# Effect of (Iron, Nickel, Zinc and Copper) Metal Particles on Heavy oil viscosity reduction

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## ABSTRACT

As conventional light crude oil reserves start to decline gradually, the significance of medium, heavy and extra heavy oil reservoir are increasing.Crude oil with API gravity less than 20 degree is termed as heavy oil. Heavy oil resources are abundant globally, comprising more than 70% of remaining oil reserves. However, these reserve are technically and economically challenging to produce due to their properties so the key to extract heavy oil form these resources is to reduce viscosity of the oil.

Compared to light oil , heavy oil is more costly to produce, process, and transport crude oil. In many cases, heavy oil must be chemically upgraded to reduced density and viscosity. Many techniques have been applied for reducing the heavy oil viscosity such as heating, blending with diluents. Bending heavy crude oil with lighter petroleum fraction such as kerosene or diesel was tired and it shows good viscosity reduction.

However, substantial amount of these costly diluents are required and some diluents are toxic to environment. Thermal recovery methods such as (steam flooding, cyclic steam simulation and steam associated gravity drainage) are the most widely used recovery method to reduce heavy oil viscosity.

This paper present an overview of common heavy oil recovery methodand major technical obstacles of extracting and transporting heavy crude oil. In addition, Investigation of the effect of adding metal particles such as (Zinc, Nickel, Iron and Copper) in heavy oil for viscosity reduction purpose during thermal recovery process.

**Keywords**

Heavy Crude Oil, Thermal Recovery, Viscosity Reducer

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## 1. Iintroduction

Heavy oil is defined as viscous type of petroleum and has reduced mobility with higher specific gravity and density compared with the conventional oil. Heavy crude oil / Bitumen reservoir constitute high volumes around the global. With gradual depletionofthe world supply of light and medium oil and it can rely on heavy oil/ bitumen deposit as alternative energy source. Therefore, the oil company are inevitably start to consider the cost and logistic to recover heavy oil / bitumen reserve[12].

According to United State Geological Survey (USGS) more than 60 % of oil reserves in the global correspond to heavy and extra heavy type of oil, so the oil industry has felt the great demand to develop these types of fields [9]. This survey also shows that, the technically recoverable reserves of heavy oil in the global are estimated at 434 billion barrels and the Middle East contain 78 billion barrels of those reserves [10].The figure below shows distribution of total world oil reserves by classification.

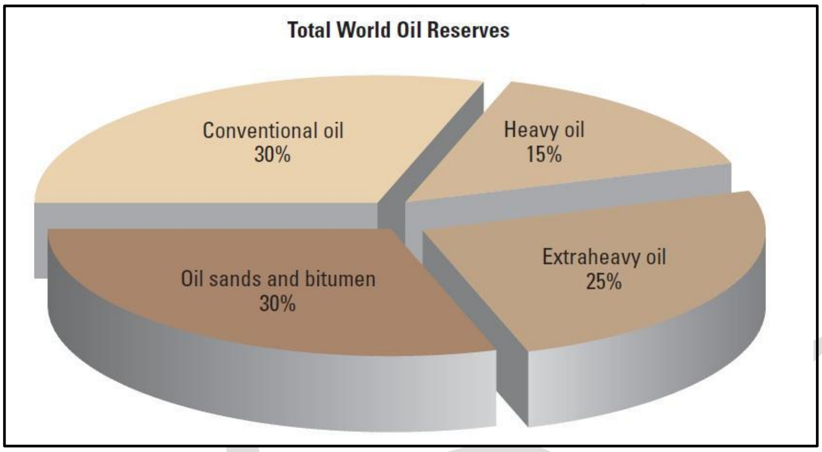


*Fig. 1:Total world oil reserves*

larter et al., (2006) [9] point out that , heavy crude oil started as lighter oil, but was degraded by various natural weathering mechanisms such as

a) Biodegradation (the most significant process in the heavy oil formation, Microbial population consume the lighter hydrocarbon when temperature actives up to 80 ℃ ). The specific gravity and viscosity of oil is raised as result of lowering gas – oil ratio (GOR)
b) Leaching (the dissolved lighter hydrocarbon molecules in the groundwater are caused by hydrodynamics of the deposit. Inside a certain reservoir, a formation of light crude oil can be found on top of a formation of heavy viscous oil.
c) Immaturity of source rock ( crude oil from a thermally immature source rock will generally be heavier than oil released by a thermal mature source rock

One of the major challenges or obstacles that can be faced during heavy oil production is low efficiency of artificial lift due to high viscosity, which result in high friction losses. This does not permit production capabilities equalize with the volume of contribution from the reservoir to wellbore. The difficulty of transporting heavy oil from the well to processing facilities is another challenges that production of heavy crude oil may face.

