DEVELOPMENT OF NIGERIA'S BITUMEN FOR NATIONAL ECONOMIC GROWTH: OPPORTUNITIES FOR MEMBRANE SEPARATION TECHNOLOGY

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ABSTRACT

Nigeria is richly endowed with a variety of solid minerals ranging from precious metals to precious stones and industrial minerals. The Nigeria Extractive Industry and Transparent Initiative (NEITI) reported that there are forty (40) different kinds of solid minerals and precious metals buried in Nigeria soil waiting to be exploited and processed. One of such minerals is Bitumen. Processed bitumen plays an important role in many everyday applications. It is one of the most used solid mineral resources. The massive investment in infrastructure that will be required to cater for this exploitation presents a research opportunity into how solid minerals are explored and processed in Nigeria. Membrane separation (MS) technique is an essential separation and purification technology that can be used for a sustainable solid mineral processing and purification. This is due to its simplicity, lower capital and operating costs, and energy efficiency. It is a commercially successful competitor to other conventional separation techniques that are currently employed for solid mineral production, purification and treatment. The essence of this paper is to acquaint the readers with the immense benefits of membrane separation techniques in the extraction of Nigeria Bitumen and possibly see necessity of investing into its development.

Keywords: *membrane filtration, energy consumption, solid minerals treatment, produced water.*

1.0 INTRODUCTION

Minerals are naturally occurring inorganic substances with a definite and predictable chemical composition and physical properties(Mohammed, et al., 2013, Vancleave, 2010). They can be in the form of solid, liquid or gas (such as metallic ores, crude oil and natural gas). Solid minerals are said to be mined in solid form before undergoing processing. And there are various forms of solid minerals; these include ores of metals (iron ore, gold), limestone, bitumen, coal and so on (Ajaka, 2009).

Bitumen is a sticky, black and highly viscous liquid or semiliquid form of petroleum. It may be found in natural deposits or may be refined product; it is a substance classed as a pitch (Muhammad, 1992). Its viscosity ranges between 8 and 10 API degrees. Its density (kg/m^3) lies between 1.0 and 1.18 and it is insoluble in water. It has a boiling point greater than 300^{0}C with melting point ranging from 54 - 173^{0}C and flash point greater than 200^{0}C. Bitumen is around 95% hydrogen and up to 5% sulfur, 1% nitrogen and 1% Oxygen and 200ppm metals (www.aboutcivil.org).

Processed bitumen plays an important role in many everyday applications. It is one of the most used solid mineral resources. It is said to be useful in Roofing, Sports, Environmental protection, pipe coating, Land slip containment, walkways, sound proofing, electrical insulation, cosmetics, medicine and textiles. Bitumen's waterproofing and adhesive properties, durability and resistance to heavy loads make it the ideal material for use in all-weather environments. It is also a prime material in applications where strength and weather proofing are essential requirements. Moreover, bitumen membranes are extensively used as sound-deny panels in the automobile markets. It is also used as bituminous paints and disinfectants on a number of different surfaces, bitumen-based lubricants, preservative to plastic, sealants, and as asphalt for road construction and maintenance (Jacques, 2009, Kristjandottir, 2006).

The total estimate of natural occurring bitumen deposit reserve in the World was in the range of 600 and 21,000 billion metric tons (3,000 and 6,100 billion bbl) (Adewusi, 1992) and about 88 countries have been identified having known deposit of heavy oil and oil sands. The largest deposits are in Athabasca area in the north eastern part of the province of Alberta Canada, this reserve contains ore 700 billion bbl. Other deposits, each containing 15 million bbl of bitumen are identified and are located in USA, Venezuela, Albania, Rumania, Malagasy and USSR (Ademodi et al., 1987, Adewusi, 1992).

Bitumen is found in large amounts worldwide but in exceptionally large quantities in Canada and Venezuela. Nigeria is also reported to have the second largest deposit of tar sand in the world containing about 41 billion barrels of oil found in cretaceous ferruginous sediments extending over about120km from Ogun state, across Ondo state to the margin of Edo state. When fully developed, the industry will no doubt meet local requirements for road construction, farming improvement and also become a source of foreign exchange for the country (Milos, 2015, Enu, 1985).

