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Overview of Heavy Crude Oil Processing Techniques

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Abstract : Many advancements are ongoing in field of crude oil extraction and put it to best use. This study has been undertaken to investigate the steps required to process the crude oil while extraction and transportation. Some of the researches have been studied to derive the practical solutions. The transportation of crude oils from the head-well to the refinery is becoming important since their production is currently rising all over the world. Such oils are characterized by a low gravity and high viscosity that renders difficult oil flow through pipelines. Conventional technology pipelining is designed for light and medium oil crudes, but the pipelining of heavy and extra-heavy crude oils may be challenging because of their high viscosities, asphaltene and paraffin deposition, increasing content of formation water, salt content and corrosion issues. In this paper, the overview has been laid on current and innovative technological solutions for crude oil processing.

***IndexTerms* – Viscosity, Pipeline, Asphaltene, Gravity drainage, Density.**

I. INTRODUCTION

As per reports from The US Department of Energy, the International Energy Agency (IEA) and World Energy Council, the crude oil demand has increased from 60 million barrels to 80 million barrels per day in last 20 years [1]. Due to demand growth, it has become imperative to consider the options of alternative energy sources along with hydrocarbons. The high expenses of recovery, transportation, processing, and poor market value of heavy crude oil and bitumen made its production in the past deemed unfeasible. The use of this hydrocarbon resource is also fueled by the depletion of traditional middle and light crude oil and the rising global demand for energy. About 700,000 barrels of synthetic crude oil are produced in Canada each day from bitumen/tar sands and heavy crude oil. These barrels are then piped to refineries in the United States and Canada [2].

Due to high atomic ratios between carbon and hydrogen, high resistance to flow and processing at the reservoir are factors impacting recovery of crude oil and bitumen. Their development has historically been encouraged due to the rising cost of crude oil, the depletion of medium and light crude oil reserves, and the quantity of unconventional crude oil (such as heavy oil and bitumen/tar sands). However, there are technological difficulties in the extraction of bitumen and heavy crude oil at every stage of the process, from production and recovery in the reservoir to transportation and processing. Because of their extreme low mobility at reservoir temperature, high density, and viscosity (1,000 cP), heavy crude oil and bitumen are typically difficult to transport via pipeline. It is challenging to transport and refine using traditional refinery techniques without first upgrading them to match typical light crude oil qualities due to asphaltene deposition, heavy metals, sulphur, and brine or salt concentration [3,4].

Crude oil exploration is challenging at all stages (via pipeline) from recovery to oil transferring for refining at reservoir due to its high density, viscosity (1000 cp) and low mobility. Extraction of light crude oil is very much complicated using conventional refinery methods, rather Asphaltene deposition, heavy metals, Sulphur and brine content complicates further triggering corrosion problems [5,6]. Process of transferring emulsion made from oil-water mixture made from reservoir is also difficult. But still heavy crude oil contributes about 15% in the total World oil reserves. The recovery of heavy crude oil has been increased in considerable amount in recent years despite of so many difficulties and heavy price rise.

The main aim of research

II. EXTRACTION

Due to high viscosity, primary recovery procedures, which rely on natural gases to force crude oil out of production wells, are not always sufficient. Thus, by adding thermal energy or injecting a fluid, enhanced oil recovery (EOR) approaches seek to produce the remaining oil after primary and secondary recovery methods [7]. The broad categories of EOR techniques include thermal, chemical (such as surfactant flooding, alkaline flooding, polymer flooding, micellar flooding, alkaline–surfactant–polymer flooding, etc.), and microbial methods. Solvent displacement includes light hydrocarbons, flue gas, carbon dioxide, nitrogen, and other substances. However, the thermal approaches are the most commonly utilized EOR technologies. This is due to the fact that they quickly reduce the viscosity of bitumen and heavy crude oil by several orders of magnitude. Nonetheless, the most widely used EOR technologies are the thermal techniques. This is because they reduce the viscosity of heavy crude oil and bitumen by several orders of magnitude rapidly, in contrast to nonthermal methods in which the mode of viscosity reduction is quite slow as they depend on diffusion and dispersion to spread the fluids. Therefore, the commonly used thermal EOR methods by the petroleum industry are steam flooding, cyclic steam stimulation (CSS), steam-assisted gravity drainage (SAGD), in situ combustion (ISC), toe-to-heel air injection (THAI), etc. The objective of the techniques is to increase oil mobility of the heavy crude oil by reducing their viscosity to improve recovery or production as well as transportation via pipelines. Subsequently, this drive of the petroleum industry to exploit heavy crude oil and bitumen resources has led to the development of several transportation techniques.