However, there are some applicable technologies which have been developed to solve viscosity problem which associated with heavy oil. These include: thermal and steam based recovery(most widely recovery method to these highly viscous), dilution of oil by using naphtha, chemical metal for viscosity reduction [ 3,5]

Generally, heavy crude oil and extra heavy crude oil production techniques can be divided into cold and thermal production methods. In cold production no thermal energy is supplied to the reservoir. However, in thermal production thermal energy is added in order to heat the viscous crude oil. The thermal production technique can divided into three major types (Steamflood, Cyclic Steam Simulation (CSS), and Steam Assisted Gravity Drainge (SAGD))[7.10]. Apart from these techniques, electromagnetic heating and electrical heating can be used as alternative thermal methods, taking into account economical and technical consideration.

## 2. Heavy oil properties and its Origin

Generally, the ‘heavy oil ‘refers to oil which has API gravity below 20 degree with viscosity between 100 cP and greater as shown in the figure (2). It also represents a large portion of the unproduced hydrocarbon reserve in the world. It is termed as heavy oil because it has higher specific gravity (Sp.gr) and density ($\rho$) compared with the conventional oil [12]. This is because heavy oil are comprised of high molecular weight components like resins and ashpaltenes[5].

According to larter et al., (2006)[9], heavy crude oil occurs as result of biodegradation and the first oil was expelled from its source rock as light or medium oil then migrated to a trap. After than it is converted into heavy oil by different chemical process such as water washing, aerobic degradation, and evaporation.

The high viscosity restrict the flow of the oil at standard reservoir temperature and pressure. Therefore, their recovery or extraction require technological costs per barrel compared to lighter crude oil. Heavy crude oil contain high level of sulfur compared with conventional light crude oil which occur in the same formation. In addition high rate of asphaltic and nitrogen, and oxygen play a significant role in making the oil heavy [10]

However, Bitumen refers to as (tar sand or oil sands) which has no ability to flow under reservoir conditions and it is produced by surface mining. **Figure**below **s**hows general classification of heavy crude oil.

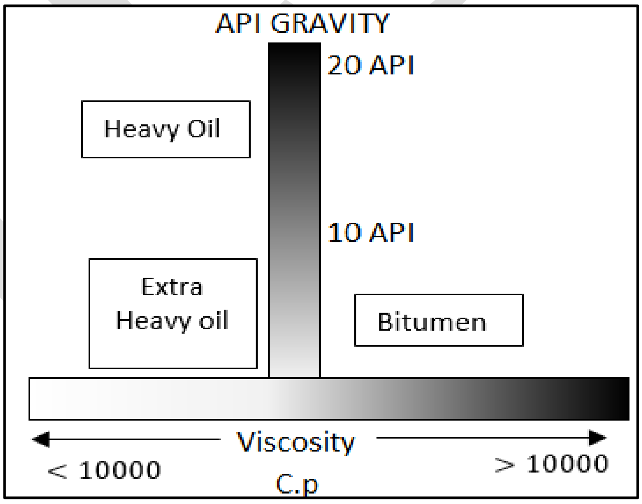


Fig.2: Classification of Heavy Crude oil according to API gravity and Viscosity.

Basically, viscosity of heavy crude oil is highly influenced by variation of temperature; therefore, the thermal recovery method are the most commonly method used in heavy oil production. The figure below illustrates the relationship between viscosity and temperature for two different heavy crude oil sample

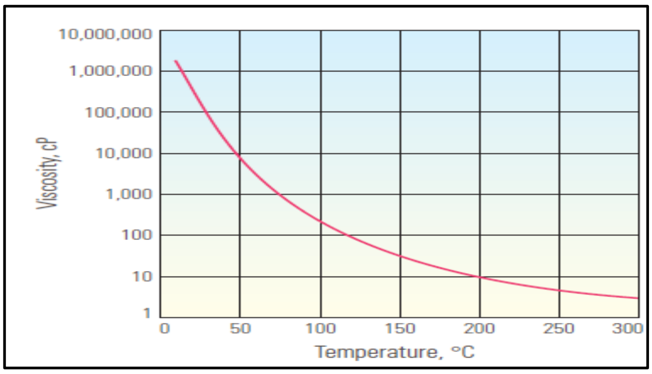


Fig.3. Relationship between Viscosity and Temperature.

