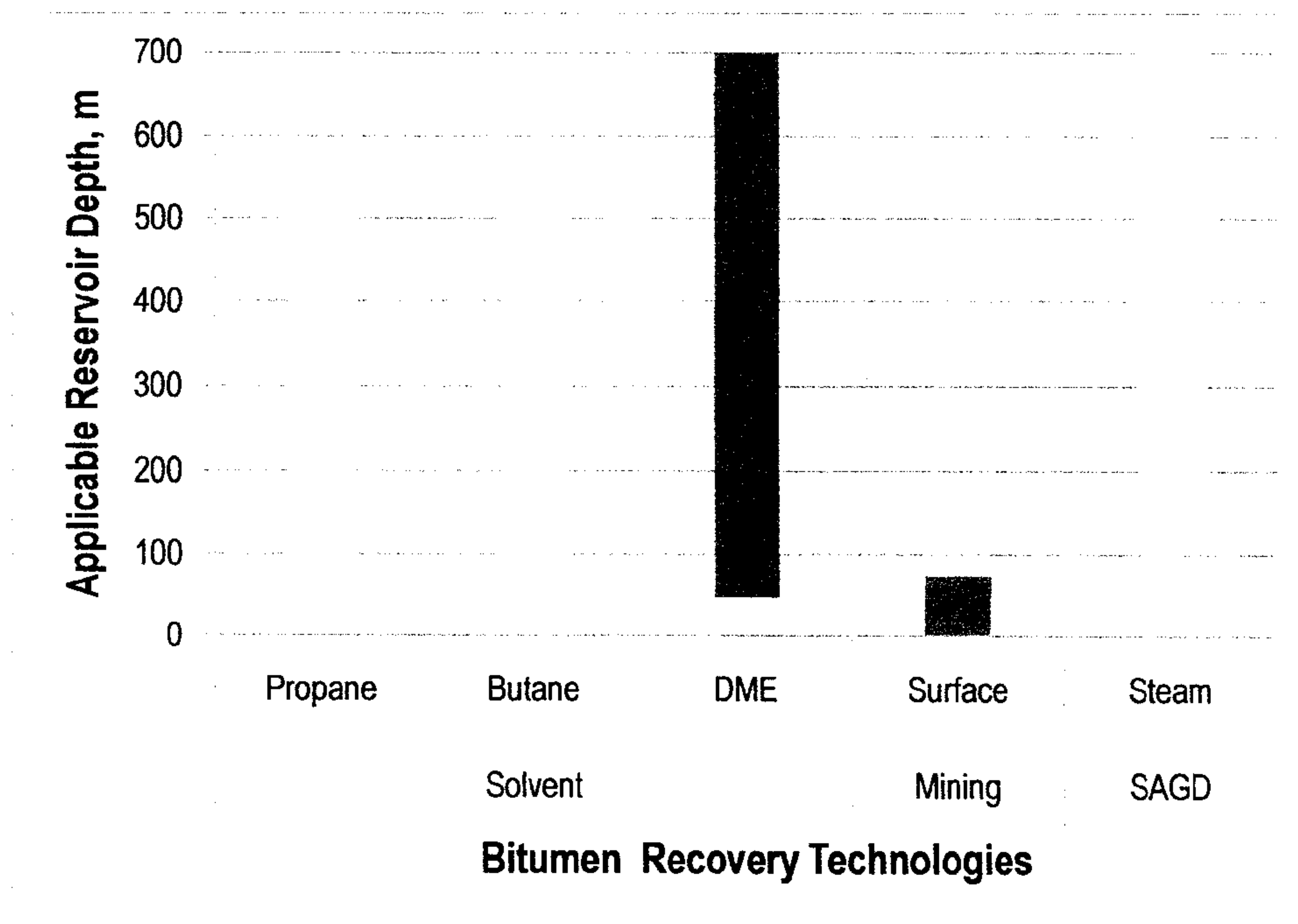


Figure 3. Comparison of the Applicability of Various Bitumen Recovery Technologies Depending on Depth of Deposition of the Oil Sands Ore in the Reservoir