III. Morphology of Emulsion

Emulsion can be carried out at several stages of crude oil processing. The stages where emulsion is required are drilling, production, transportation and processing of crude oils and in many locations such as in hydrocarbon reservoirs, well bores, surface facilities, transportation systems and refineries. A good knowledge of petroleum emulsions is necessary for controlling and improving processes at all stages. These complicated processes had been researched several times in last 40 years to make a better understanding. Still many perceptions remain unclear about the particular characteristics of emulsion. The complexity comes mostly from the oil composition, in particular from the surface-active molecules contained in the crude oil. These molecules cover a large range of chemical structures, molecular weights, and HLB (Hydrophilic-Lypophilic Balance) values; they can interact between themselves and/or reorganize at the water/oil interface. To make the system even more complex these petroleum emulsions may also contain solids and gases.

The disperse phase is sometimes referred to as internal phase, and the continuous phase as the external phase. Depending on which one is the disperse phase, emulsions of quite different physical characteristics are usually obtained [4]. The following types of emulsions are now readily distinguished in principle:

- Oil-in-water (O/W) for oil droplets dispersed in water
- Water-in-oil (W/O) for water droplets dispersed in oil
- Oil-in-water-in-oil (O/W/O) and
- Water-in-oil-water (W/O/W).

The last two types are called multiple emulsions and are also present in some cases in which the dispersed droplets themselves contain even more finely dispersed droplets of a separate phase. The term morphology of emulsion means presence of emulsion as water-oil emulsion, oil-water-emulsion or multiple emulsions. To identify the type of emulsion some quality tests are carried out. These are based on the observation of a physical phenomenon that depends on the prevailing polarity in the continuous phase [5]. The morphologies of some different type of emulsions are shown in Figure 1.