## 2.1. Heavy oil / Bitumen reservoir

Heavy oils are reserved at shallow depth and have less effective seals (almost 1000 meter blew the surface). That is the reason of low reservoir temperature which is between (40-60 ℃) .It is clear that the less effective seal is due to the low seal pressure, which may cause the dissolved gases to leave the oil, increasing its viscosity [11,13]

The formation lithology of heavy oil is generally sandstone deposited as turbidity with high porosity and permeability. No obvious differentiation is made between heavy oil and oil sand (tar sand). However, the oil in (oil sand) is immobile fluid under naturally existing reservoir condition, heavy oil is somewhat mobile fluid under existing reservoir pressure.

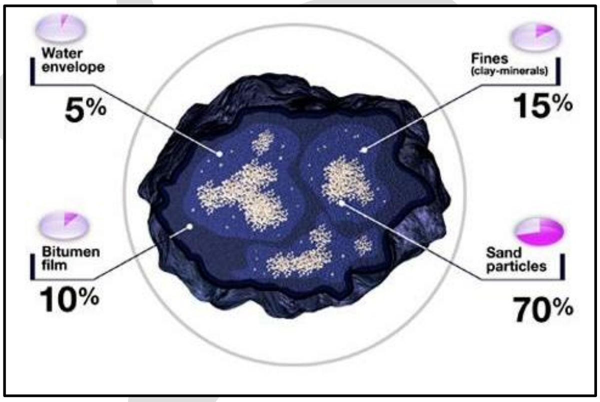


Fig.4: Composition of oil sand (Total Oil Company)

## 2.2. Heavy Crude Oil production Techniques

Various extraction methods are available to produce or extract heavy crude oil due to the high density and viscosity properties which crude oil have. These methods or techniques are:Surface mining, cold and thermal recovery method.

### 1. Surface mining

Surface mining is a primary recovery method and it is applicable when heavy crude oil is located in shallow formations up to 200 m over large areas, making this method more economical thanconventional borehole production.

This recovery method include using shovel and truck, and transport crude oil manually to processing facilities[14]. However, surface mining method consider as controversial because of the large and noticeable environmental consequence.

## 2. Cold Heavy Oil Production (CHOP)

Producing heavy crude oil by cold production is similar to conventional recovery methods, since heavy oil is produced by a borehole without any heat application. However, heat can be utilized when the crude oil viscosity is low enough at standard condition to allow the oil to flow at economic rate [14].

In order to access as much of the reservoir as possible, horizontal well can be drilled. Then dilutes such as naphtha and pumped to minimize fluid viscosity, and artificial lift systems such as electrical submersible pump (ESP), Progressing Cavity Pumps (PCP) are used to lift heavy crude oil to surface.

CHOP method has lower financial expenditure comparing with thermal method, but the recovery factor is low between 6-12% ‘according to Schlumberger oil field’.

## 3. Thermal Recovery Method

Thermal recovery method refers to all process that apply heat to the reservoir and improving the ability of crude oil to flow by reduction its viscosity. The major goal of this process is reducing the mobility ration of the oil; therefore, increase the productivity and recovery. In general, this method can be divided into major process thermal process such as ( steam flooding , cyclic steam simulation , steam associated gravity draing ,and In-situ combustion ) . In addition, there are some other methods which no widely applied like (electrical heating /electromagnetic heating and hot water flooding)

### *A. Cyclic Steam Stimulation (CSS)*

This type of recovery method is also called Soak or Huff-and –Puff. Cyclic steam simulation process involves injecting small amount of steam into a well followed by period of production from the same well. The Cyclic Steam simulation (CSS) involves three stages, collectively termed a cycle and vertical and horizontal well can be used [13].

It consider as single well process where the well is acting as injector and producer at the same time. This recovery process is predominately a vertical well process, with each well alternately injected with steam and producing heavy oil and steam condensate [11].The figure below illustrates the stages of cyclic steam simulation

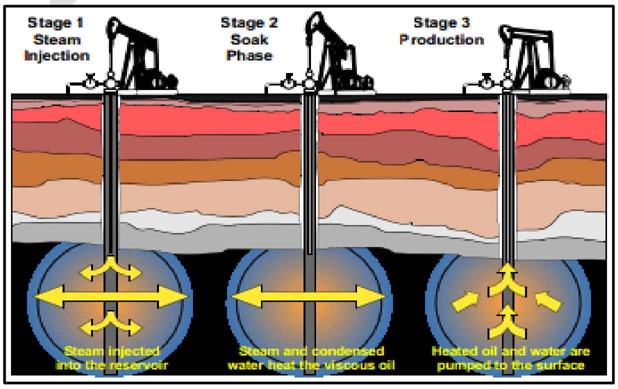


Fig.5: Cyclic Steam Stimulation

First of all,high pressure and temperate steam is pumped for a period of time(several days or weeks) .Then injection is paused for a while to allow the formation to soak and permit the steam to heat the oil in the zones around the well and lower the heavy oil viscosity.

