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COMPARISON OF TRIETHANOLAMINE (TEA) AND ETHYL VINYL ACETATE (EVA) AS FLOW IMPROVERS OF CRUDE OIL.

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Abstract: This research presents a study on the comparative analysis of the efficiencies of triethanolamine (TEA) and ethylvinylacetate (EVA) as flow improvers for crude oil transport. Varied concentrations (by volume percentage) of 0%, 0.025%, 0.05%, 0.1%, 0.2%, 0.4% and 1% of triethanolamine were introduced into separate but same quantities of crude oil and stirred. The viscosity and pour points were monitored at varied temperatures (30°C, 40°C, 50°C, 60°C, 70°C) to ascertain optimum concentration and temperature of best flow improvement with that of zero concentration serving as control. Similar thing was done with EVA at same conditions. TEA and EVA both drastically dropped viscosity of the crude close to what temperature alone could offer but rose immediately after the minimum concentration of 0.025% with EVA and TEA on further diluent addition. TEA viscosity rose steeply and later tended towards a constant viscosity. This was also the trend with EVA, but it rose gently unlike TEA at increased concentration of the additive. Using room temperature (30°C) for the two additives (TEA and EVA) as reference point at 0.025% concentration of each to the same volume of crude oil, TEA gave a minimum viscosity of 0.1124centistokes and EVA gave 0.1184centistokes. Similar trend was also observed at the apex temperature (70°C) at 0.025% concentration (TEA viscosity = 0.0997centistokes and EVA = 0.1015centistokes). In the end, TEA was observed to be better than EVA although EVA has its own relative advantage especially at higher temperatures and concentrations. Higher temperature from 40°C and above degraded TEA but not EVA, as a result was inhibitory to the reverse rise in viscosity in TEA. Hence, having established TEA and EVA as good drag reducing agents, the additives if used in the proper calculated quantities will act optimally in improving crude oil transport. Outcome of this research will find application in our oil and gas industry where challenges in crude oil transport has been overwhelming as a result of wax formations in the pipelines.

Key Words: Crude oil, triethanolamine, ethylvinylacetate, viscosity, drag reducing agent, flow improver, temperature.

I. INTRODUCTION

Serious global studies still envisage that in the next 20 years, not less than 80% of the world's energy needs will come from petroleum, natural gas and coal. As a result, crude oil will still be the prevailing energy source for the next 50years (Atta, El-Ghazawy, Morsy, Hebishy, & Elmorsy, 2015).

Crude oils are complex hydrocarbon blends having nonpolar n-paraffins and polar components like asphaltenes. As indicated by certain screenings from the International Energy Agency (IEA), heavy oil shows not less than half of the recoverable oil assets of the world. Heavy oil is defined to be petroleum with a density equal or less than 20 API, but when it has 10 API or less, it is seen as extra heavy oil or bitumen, that is denser than water (Khan, 1996). The production storage and transport of heavy and extra-heavy oil presents many operational challenges that limit their economic viability. Pipeline proves the most efficient means of transport for crude oils and its derived products continuously and financially too. Be that as it may, the transport of heavy and extra heavy crude oils by pipelines is troublesome owing to the low flow of the crude precipitation and settling of wax/asphalteneon pipeline walls. Crude oils with substantial wax regularly give serious issues at transportation and storage, especially in temperate regions (Soniet al., 2005), arising from good quantity of paraffin wax in the crude oil which opposes the mobility of crude oil because of crystallization of wax.

Waxes are dense paraffinic solids that form out of a crude oil making a gel substance. Wax formation is a liquid-solid phase change from a liquid mixture that is greatly affected by decrease in temperature. In the petroleum industry, precipitation of wax is unwanted as it can lead to blockage of pipelines and process facility. The settling of wax raises viscosity, as well as the roughness of pipeline leading to an increased drop in pressure. Hence, it makes economic sense to avoid and/or solve the wax deposition concerns whereby



introduction of a polymeric chemical additive at parts per million (ppm) level to the crude oil can highly achieve reduction in viscosity. Even though, treatment of crude oil for inhibition of wax deposition can be done other ways than using chemical additives, it prevails as the preferred solution over others like pigging, heating and biological treatments (Atta et al., 2013).