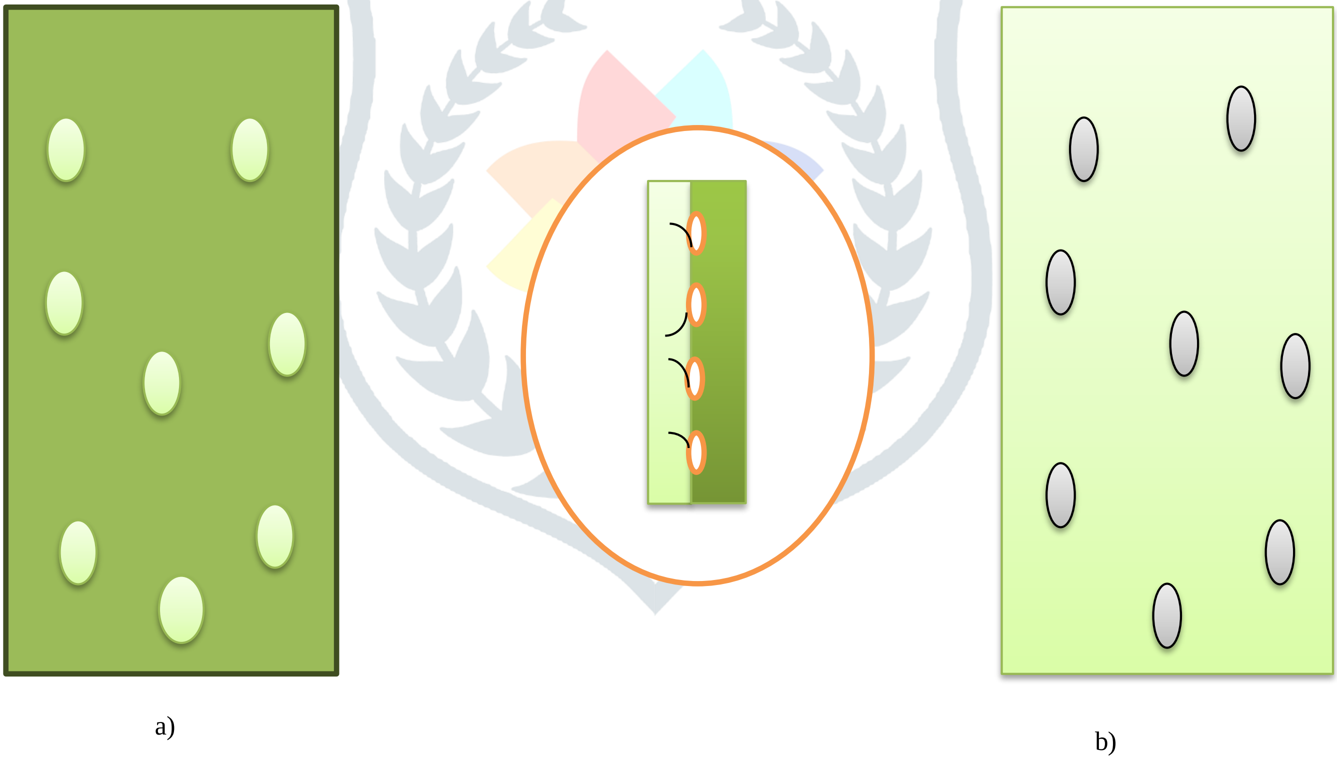

Fig. 1 : Schematic representation of emulsion structures. a) O/W emulsion; b) W/O emulsion. Encircled: enlarged view of a surfactant monolayer sitting at the oil-water interface.

The foremost fundamental strategy to check simple emulsion or multiple emulsion is by contacting a drop of the emulsion with water or oil and observing whether the external phase is miscible or not with it. This is very basic test so the results from this type of test are sometimes unclear and do not allow differentiation. The electrical conductivity measurements can also be used to determine the type of emulsion. The aqueous phase in an emulsion usually contains electrolytes and in most cases non-polar liquids exhibit very low electrical conductivity. Therefore, the conductivity of emulsion is very high when the aqueous phase is continuous and very low when the oil is the continuous phase [9]. Moreover, the optical microscopy method can also be used to discern between simple and multiple emulsions because of the difference between the water and oil phase under microscopic observation.

IV. TRANSPORTATION

Transportation of crude oil through pipeline is entirely dependent on natural gases that push the crude oil out of production well. High viscous pressure resists the flow of oil. Thus, enhanced oil recovery (EOR) techniques are necessary for production of remaining oil left after primary and secondary recovery methods by introducing heat energy or injecting a fluid [6,7]. The EOR methods are broadly classified into: thermal, solvent displacement (i.e. light hydrocarbons, flue gas, carbon dioxide, nitrogen, etc.), chemical (i.e. surfactant flooding, alkaline flooding, polymer flooding, micellar flooding, alkaline–surfactant–polymer flooding, etc.) and microbial methods. Due to the property of fast viscosity reduction upto several magnitude orders, preferably thermal techniques are used. The non thermal methods do just the reverse by decreasing mode of viscosity very slowly. Their dependency on diffusion and dispersion to spread the fluids make them less preferable. Thermal EOR techniques are majorly used for petroleum industry. Those techniques are: toe-to-heel air injection (THAI), in situ combustion (ISC), cyclic steam stimulation (CSS), steam flooding, and steam-assisted gravity drainage (SAGD). Reducing the viscosity of the heavy crude oil is the aim of these procedures in order to enhance its mobility for pipeline transit and better recovery or output. Due to exponential demands of heavy crude oil in petroleum industry different transportation methods are being developed continuously.