After this period, the well is established to recover heated oil and pump the heavy oil out. This process is repeated over multiple cycles as long as the well is commercial or until the ratio of produced oil to steam injection decline to a level that is considered uneconomic [12].

According toNaqvi, 2012[11]the steam injection has slight contribution to the physical mechanisms that push the oil tothe well. Therefore reservoirs with small or no primary energy are not good candidates for steam injection

Cyclic steam injection method shows a reasonable recovery factor with up to 40 % when it is applied in South America.However, one of the main disadvantages of this process is that it is preferred production on heavy oil reservoirs that contain high pressure steam without fracturing the overburden [11].

Furthermore, oil recovery for each single cycle depend on:

1) Pay zone thickens (CSS process is economical for reservoir that contain pay zone of more than 10 meter).
2) Porosity should be not less than 30% , and good horizontal permeability ( more than 1 Darcy )
3) Oil in place.
4) Volume of steam injection.

The key economic indicator of the cyclic steam simulation process is the oil steam ratio (OSR). Oil steam ratio is the ratio of the produced volume of oil in each cycle to the injected volume of stem [11].

### *B. Steam flooding*

It is also called steam driving (SD). It is multi-well process where two isolated well are used, one for injection and other for oil production. Steam is injected through injector wells with the target of driving or flooding oil toward producer wells. Injection and production well goes continuously until the process becomes uneconomic or replaced by alternative process.

Steam has the ability to reduce oil saturation in the hot steam zone, forcing the movable oil to move out of the steam zone. The amount of recoverable oil is depend oil steam zone as the steam zone grow, more oil is moved and accumulated in unheated produced zone. Then the accumulated oil is extracted by busing various artificial lift means. Figure below shows a schematic diagram of steam flooding process.

The reservoir recovery factor (RF) may be up to 50% but this method require high capital expenditure due to high energy amount through the steam injectors. The success of the project is depend on the amount of steam injection rate. For example, high injection rate lead to early steam breakthrough, while low rate mean excessive heat losses to over and under burden.

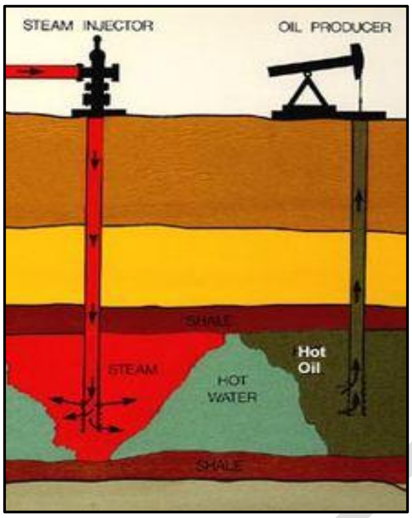


Fig.6:Steam flooding or driving process.

### C. Steam Associated Gravity Drainage (SAGD)

For thick formation and heavy permeability reservoir with heavy oil, Steam Associated Gravity Drainage (SAGD) was proposed by butler in the late of 1970s (Butler, 1998). The SAGD technique are normally applied to reservoirs which formation thickness are greater than 50 feet. This process was primarily developed to recover bitumen from Canadian oil reserves. This method have been performed over long period, this method considers an effective method for highly viscous crude oil and various commercial projects are currently used it [1].

This process involves drilling of two parallel horizontal wells in the bottom zone of the thick sand reservoir formation (approximately 15 feet). Normally, the distance between the couple of horizontal wells is (15-20 feet) and separated by each othervertically [11]

The steam is injected or pumped in the top of the horizontal well, while heated crude oil and water are produced from lower part [1]. As the steam increases into the formation, the oil is heated and separate it from the sand. This result in increases in oil mobility and oil drain by means of gravity toward the lower well or production well.