Bitumen is used primarily for paving roads and for the production of water proofing products, such as roofing felts and for sealing flat roofs. As a result of the increase in oil price since 2003, upgrading of bitumen to synthetic crude has become economical. Considering the scarcity of prime coking coals, bitumen extract has also been used as additive to upgrade medium coking coals to cokeable grade for coke making. The Nigerian market for bitumen has been estimated at about 150,000 per annum (Sepulveda et.al, 2010, Weskamp et.al, 1987). Thus, incorporating energy efficient and cost effective separation technology such as membrane into exploration, processing and purification of bitumen in Nigeria cannot be over emphasized. Specific roles of membrane separation processes in the bitumen industry include separation of bitumen from sand, water and minerals, treatment or removing residual water and upgrading various fractions.

2.0 OVERVIEW OF MEMBRANE SEPARATION TECHNOLOGY

In several processing industries, separation technology is widely used for separation and purification of mixtures. In the industry, separation process consumes 40% of industrial energy needs which is equivalent to 13.2% of total energy consumption. Separations take advantage of differences in physical or chemical properties of the mixture components. Out of the several separation techniques that are presently available, membrane separation technology could be used to bring about significant reduction energy consumption in solid mineral processing. There are several other advantages of using membrane separation technology when compared to other techniques (Ahmad, et al., 2013, Ahmad, et al., 2014, Koros, et al., 2009).

1. Membrane can separate components of mixtures in its native state.
2. Theoretically, all the industrial separation needs can be met by using membrane process
3. Most membrane processes generally do not require a phase change to make a separation
4. It is a modular separation system which requires relatively less energy
5. Membrane processes present basically a very simple flow sheet
6. Systems employing differing classes of membranes ranging from microfiltration to reverse osmosis allow for precise contaminant removal at the lowest cost
7. Membrane systems typically require 50-70% less space than conventional technologies
8. Membrane system have competitive life expectancy
9. Membrane processes are environmentally benign since they require the use of relatively simple module,non-harmful materials or solvent and less carbon emission.
10. Membrane system contains no moving parts.

Table 1 Comparison of Energy Consumption of Membrane with Conventional Separation Techniques used Process Industry(Blume, 2004, Collings, et al., 2004, Eykamp, 1997, Gottschlich and Jacobs, Humphrey and Keller, 1997, Koros, Kratochvil, Shu and Husain, 2009)

Processes	Energy Consumption
Suspended Particles and Macromolecular Solutes Processing	
Flash Evaporation	73kwh/m^3
Micro/ Ultra Filtration	7.6Kwh/m^3
50millions gallons/day Seawater Processing	
Thermal Distillation Plant	78.5Kwh/m^3
State-of-the-art Seawater RO	6.7Kwh/m^3
Propylene/Propane Separation	
Cryogenic Distillation	0.302Kwh/lb propylene prod
Vapor Permeation Membrane	0.050Kwh/lb propylene prod

Table 1 shows the comparison between the energy requirement for membrane and other conventional separation processes used in the process industries.

Despite the advantages of membrane over other separation processes, its use in industry is still relatively low. Some of the major reasons for this is the fear that is usually associated with the use of new technologies. Moreover, the life span of the conventional separation process plants (which may be up to 30 years) makes it difficult to immediately replace them with new ones. Thus, it is technically and economically advisable to initially inculcate the use of membrane while building new processing plants rather than replacing them in already existing plants. For existing plants, membrane can be introduced in the form of retrofit and use as hybrid along with the existing separation units.
Membrane separation processes differ based on separation mechanisms and size of the separated components. The widely used membrane process include microfiltration (MF), ultrafiltration (UF), nanofiltration(NF), reverse osmosis(RO), dialysis, electrodialysis, gas separation, pervaporation, membrane distillation, membrane crystallization and membrane contactors(Adewole, et al., 2013, Adewole, et al., 2015, Criscuoli, 2009, Eykamp, 1997, Li and Chen, 2005). All these processes differ in membrane material characteristics, membrane pore size and operating pressure to which they are exposed to. For instance, microfiltration membrane is defined as having pore size >0.1micron, ultrafiltration is as having between 0.01 and 0.1micron, while nanofiltration is defined as > 0.001 and <0.01micron (Eykamp, 1995, Meynen, et al., 2014, Petersen, 1993).