To deal with the rise in production of quantity of crude oil an appropriate method is required to transport the crude oil for storage or to refinery. Due to these practical situations pipeline is one of the most convenient, affordable and continuous means of transport for crude oil and its byproducts. Nonetheless, a significant amount of high molecular weight of hydrocarbons, that could be due to saturates, resins, aromatics, and asphaltenes presence in heavy crude oil. The main issue arises due to insolubility of Asphaltenes. The Straight chain hydrocarbons like pentanes, heptanes do not have the ability to dissolve Asphaltenes portion of crude oil. Therefore, problems due to asphaltenes instability such as precipitation due to compression below asphaltene precipitation onset pressure may occur while transporting heavy crude oil [8].The problems start arising such as high-pressure drop along the pipeline due to high viscosity of the heavy oil making it more costly due to increase in precipitation and thus increasing energy consumption. Additionally, clogging of the pipe walls due to asphaltenes deposition, which decreases the accessible cross-sectional area for oil flow that causes reduction in flow rate and rise in pressure drop and multiphase flow, may occur [9]. This scenario can be improved by pre heating the heavy crude oil as well as pipelines while transferring, also blending or dilution with light hydrocarbons, heavy oil-in-water emulsification is carried while transporting through pipeline. Thus making partial upgradation and improving the core-annular flow [10]. Each of these techniques is aimed at reducing viscosity as well as the energy required for pumping, to enhance flowability of the oil via pipelines [11].