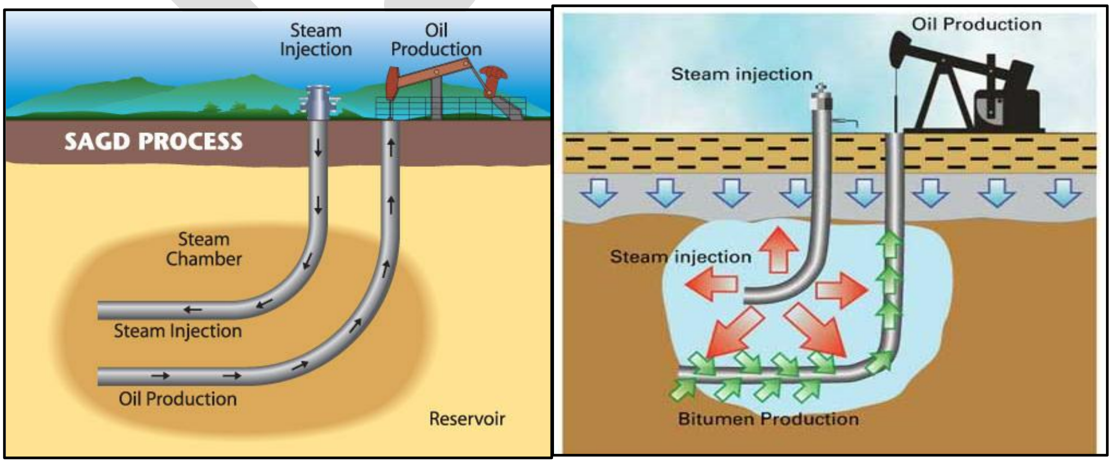


Fig.7:Process of Steam Associated Gravity Drainage (Canadian centre for Energy Information)

According to Naqvi, (2012)[11], the pumped steam minimize the oil viscosity to values between (1-10 cP), based on the temperature and steam chamber that increase vertically and laterally.

Although, the injection and production wells are close to each other approximately (6-8m), the steam chamber mechanism causes the steam saturated zone. This rise on the top of reservoir to allow the drainage.Generally, two types of flow occur during SAGD process. One at the ceiling of steam chamber “Ceiling Drainage” where heavy oil is moved away from the front after mobilization where steam rise usually block liquid drainage .The next flow is along the slope of steam chamber “Slope Drainage”, gravity holds mobilized oil against the slop where oil mobility controlled by conduction heating from steam zone [1,4] Figure 8shows mechanism of steam associated drainage gravity (SADG).

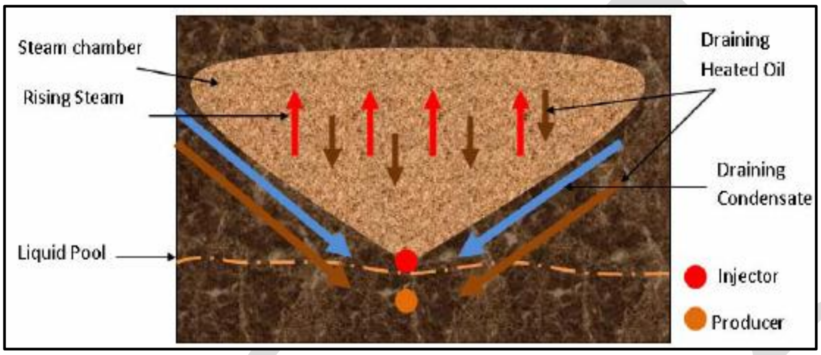


*Fig.8:Steam –Associated Gravity Drainage Mechanism (*Bahlani& Babadagli, (2009)

The recovery factor of SAGD method are very sensitive to geology formation of the field and not appropriate for clear water formation. This method is significantly improve heavy oil recovery between (50-60)% of the original oil in place ,so it considered as more efficient method compared to other thermal recovery methods because it operates on low pressure[11]. However, the capital expenditure of heat energy is the major economic constrain associated with steam associated gravity drainage.

Accordign toAlbahlani and Babadagli,2008[1]the success of SAGD in some projects depend on several factors:

1) Precise reservoir descriptions
2) Efficient consumption of heat injected into reservoir.
3) Good understanding of displacement mechanism.
4) Good understanding of geo-mechanics.

### ***D. In situ combustion (ISC)***

This method considers as old thermal recovery method which applied in low gravity oil reservoir. In this process, heat energy produces by generating fire inside the reservoir rock and burning part of the heavy hydrocarbon in place produces. Then heavy hydrocarbon are cracked, vaporized to low boiling point hydrocarbon.

Basically, the oil is driven out by injectingair (dry or moist) into reservoir and special heater is lowered into the well to ignite the oil and start the fire. Then the fire spread and pushing mixture of hot combustion gases, air injection well to producing well. During this process the viscosity of oil is reduced and displace the mobile oil toward production well.