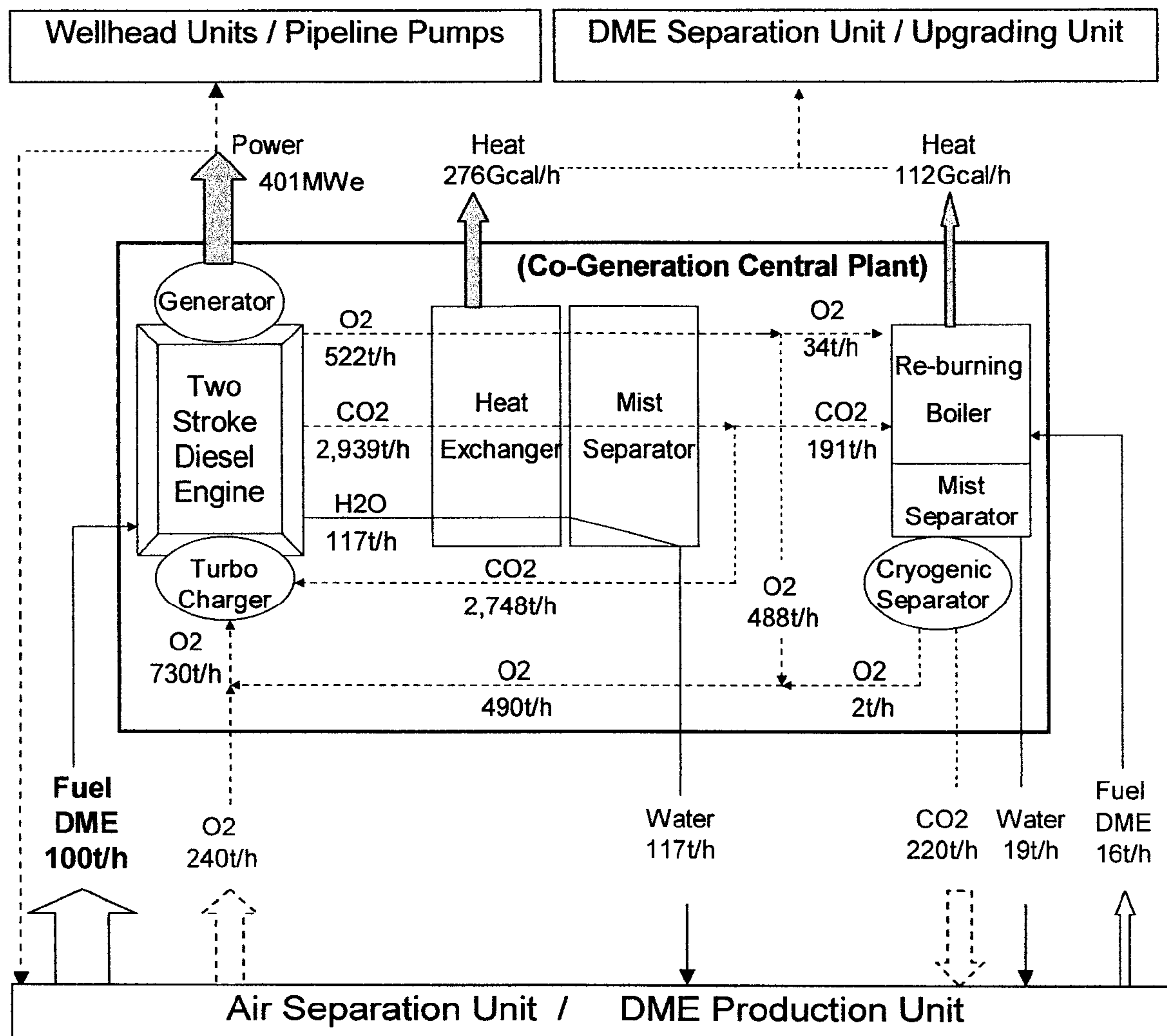


Figure 4. Di-Methyl Ether (DME) Fired O₂-CO₂ Drive Two-Stroke Diesel Co-generation with Re-burning O₂-CO₂ Drive Boiler and Cryogenic CO₂ Capture