Settling of crystallized wax brings about higher crude oil viscosity, with attendant high transport expense from the increased rate of energy use for pumping, drop in pumping capacity, and the minimization of effective pipe cross section due to wax deposition (Anons, 2013). Depending on the nature of the crude oil including total wax content, the chain length and shape (linear or branched), amount and wax kind present in crude, the pour point depressants (PPD) in crude oil alter the structure of wax crystal by co-crystallizing with the wax changing it from extensively interlocking plates to more crystals compact. Similarity level of the polymer structure to wax components, determines its effectiveness as to its ability to attach to wax components and create an inhibition for networking of wax particles.

(Johnston, Lauzon, & Pierce, 2009) explained flow improvers or pour point depressants, PPD (also known as drag-reducing agents, DRAs) as long-chain, ultra-high-molecular-weight that decreases the amount of turbulence in liquid streams. They are usually used to bring down the pour point, viscosity, yield stress of the crude oil and enhance the fluidity of waxy crude oil, hence minimizing the extra pumping expense whilst assuring flow or fluidity of the crude.

Soniet al. (2006) discussed the synthesis and evaluation of polymeric additives as pour point depressants and flow improvers for crude oil. They studied the rheological properties of crude oil (with or without additives) in terms of shear rate, shear stress, yield stress and viscosity and listed three main characteristics for any additive to behave as flow improver should have, which are:

- (i) A wax like paraffin part, typically mixture of linear alkyl chain of 14 to 25 carbon atoms long that co-crystallize with "oils" wax forming component.
- (ii) A polar component typically acrylates or acetates that limits the degree of co-crystallization.
- (iii) Polymers that when adsorbed on the growing wax crystals stericly hindered their growth, resulting into small crystal.

It should be noted that any additive as a pour point depressant may be ineffective to reduce viscosity, yield stress and enhance the flow. The following factors according to Soniet al. (2006) play an important role in the efficiency of flow improvers and pour point depressants a number of pendant of alkyl side chains and the length and distance between them.

- the solubility of the additives in crude oil which depends on their average molecular weights.
- amorphous and crystalline parts of additive are very important in determining its efficiency
- physical and chemical stability of additive.
- if additive is copolymer then monomer to monomer ration should be taken into consideration.

Triethanolamine (TEA) co-polymer, satisfies most of these requirements. TEA is a part of a class of organic compounds called ethanolamines; combines the properties of amines and alcohols. It is a viscous organic compound that is both tertiary amine and triol (with three alcohol groups) (IARC, 2012). It is a weak base, colourless and has a mild ammoniacal odour. TEA has molecular formula $C_6H_{15}NO_3$ with relative molecular mass of 149.19, boiling point of $335.4^{\circ}C$, melting point of $20.5^{\circ}C$, density of $1.1242g/cm^3$ at $20^{\circ}C$, vapour pressure less than $1.3pa$ at $20^{\circ}C$. It is miscible with water, acetone, ethanol and methanol; soluble in chloroform and slightly soluble in benzene, diethyl ether and lignans (Lide & Milne, 1996). TEA is produced from the reaction of ethylene oxide with aqueous ammonia. It is used primarily as an emulsifier and surfactant. It is a common ingredient in formulations used for both industrial and consumer products. The triethanolamine neutralizes fatty acids, adjusts and buffers the P^H and solubilises oil and other ingredients that are not completely soluble in water. It reacts with acids to form salt and soap and is also used as flow improver additive in crude oil (DOW, 2010). Since viscosity reduction is essential to improve mobility of heavy crude oils; doping with solvent like triethanolamine (TEA), which keeps the wax dispersedly suspended in solution, is essential in ensuring oil mobility. Based on the evaluation of preliminary studies, Taiwoet al. (2003), showed triethanolamine (TEA) to be a very good wax deposition inhibitor.

On the other hand, the copolymer of ethylene and vinyl acetate is called Ethylene-vinyl acetate (EVA) or poly (ethylene-vinyl acetate-PEVA). The vinyl acetate weight percent normally ranges between 10 to 40%, and the rest being made up of ethylene. It is almost an elastomeric material in softness and flexibility though a polymer but may be processed like other thermoplastics. It is a material that is very clear and glossy, low-temperature toughness, resists stress-cracking, hot-melt adhesive waterproof characteristics, and resists UV radiation. EVA is characterized by a distinctive odour of vinegar and competes with rubber and vinyl goods in various electrical applications. Ethylene vinyl acetate (EVA) polymer chains consist of the unit monomers linked through addition of free-radical polymerization reaction via the double bonds of ethylene and vinyl acetate (VA) monomers. With wax and resins as additives EVA can be used to make hot melt adhesives, hot glue sticks, and top of the line soccer cleats. It is utilized as a clinginess-enhancing additive in plastic

wraps. EVA is used in making craft foam sheets usually for children's foam stickers among other applications.