In addition, the high temperature is fair enough to crack heavy oil into light hydrocarbon product [11]. ISC is an attempt to extend thermal recoverytechnology to deeper reservoirs and or more viscous crudes. The volume of oil burnedand the volume of heat created during in-situ combustion can be controlled to someextend by varying the amount of air injected into the reservoir. In-situ combustion recovers 10-15% of the original oil in place.

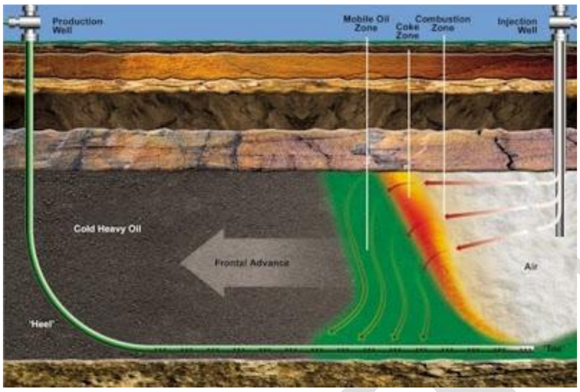


Fig.9: schematic diagram of In-Situ combustion (www.insitucombustion.ca)

Several parameter have been defined by Alexander et al.,(1962)[2] in order to find out the design of the ISC process are as follows :

a) Fuel concentration per unit reservoir volume burned.
b) Fuel composition
c) Oil production rate.
d) The volume of reservoir swept by the combustion zone.
e) Air injection rates and pressures.
f) The amount of air required to burn the fuel.

### 2.3. Challenges of producing heavy crude oil

The most common production or extraction challenges which heavy crude oil field development have to overcome are illustrated in the following points:

#### 1. Solid participation

A) Asphaltenes: are high molecular weight (Mw) hydrocarbon that are found in crude oil and can be defined as a class of hydrocarbon insoluble in alkanes but soluble in toluene or benzene. This chemical substance cause several flow assurance problem during oil production.
Precipitation of Asphaltenes due to decreasedsolubilityin the produced hydrocarbon can case several effects:
- Reduction in pipe flow area
- Increased friction pressure loss
- Wettability alteration
- Pipeline blockage

Generally, heavy crude oil contains high amount of aspheltene which has the tendency to combine, making the crude oil high viscous. In this situation, diluting crude oil with lighter hydrocarbon is the most feasible strategy to reduce the viscosity of crude oil. This process involves fluid injection, which has capability to modify the composition of the heavy crude oil so the aspheltene could be disrupted and precipitate.[4,5]

### B) Scaling

One of the problems that face reservoir and production systems during recovering heavy crude oil is calcium naphthenes precipitation. This issue may increase specially by injection sea water into the reservoir, changing concentration of salt and level of PH in the liquid.

Essentially, in normal reservoir this may be prohibited by injection of inhibitor; however, this may be prevented in heavy oil reservoir due to low mobility issue.

## 2. Heavy oil Pumps Selection

Generally, pumps are vital for carrying oil from wellsite to facilities part. However, there are more than one factor which should take into consideration when selecting heavy oil pumps. These parameters are:

a) Viscosity of Oil
b) Solids production
c) Existence of gas in produced fluid

There are two types of pumps used commonly in oil industry 1) positive displacement (PD) pump and 2) dynamic pumps. In positive displacement pump, the multiphase flow is trapped in a confined volume and as the fluid flow from one end of the pump to another, the pressure increase. However, the dynamic pumps has two parts: rotating part or impeller and stationary part known as stator. The kinetic energy is provided from impeller to the multiphase fluid. Then as the fluid expand in the stationary part, the kinetic energy of the fluid decline while the pressured increase gradually [7].

It is obvious that viscosity of oil will influence on the performance on pumps, but in different behaviours. Theoretically, first category of the pumps or PD pumps, has the ability to up 100,000 cP oil viscosity. Conversely, the dynamic pumps are unattractive for oil viscosities above 100 cP. It can be concluded that the positive displacement pump are favoured for heavy oil.

In addition, it is essential when selecting crude oil pump take into account solid content. Because it may increase apparent viscosity of the fluid due to solid suspension. Eroding and depositing effect are another significant factor should take into consideration. These problems reduce lifetime of a pump.

However, these problem could be solved either by installing sand control or remover at the upstream of the pumps, or by selecting low velocity pumps like twin screw pumps.

## 3. Methodology

Although various investigation have been made to determine the effect of metal particles on viscosity of heavy crude oil, this research try to find out whether metals such as (Iron, zinc and nickel)can provide significant reduction of heavy oil viscosity without presence of hydrate .This project also seek the effect of different types of metal (iron, copper, nickel and zinc) on heavy oil viscosity.