Dialysis is the transfer of solute molecules across membrane by diffusion from a concentrated solution to a dilute solution. In the electrodialysis process (such as the concentration of brine) a typical electrodialysis stack consists of a series of anion-exchange and cation-exchange membranes arranged in an alternating pattern between an anode and a cathode to form individual cells (Strathmann, 1995). A reverse osmosis membrane separates the various low molecular-weight molecules and ions from the solvent by forcing the solvent or major component to pass selectively through the membrane by applying pressure greater than the normal osmotic pressure. Separation occurs based on size, solubility, and/or charge of the various penetrant species(Strathmann, 1995). Ultrafiltration is another pressure-driven membrane process capable of separating somewhat larger solution components on the basis of molecular size and the shape under an applied pressure difference across the membrane. In this process, the smaller molecules pass through the membrane and are collected as permeate while the larger molecules are retained by the membrane (Blume, 2004, Eykamp, 1995, Li, et al., 2005). The microfiltration process is similar to the ultrafiltration process, except that its effective separating range is from 1000Å to 100000Å in molecular size whereas the ultrafiltration range is from 10Å to 1000Å (Petersen, 1993,Singh,etal.,2012). The most commonly used synthetic membrane devices (modules) are flat sheets/plates, spiral wounds, and hollow fibers.

Flat plates are usually constructed as circular thin flat membrane surfaces to be used in dead-end geometry modules. Spiral wounds are constructed from similar flat membranes but in the form of a “pocket” containing two membrane sheets separated by a highly porous support plate (Osada et al., 1992). Several such pockets are then wound around a tube (figure 1) to create tangential flow geometry and to reduce membrane fouling. Hollow fiber modules consist of an assembly of self-supporting fibers (figure 2) with dense skin separation layers, and a more open matrix helping to withstand pressure gradients and maintain structural integrity (Osada et al., 1992). The hollow fiber modules can contain up to 10,000 fibers ranging from 200 to 2500 µm in diameter. The main advantage of hollow fiber modules is very large surface area within an enclosed volume, increasing the efficiency of the separation process
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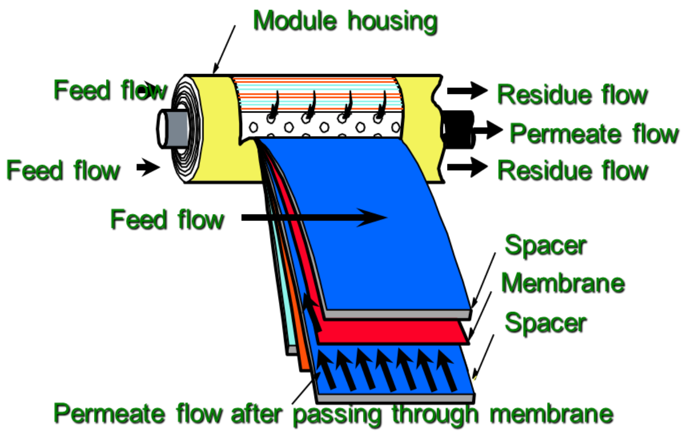

Figure 1: Spiral wound membrane module;(Source: MTR Inc, ***Aquilo Gas Separation)***

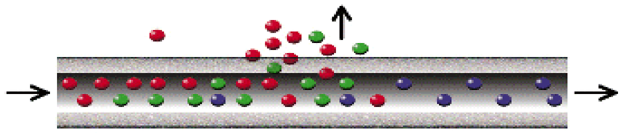

Figure 2: Cross Section representation of Hollow Fiber; (Source: MTR Inc, Aquilo Gas Separation)