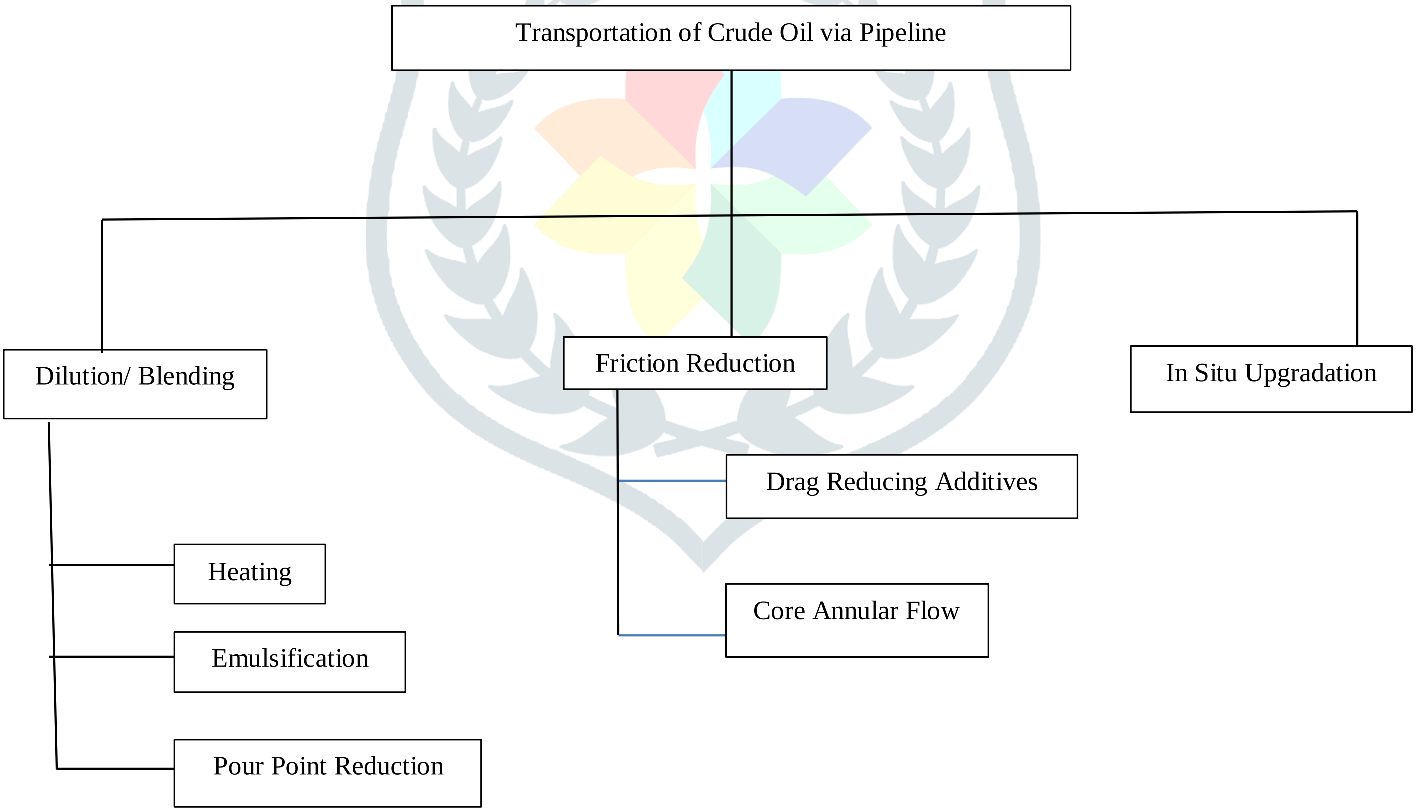

Fig 2: Diagrammatic display of methods of improving heavy crude oil using Pipeline

The methods used for transporting heavy oil through pipelines are generally grouped into three as shown in Fig. 2: (a) viscosity reduction [e.g. preheating of the heavy crude oil and bitumen and subsequent heating of the pipeline, blending and dilution with light hydrocarbons or solvent, emulsification through the formation of an oil-in-water emulsion and lowering the oil's pour point by using pour point depressant (PPD)]; (b) drag/friction reduction (e.g. pipeline lubrication through the use of core-annular flow, drag reducing additive); and (c) in situ partial upgrading of the heavy crude to produce a syn crude with improved viscosity, American Petroleum Institute (API) gravity, and minimized asphaltenes, Sulphur and heavy metal content [12].

a) Dilution

The major problem arises due to high viscosity at reservoir thus making it difficult to recover and transport crude oil using pipeline as means of transport. The most common way to overcome this problem in petroleum industry being used since 1930 is by using blending or dilution in pipeline thus reducing the viscosity for crude oil. In comparison to crude oil the diluted or blended oil always has lesser viscous nature thus resolving the problem [13]. Most commonly used dilutants produced from natural gas can be naphtha, kerosene, lighter crude oils, etc. Organic solvents could also be another option like alcohol, methyl tert-butyl ether, tert-amyl methyl ether [14].

Viscosity of blended mixture is tested and the density of heavy crude oil is determined then accordingly the dilutants are used to lower the cost of pumping through pipeline. This technique makes transportability of crude oil through pipeline more cost-effective. The reason being readily availability of dilutants and its lower prices.

b) Heating

The flow in the pipelines can be enhanced by raising the temperature for heavy crude oil and lowering its viscosity. Viscosity quickly decreases as a result of heating, or raising the temperature in the pipeline, reducing the oil's resistance to flow. Heating is therefore a different way to improve the flow characteristics of bitumen and heavy crude oil. The problem is mostly resolved by the amount of viscosity reduction for heavy oils and the temperature increase. This involves preheating the heavy crude oil followed by subsequent heating of the pipeline to improve its flow. However, heating to increase the temperature of the fluid involves a considerable amount of energy and cost as well. Other issues include greater internal corrosion problems, due to the increase in temperature. However, heating the pipeline may possibly induce changes in the rheological properties of the crude oil which may result in instability in flow. Many number of heating stations are required adding to the cost, in addition to heat losses occurring along the pipeline as a result of the low flow of the oil. However, most of the times the pipeline is insulated to maintain an elevated temperature and reduce the heat losses to the surroundings Additionally, sudden expansion and contraction long the pipeline may induce challenging problems. Consequently, the cost of operating the heating as well as the pumping systems over a long distance from the oil field to the final storage or refinery is on the high side [15]. The method might not be viable for transporting crude oil when it comes to subsea pipelines. Finally, the cooling effect of the surrounding water as well as the earth lowers the efficiency of the technique.

c) Emulsification of the heavy crude in water

During drilling and transportation, the hydrocarbon reservoir, or well bore, contains an emulsion of crude oil and water. One of the newest methods for pipeline transportation of heavy crude oil is this technique, which can be used for oil-in-water (O/W), water-in-oil (W/O), or double emulsions such as water-in-oil-in-water (W/O/W) and oil-in-water (O/W/O) with drop sizes in the micron range. An alternate method for improving the flowability of heavy crude oil via pipelines is the production of an oil-in-water emulsion.