Theoretically, the presence of these metals in heavy oil will change fluid composition and reduce viscosity through catalytic reaction. In order to perform this research a series of experiments have been conducted in order to find out the effect of adding metal particles into heavy crude oil for viscosity reduction purpose.

In the experiment metals are added to the base fluid (consist of 85% bitumen crude and 15%n-dodecane) in order to find out how these metal effect on viscosity of the mixture. The sample prepared at room temperature and try to keep the heavy oil properties. The API density of the base fluid measure and it was 13degree. The dated of heavy oil are illustrated in the table below:

Table 1: Heavy Oil sample data

| Type of fluid | Viscosity at 20 ℃ C.P | API degree | Density gm/cc |
|---|---|---|---|
| Heavy crude oil | 5700 | 13 | 0.979 |

## 4. Result and Discussion.

Viscosity measurement results are shown in the figures below. These figures shows the relationship between viscosity ($\mu$) in cP and concentrations of metal (Fe, Zn,Ni and Cu) particles in percentage .

Generally, there is some reduction in crude oil viscosity but not fair enough comparing with base fluid. Conversely, viscosity of mixed fluid is observed to increase when metal particles are added to base fluid. It is clear that heating the mixture up to 75 ℃ has no constant effect on viscosity of mixture.

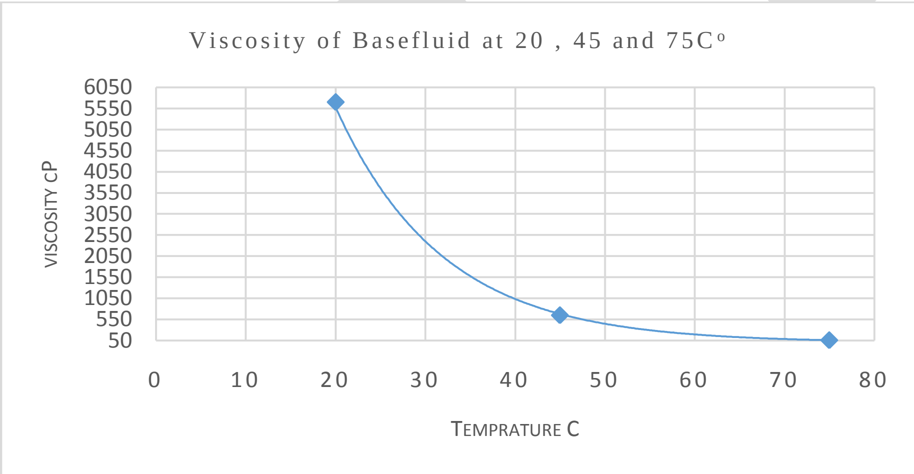


Fig.10: Viscosity and Temperature relationship of base fluid.