Having established earlier that chemical additive is the most economical and efficient means of mitigating wax crystallization and deposition problems, this research work focuses on comparative analysis of triethanolamine and ethyl vinyl acetate as flow improver.

Experiment

Materials: Separating funnel, Retort Stand, 50ml and higher volume beakers, 25ml, 50ml, 100ml, 1000ml measuring cylinders, Pipette, Thermometer, Viscometer, Crucible Pycnometer, Constant temperature water bath (Manufacturer: Grant Instr. UK, Model: SE20)Magnetic hot plate (Manufacturer: Jenway Ltd UK, Model: 1000), Heating mantle (Manufacturer: Conraw UK, Model: E 22 H), Furnace (Manufacturer: Barnstead International, Model: FD 1530 M), Drying Oven (Manufacturer: B.Bran Scientific UK, Model: DHG - 9023A) Pour point apparatus (Manufacturer: Koehler Instr. Co. USA, Model: K46000), Digital weighing balance (Manufacturer: Ohaus UK, Model: PRO - AV313C), Moisture analyzer (Manufacturer: Ohaus UK, Model: MB 35 Halogen), Infrared Spectrometer(Perkin Elmer, spectrum 100, FT-IR Spectrometer, version 6)

Laboratory Reagents:Triethanolamine, Ethyl Vinyl Acetate, Fat, Ethanol/Ether mixture, KOH, Phenolphthalin, HCL, Distilled Alcohol, NaOH, Sodium Thiosulphate,

Acetic acid, Chloroform solution, Saturated Potassium Iodide Solution, Distilled Water, Starch Indicator, raw crude oil, triethanolamine, ethylvinyl acetate.

Methods:Theraw crude oil is shaken, kept to settle which separated into layers. It was separated by means of the separating funnel. measuring cylinder was now used to measure out some calculated quantities of crude sample (25ml) into small beakers for viscosity test and afterwards pour point test. Its variant behaviour in terms of viscosity was also monitored/checked at different temperatures viz: 30°C, 40°C, 50°C, 60°C and 70°C. Calculated quantities in percentage of Triethanolamine (TEA), guided by the range of most efficient quantities of additives that appreciates flow rate from literature, were introduced into the separated crude samples in the beakers namely: 0.025%, 0.05%, 0.1%, 0.2%, 0.4% and 1%. They were properly stirred and poured into the viscometer. The viscometer was operated and the time taken for the volume poured to drain was taken. This time was used to work out the viscosity. The viscosity and pour point of each as measured were recorded as in the tables.

Five test temperatures were used for each sample viz: 30°C, 40°C, 50°C, 60°C and 70°C to decipher the optimum condition of improved flow for each chemical and at a particular quantity.

The same process as in 3.3-4 was repeated using this time, Ethyl vinyl Acetate (EVA) and recorded for efficiency comparison.

II. RESULTS AND DISCUSSION

Results

Table 1: Time and Viscosities of Crude Oil at Different Concentrations (in percentage) of Triethanolamine (TEA) and Temperatures (in degree celsius).

| | Time(s) | Viscosity (Centistokes) |
|---|-------------|-------------------------|
| Raw Crude Oil + 0% TEA & EVA | 9.35 | 0.2767 |
| Crude Oil + 0.025% TEA | 3.80 | 0.1124 |
| Crude Oil + 0.05% TEA | 4.51 | 0.1335 |
| Crude Oil + 0.1% TEA | 5.69 | 0.1684 |
| Crude Oil + 0.2% TEA | 5.97 | 0.1767 |
| Crude Oil + 0.4% TEA | 6.29 | 0.1861 |
| Crude Oil +1% TEA | 6.61 | 0.1956 |