d) Friction reduction

As the dominant transport fluid property, high crude oil viscosity poses great challenges to oil production, refining and transportation through wells and pipeline. The viscous drag, wall friction and pressure drop in the pipeline are much higher in heavy oil compared to conventional light oils. The drag is the result of stresses at the wall due to fluid shearing causing a drop in fluid pressure [16]. This makes it challenging to pump the oil for longer distances. Therefore, drag reduction is a lubrication technique based on core-annular flow to reduce pressure in the transport of heavy oil via pipelines. The commonly used techniques to lower the friction to enhance pipeline transportation of heavy crude oil include drag reducing additives and core-annular flow. Both technologies reduce flow drag by varying the velocity field such as dampening the turbulent fluctuation in the near wall region of the pipeline, while the flow in the heavy oil pipeline is laminar or slightly turbulent with minimum flow resistance based on viscosity influence on flow drag [15]. However, most studies on flow drag reduction pay attention mainly to reducing the viscosity by physical or chemical methods, but according to Newton's viscosity law flow drag depends upon fluid viscosity and velocity profile.

e) Drag-reducing additives

Drag reduction by the use of an additive becomes an option since the pressure drop experienced during the long-distance pipeline transportation of heavy crude oil is more severe. Most crude oil transmission via pipelines occurs in a turbulent flow regime. Additionally, a large portion of the energy used to transport the crude oil is lost due to significant frictional loss brought on by high viscosity. High drag in turbulent flow is brought on by fluid eddies' radial transfer of flow momentum. A 30–40% drag reduction is observed via the polymer drag reduction reaction when methyl methacrylate is added to turbulent monochlorobenzene running through a pipeline. Drag-reducing chemicals aid in lowering friction both within and close to pipeline walls in this way.

f) In situ upgrading

The increasing exploitation of vast heavy oil resources to meet global energy demand and the concern for the environment have led to the incorporation of in situ upgrading with enhanced oil recovery. In situ upgrading is achievable during thermal recovery methods such as ISC, SAGD, CSS and subsequently the novel THAI and its addon catalytic upgrading process in situ (CAPRI), collectively called THAI–CAPRITM [17,18]. In order to enhance the flow of heavy crude oil from the oil reservoir to the production well, these procedures rely on the lowering of its viscosity by heat. The upgrading results from the heavy molecules' heat separation into smaller ones. The heavy crude oil viscosity is greatly reduced by these in-situ thermal cracking events, which enhances flow and output. The THAI–CAPRI process, however, incorporates a catalytic upgrading process into the recovery, out of all these processes.

V. CONCLUSION

Crude oil processing steps are studied in this research. To increase the exploitation of crude oil, technological advancements are very important. The transportation using pipelines, emulsion and extraction techniques need further developments. Such technologies address the improvements for ease of operation, reliability, cost, size, maintainability, infrastructure and resource utilization, type of crude oil, and improved crude oil quality. With the increasing production of heavy and extra-heavy crude oils in North America, South America and Eastern Asia, more technological innovation as well as research and development will be needed in order to generate specific solutions for crude oil transportation. Indeed, current and future responses to the transport of heavy and extra-heavy crude oils should take into consideration the composition and physicochemical properties of producing oils, regional logistics between the head-well and the exporting or refining sites, current infrastructure and operational concerns, transport distances, quality of crude oil to export or refine, associated operational and maintaining costs, strict regulations for spills, environmental awareness for water, etc. Crude oil can be transported by reducing viscosity will be affordable in such production areas with large deposits of lighter crude oils, condensates or water as well as site suspensibility to allocate mixing and/or emulsifying infrastructure. The characteristics and behavior of specific diluted or emulsified crude oils should be understood in order to address a cost-effective solution to pipeline and refiners. The needs for improved and new chemicals should boost the research and development on surfactants, flow improvers, drag reducing agents, catalysts and other valuable additives. Besides the need for fundamental research, future developments on crude oil transportation should be based on results from pilot plant and semi-industrial facilities, like instrumented loop pipelines and reactors, in order to offer to the end-users a reliable and tailor-made technology. In the near future, the technological advancements are likely to be aligned with the anticipated requirements to transport the increasing production of heavy and extra-heavy crude oils.

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