3.0 SEPARATION METHODS IN BITUMEN INDUSTRY

The extraction of bitumen from oil sand mines involves the liberation and separation of bitumen from the associated sands in a form that is suitable for further processing in order to produce a marketable product. Among several processes for bitumen extraction, the Clark Hot Water Extraction (CHWE) process is a well-developed commercial recovery technique. In the CHWE process, mined oil sands are mixed with hot water to create slurry suitable for extraction. Caustic soda is added to adjust the slurry pH to a desired level in order to enhance the efficiency of the separation of the bitumen. Recent industry development has shown the feasibility of operating at lower temperatures and without caustic addition in the slurring processes. In the CHWE process, the extract typically comprises hydrocarbon predominant phase (known as tailing stream) which is made up of coarse solids, some fine solids, and water. A typical composition of bitumen froth stream is about 60wt% bitumen, 30wt% water and 10wt% mineral matter(solids). The water and mineral matter in the froth are considered as contaminants. Therefore, the froth needs to be purified to eliminate the contaminants or reduce them to a level suitable for feed into an oil refinery or an upgrading facility.

The process to reject the water and mineral matter contaminants are known as froth treatment process. Due to the high viscosity of bitumen, the first step in the treatment is usually the introduction of a solvent. There are two major commercial approaches to reject the froth contaminants, namely naphtha solvent-based froth treatment, and paraffinic solvent-based froth treatment. Solvent addition (dilution) increases the density differential between bitumen, water and mineral matter. Contaminants rejection can be carried out by a number of methods, such as centrifugation or gravity separation. The separation scheme generally results in a product effluent stream of diluted bitumen and a reject or tailings stream, commonly referred to as the froth treatment tailing (which comprises of mineral matter, water, residual solvent, and some residual bitumen). In the paraffinic froth treatment process, the solvent dilution reduces the precipitation of asphaltenes from the bitumen as an additional contaminant which results in an improvement in the efficiency of the contaminant rejection process(Milos, 2015).

An example of froth treatment (NFT) is disclosed in US Patent (Tipman and Sankey, 1993). Addition of naphtha may yield a bitumen product containing 1 to 3wt% water and <1.0wt% solids. However, such product composition does not meet pipelines specifications and renders the NFT product stream unsuitable for transportation through pipeline. Paraffinic froth treatment (PFT) was described in Canadian Patents(Sharma and Raterman, 2014, Shelfantook, et al., 2002). Addition of sufficient amount of paraffinic solvent results in asphaltene precipitation, formation of aggregates with the contaminants, and settling. Unfortunately, conventional treatments which separate water and mineral matter will not remove very fine particulate (fines) from the froth. Therefore, PFT settling vessels are sized to allow gravity settling of fines and other contaminants. This process provides a solids free bitumen product (<300ppm solids, <0.5%BS&W) suitable for transportation in a common carrier to refineries. Bitumen of such quality is termed ‘’fungible’’ because it can be processed in conventional refinery processes without fouling the refinery equipment. However, PFT is energy intensive and expensive and results in a waste stream of asphaltenes (a potentially valuable commodity).

In general, water based extraction and solvent-based extraction are the two processes that have been used to extract bitumen from mined oil sands. The CHWE process, described above, is the most commonly employed water-based extraction, water is the dominant liquid in the process and the extraction occurs by having water displace the bitumen on the surface of the solids. In the case of solvent-based extraction, the solvent is the dominant liquid and the extraction of the bitumen occurs by dissolving bitumen into the solvent.

Solvent based extraction processes for the recovery of the hydrocarbons have been proposed as an alternative to water-based extraction of mined oil sands. However, the commercial application of a solvent-based extraction process has, for various reasons, eluded the oil sand industry. A major challenge to the application of solvent-based extraction to oil sands is the tendency of fine particles within the oil sands to hamper the separation of solids from the hydrocarbon extraction. Solvent extraction with solids agglomeration is a technique that has been proposed to deal with this challenge. The original application of this technology was coined Solvent Extraction Spherical Agglomeration (SESA). A more recent description of the SESA process can be found in (Sparks, et al., 1992).Solvent extraction bitumen has a much lower solids and water content than bitumen froth that was produced in the water-based extraction process. However, the residual amounts of water and solids content in solvent extraction bitumen may nevertheless render the bitumen unsuitable for marketing.