| | Viscosity (Centistokes) |
|---|-------------------------|
| Raw Crude Oil + 0% TEA & EVA | 0.2767 |
| Crude Oil + 0.025% TEA | 0.1124 |
| Crude Oil + 0.05% TEA | 0.1335 |
| Crude Oil + 0.1% TEA | 0.1684 |
| Crude Oil + 0.2% TEA | 0.1767 |
| Crude Oil + 0.4% TEA | 0.1861 |
| Crude Oil +1% TEA | 0.1956 |



| Concentration of TEA in Crude Oil (%) | Viscosity (Centistokes) |
|---------------------------------------|-------------------------|
| 0 | 0.2767 |
| 0.025 | 0.1124 |
| 0.05 | 0.1335 |
| 0.1 | 0.1684 |
| 0.2 | 0.1767 |
| 0.4 | 0.1861 |
| 1 | 0.1956 |

| | 30°C | | 40°C | | 50°C | | 60°C | | 70°C | |
|------------------------------|---------|-------------------------|---------|-------------------------|---------|-------------------------|---------|-------------------------|---------|-------------------------|
| | Time(s) | Viscosity (Centistokes) | Time(s) | Viscosity (Centistokes) | Time(s) | Viscosity (Centistokes) | Time(s) | Viscosity (Centistokes) | Time(s) | Viscosity (Centistokes) |
| Raw Crude Oil + 0% TEA & EVA | 9.35 | 0.2767 | 5.30 | 0.1568 | 4.03 | 0.1192 | 3.66 | 0.1083 | 3.57 | 0.1056 |
| Crude Oil + 0.025% TEA | 3.80 | 0.1124 | 3.65 | 0.1080 | 3.55 | 0.1050 | 3.48 | 0.1030 | 3.37 | 0.0997 |
| Crude Oil + 0.05% TEA | 4.51 | 0.1335 | 3.53 | 0.1045 | 3.43 | 0.1015 | 3.39 | 0.1003 | 3.19 | 0.0944 |
| Crude Oil + 0.1% TEA | 5.69 | 0.1684 | 4.17 | 0.1234 | 3.90 | 0.1154 | 3.75 | 0.1110 | 3.63 | 0.1074 |
| Crude Oil + 0.2% TEA | 5.97 | 0.1767 | 4.40 | 0.1302 | 3.92 | 0.1160 | 3.82 | 0.1130 | 3.72 | 0.1101 |
| Crude Oil + 0.4% TEA | 6.29 | 0.1861 | 4.76 | 0.1408 | 4.10 | 0.1213 | 3.89 | 0.1151 | 3.80 | 0.1124 |
| Crude Oil +1% TEA | 6.61 | 0.1956 | 5.02 | 0.1485 | 4.39 | 0.1299 | 4.08 | 0.1207 | 3.92 | 0.1160 |

Graphs/Charts of Crude Oil Viscosity at Different Concentrations of Pour Point Depressants/Flow Improvers.