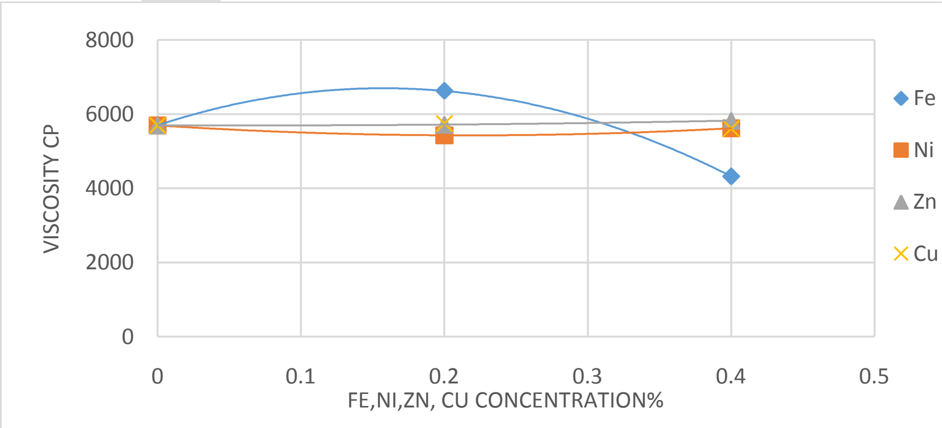


Fig.11: Metal concentrations vs. viscosity relationship at 20 Cº

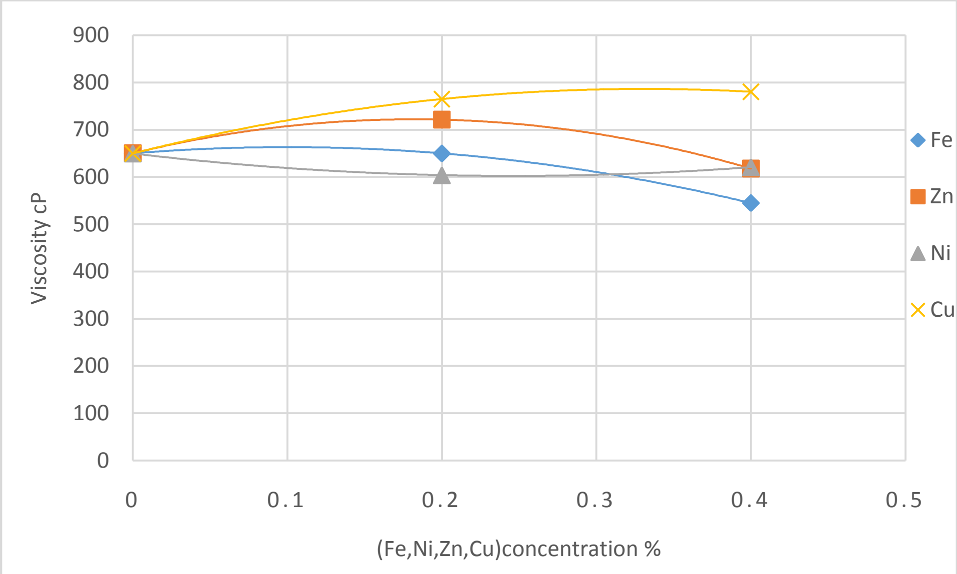


*Fig.12: Metal and viscosity relationship at 45 C$^{o}$*

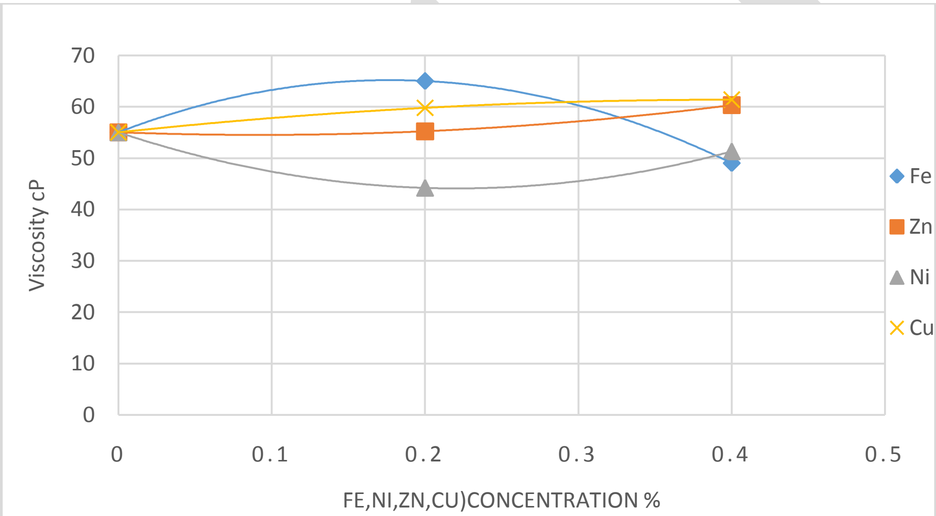


Fig.13: Metal concentrations vs. viscosity relationship at 75C$^{o}$

## 5. Conclusion

The growing world oil demand is leading to the development of the large world resources of heavy oil which can be extracted by applying different techniques from the conventional methods.

Heavy oil is defined as acrude with API gravities less than 20$^{o.}$ It contain high proportion of asphaltic molecules, including resins and Asphaltenes.

This type of crude oil is formed by biodegradation. Where it cause oxidation to light oil, and decreasing gas oil ration (GOR) and rising acidity, density, viscosity and sulfur content in the oil. In addition, other mechanism such as water washing and phase fractionation, contribute to the formation of heavy oil.

Compared to light oil, heavy oil is more costly to produce, process, and transport. In many cases, heavy oil must be recovered toreduceits density and viscosity. Normally, heavy oil reserves are concentrated in a relatively small depth .Utilized method of production ca be divided into the following groups

a) Surface mining
b) Cold production
c) Thermal methods.

Theoretically, the presence of (Zinc, Copper, Iron and Nickle) metals in heavy oil will change fluid composition and reduce viscosity through catalytic reaction. However, in this project we concluded that there is some viscosity reduction but not enough comparing with base fluid.

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