3.1 Bitumen Extraction and Processing in Nigeria

Nigeria's Ministry of Mines and Steel Development identified three potential methods of bitumen extraction in Nigeria:

- Small-scale surface mining
- Large-scale surface mining and
- In-situ extraction.

The depth of bitumen below the surface determines which extraction type is possible. Both in-situ and large scale surface mining operations are most likely to extract bitumen for upgrading into synthetic crude oil and/or other petroleum products. Bitumen from small scale surface mining is likely to only be economical to use for paving roads. Details of all the three types of extraction and their impact are described in literature (Grant, et al., 2013, Milos, 2015).

In Nigeria, the approximate locations of the different types of oil are perhaps best explained as a gradient running north to south, with the heaviest oils generally in the north at the surface and the lightest in the south deep underground (figure Nigeria's Bitumen Belt (Lagos, Ogun, Ondo, and Edo States. Copied from Milos (2015)).3). The region which contains bitumen spans roughly across four states, namely Lagos, Ogun, Ondo, and Edo states. Much of the areas where heavier forms of oil and bitumen can be found remain under explored. Thus, the precise locations of each resource are unknown. The most comprehensive bitumen study to date is Geotechnical Investigations of the Ondo State Bituminous Sands from 1974, and was led by Professor O.S. Adegoke's of the Geological Consultancy Unit of the University of Ife. Few significant studies have been carried out since. The extents shown on the map in Figure 3 identify the zones where surface mining and in-situ mining are most likely to occur (Adegoke, 1980). Some geologists speculate this zone extends all the way to the conventional oil blocks further south.

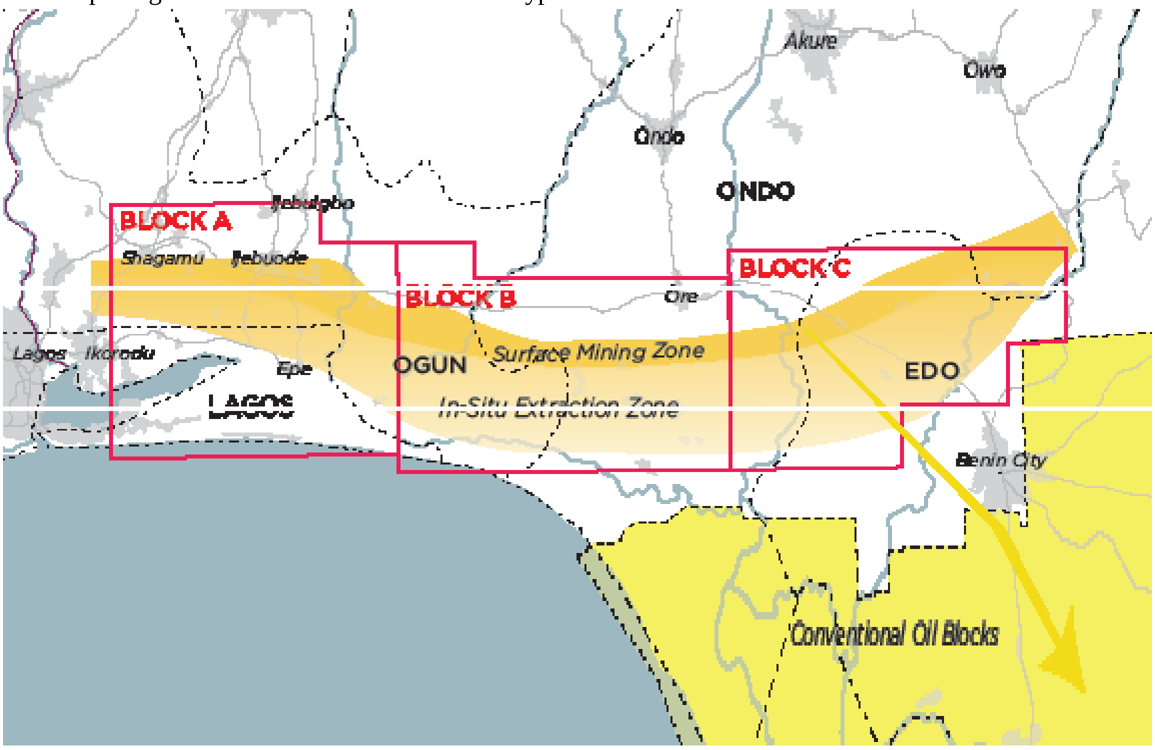

Figure 3: Nigeria's Bitumen Belt (Lagos, Ogun, Ondo, and Edo States. Copied from Milos (2015)).