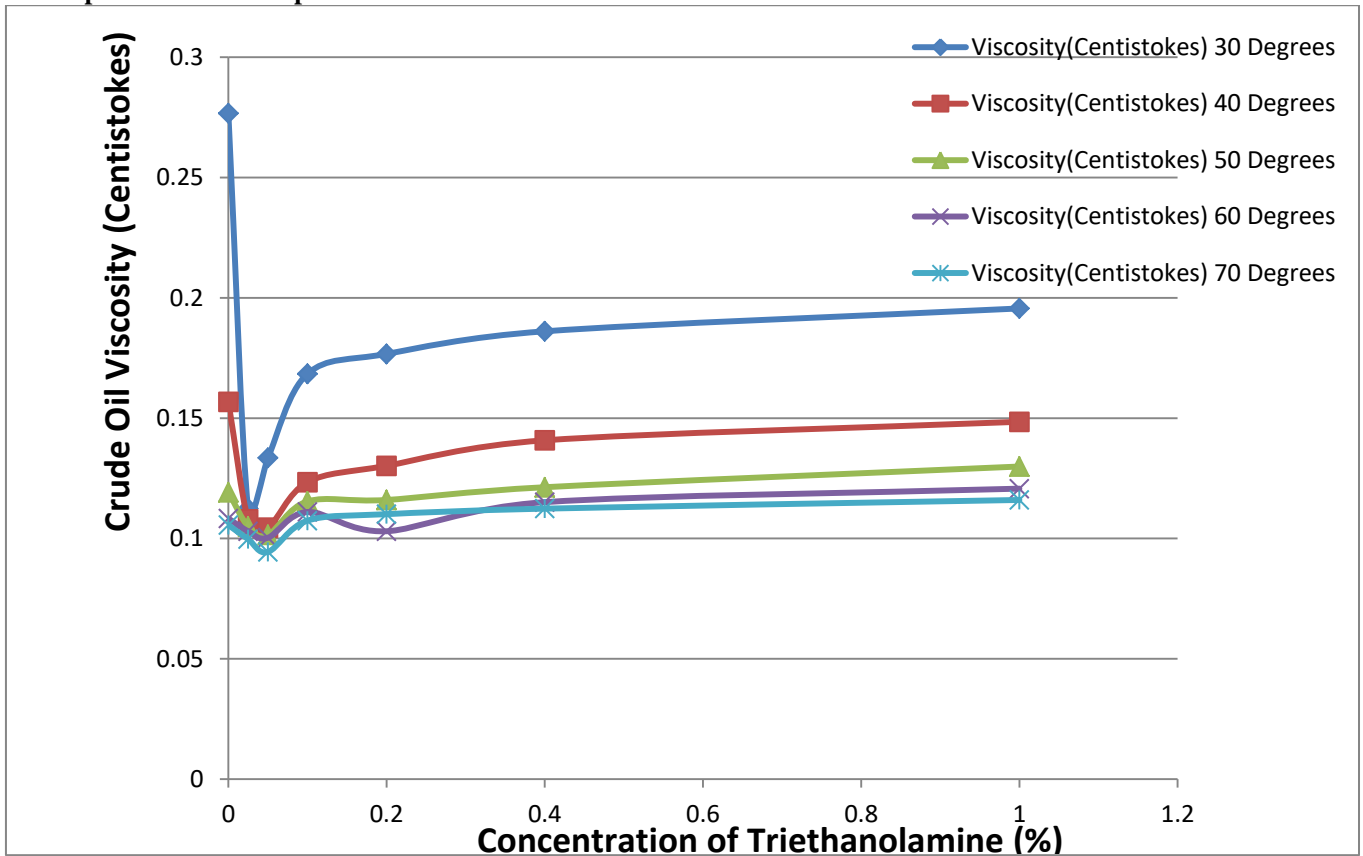


Fig.4.1 Graph of Viscosity against Concentration (TEA) at Different Temperatures.