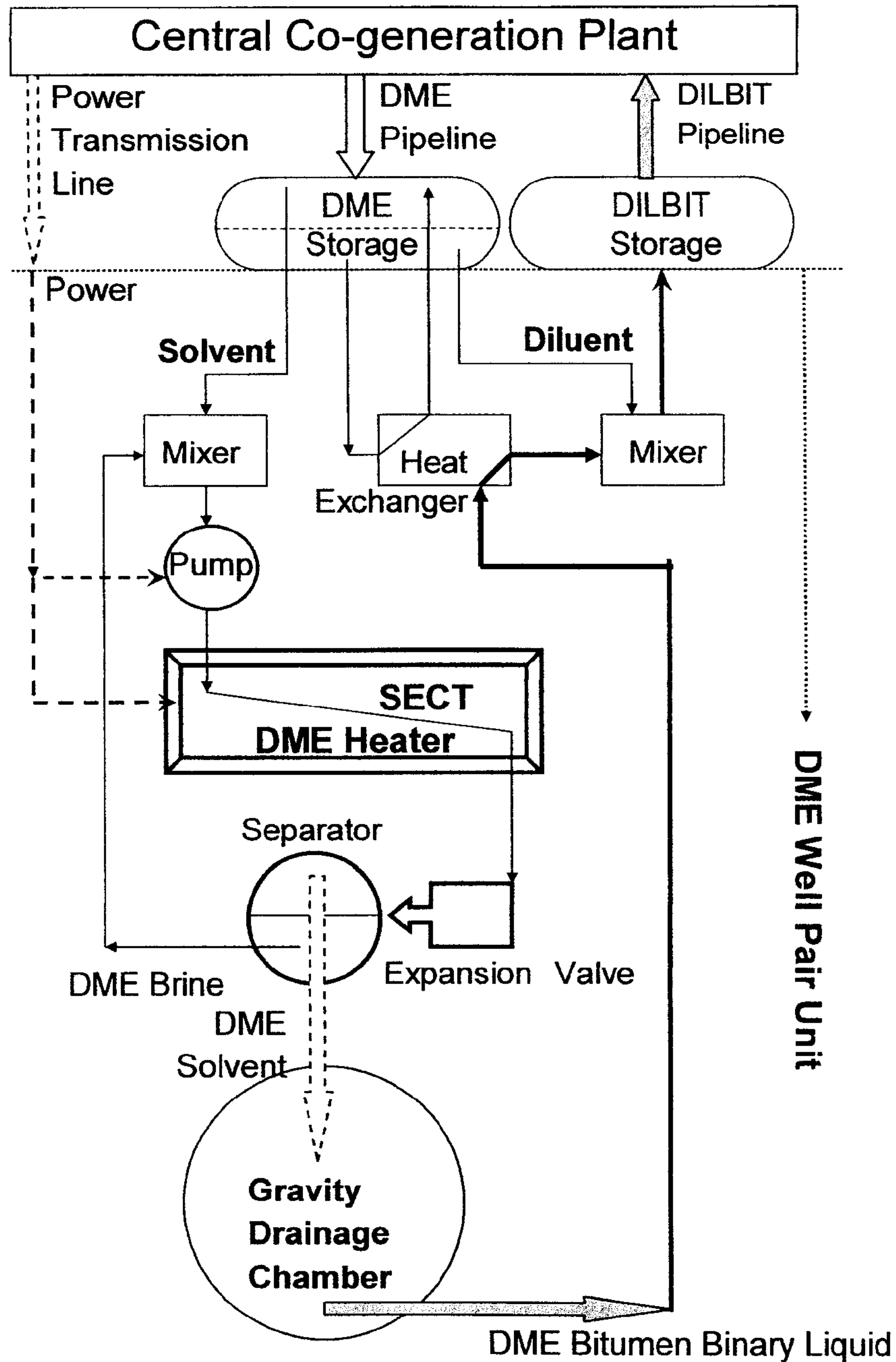


Figure 5. Skin Electric Current Tracing (SECT) Method for Heating Di-Methyl Ether (DME) to be Applied for In-situ Bitumen/ Heavy