4.0 ROLES OF MEMBRANE TECHNIQUES IN THE EXTRACTION OF BITUMEN

Membrane technology can be introduced into various stages of bitumen processing. This section is focused on description of some membrane separation processes that are suitable for use in bitumen processing. The U.S patent (Feimer and DesJardine, 1993)disclosed a method of ultrafiltration of heavy hydrocarbons through a multi-stage membrane system. The patent describes at least two identical and sequential ultrafiltration steps to remove metals, conradson carbon residue (CCR), and asphaltenes. Variety of membrane materials such as polymide, polysulfone, polyaryl sulfide, polycarbonate, polyamide, polyacrylonitrile, or ceramic materials can be used in the system. Another U.S Patent (Smith, 1998) demonstrated a process for the selective removal of asphaltenes and metal compounds from oil by ultra-filtration using a membrane. It emphasized the use of ceramic membrane because of its initial fouling resistance.

The invention disclosed in the U.S Patent (Koseoglu, 2014) was directed towards a process for upgrading a heavy oil feedstock. The procedure for heavy oil processing involves thermal cracking of the oil to produce a product stream which is then cooled to an intermediate temperature at which light ends and water can be volatized and removed in flash towers. Following a further cooling, the stream is mixed with an alkane solvent to facilitate asphaltenes precipitation. However, asphaltenes do not settle due to the high viscosity of the liquid. To solve this problem, the inventors suggested a two-step membrane ultrafiltration of the feed stream.

Bitumen product may be produced through a number of extraction methods known in the art. The product effluent stream may comprise bitumen, solvent, precipitated asphaltenes, water and mineral matter. The mineral matter may comprise clay, sand, particulate matter, bulkier contaminants such as coal, wood, shale or large particles, and other solids. Typically, the naphthenic froth treatment (NFT) bitumen comprises 2-3%w/w solids and/or water and does not meet pipeline specifications for transportation. All the contaminants may be removed by filtration-methods (microfiltration, ultrafiltration, or nanofiltration) (Ashtari, et al., 2012, Bakhshayeshi, et al., 2012, Eykamp, 1995, Li, Liang and Chen, 2005, Schwarze, et al., 2012, Singh, Ray, Xie and Hoang, 2012, Ullah, et al., 2012).

A method of water treatment in an in-situ recovery method of producing bitumen from oil sand comprise of separating bitumen-mixed stream so as to leave oil-containing water(which is called "produced water"). The bitumen-mixed fluid could be recovered from the oil sand well via microfiltration membrane using polytetrafluoroethylene (PTFE). Membrane configurations may include flat sheet membranes, spiral wound membranes, tubular membranes, or hollow fiber membranes. All these configurations permit separation of water, mineral matter or asphaltenes from a bitumen stream.

5.0 CONCLUSION

The potential application of membrane separation technology in bitumen processing was presented. The following conclusion can be drawn:

Academic-Industry collaborative is vital in further exploration and development of needed membrane separation techniques and subsequent application in bitumen processing.

Valuable savings could be achieved by using commercially available ready-made membrane systems while aggressively pursuing development of more novel membrane materials and modules to meet up other complex separation challenges in bitumen processing.

Developing countries such as Nigeria need to incorporate membrane units from the beginning of bitumen processing plant construction because conventional energy intensive separation units have 30-50 years useful lives. It is therefore difficult (for economic reasons) to replace them with membrane in future.

Membrane can also be incorporated into existing bitumen processing plants in the form of retrofit and hybrid separation units.

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