Oil Recovery and Pipelining of Binary Liquid

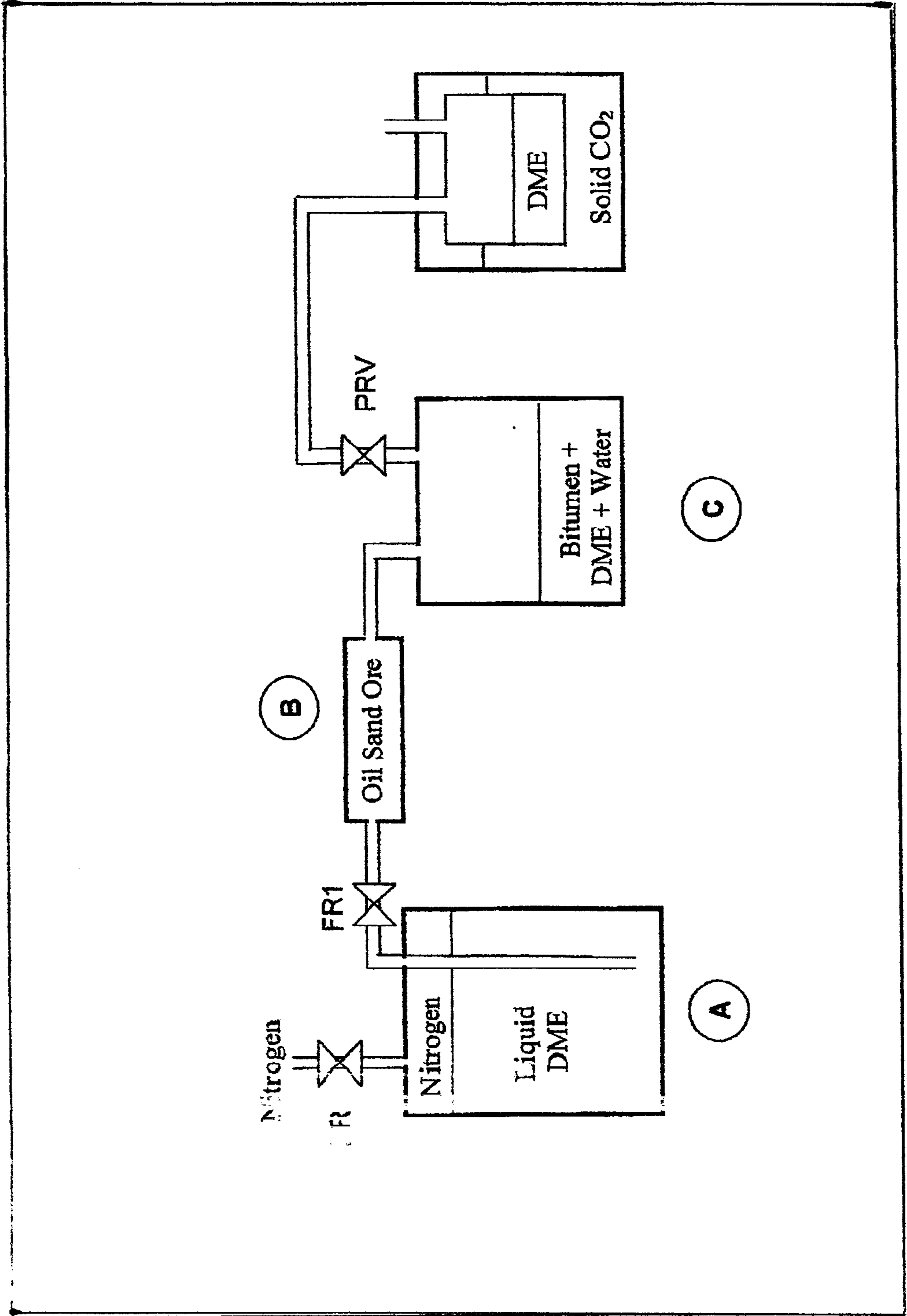
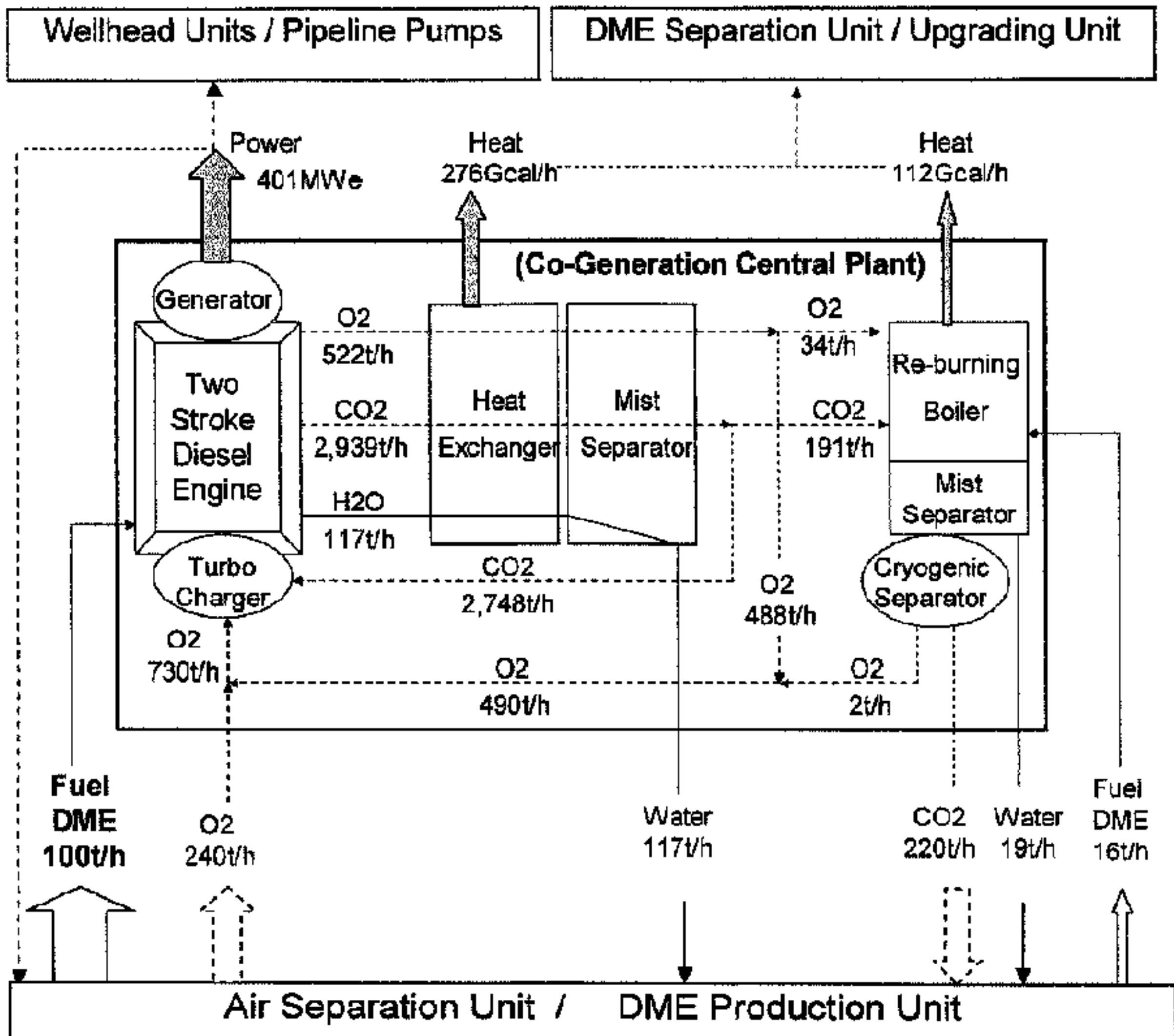


Figure 6. Diagram of the Experimental Set-up Employed for Extraction of Oil Sands Ore with Liquid DME



Di-Methyl Ether (DME) Fired O₂-CO₂ Drive Two-Stroke Diesel Co-generation with Re-burning O₂-CO₂ Drive Boiler and Cryogenic CO₂ Capture