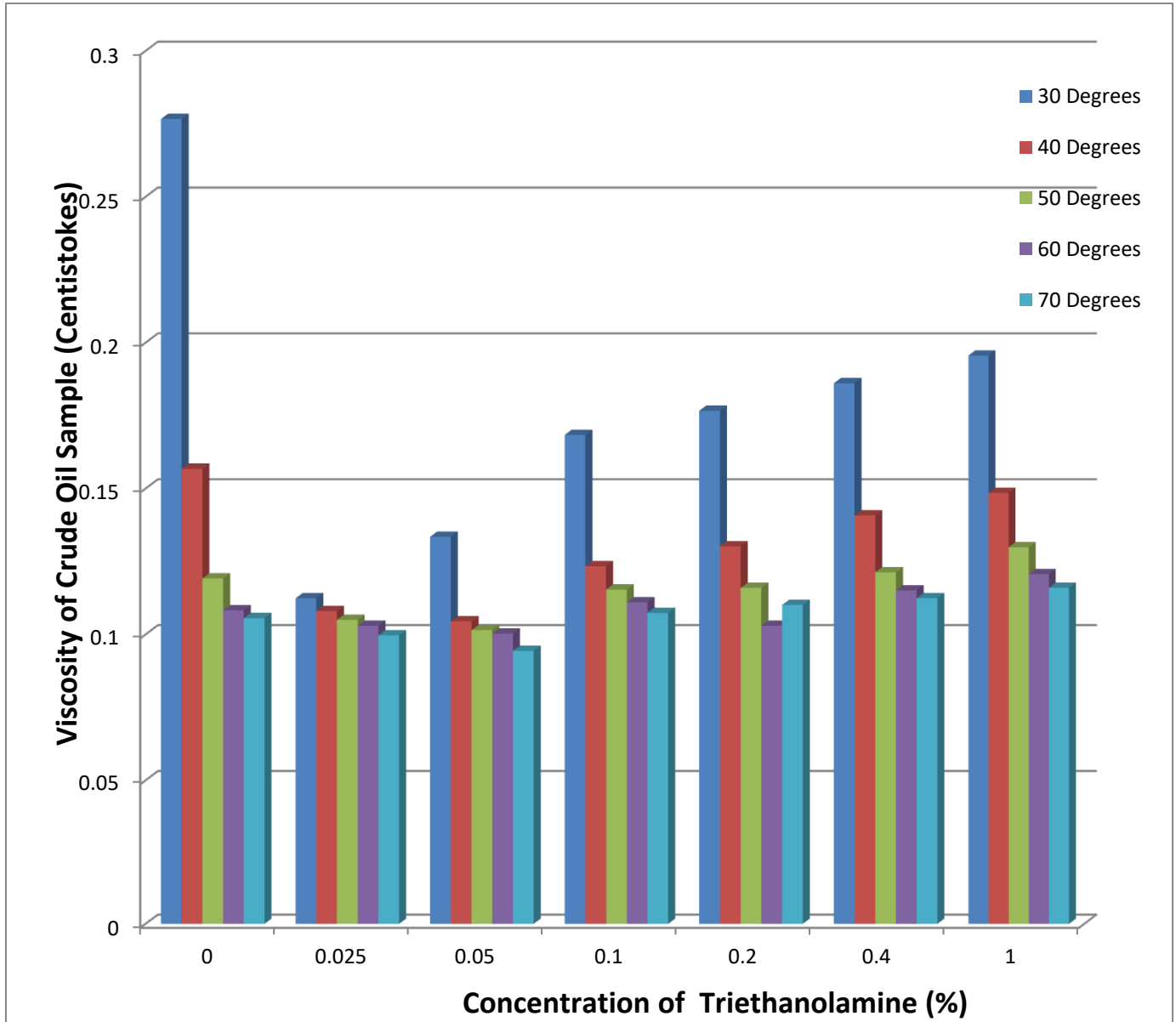


Fig. 4.2 Chart for Viscosity versus Concentration (TEA) at Varying Temperatures.

Table4.3: Viscosities of Crude Oil at Different Concentrations (in Percentage) of Ethyl vinyl acetate (EVA) and Temperature (in degree Celsius).

| | Time(s) | Viscosity (Centistoks) |
|------------------------------|---------|------------------------|
| Raw Crude Oil + 0% TEA & EVA | 9.35 | 0.2767 |
| Crude Oil + 0.025% EVA | 4.00 | 0.1184 |
| Crude Oil + 0.05% EVA | 4.08 | 0.1207 |
| Crude Oil + 0.1% EVA | 4.10 | 0.1213 |
| Crude Oil + 0.2% EVA | 4.12 | 0.1219 |
| Crude Oil + 0.4% EVA | 4.23 | 0.1252 |
| Crude Oil + 1% EVA | 4.69 | 0.1388 |

| | 30°C | | 40°C | | 50°C | | 60°C | | 70°C | |
|------------------------------|---------|-------------------------|---------|-------------------------|---------|-------------------------|---------|-------------------------|---------|-------------------------|
| | Time(s) | Viscosity (Centistokes) | Time(s) | Viscosity (Centistokes) | Time(s) | Viscosity (Centistokes) | Time(s) | Viscosity (Centistokes) | Time(s) | Viscosity (Centistokes) |
| Raw Crude Oil + 0% TEA & EVA | 9.35 | 0.2767 | 5.30 | 0.1568 | 4.03 | 0.1192 | 3.66 | 0.1083 | 3.57 | 0.1056 |
| Crude Oil + 0.025% EVA | 4.00 | 0.1184 | 3.91 | 0.1157 | 3.70 | 0.1095 | 3.55 | 0.1050 | 3.43 | 0.1015 |
| Crude Oil + 0.05% EVA | 4.08 | 0.1207 | 3.92 | 0.1160 | 3.72 | 0.1100 | 3.57 | 0.1056 | 3.45 | 0.1021 |
| Crude Oil + 0.1% EVA | 4.10 | 0.1213 | 3.94 | 0.1166 | 3.76 | 0.1113 | 3.60 | 0.1065 | 3.48 | 0.1030 |
| Crude Oil + 0.2% EVA | 4.12 | 0.1219 | 3.98 | 0.1178 | 3.82 | 0.1130 | 3.62 | 0.1071 | 3.54 | 0.1047 |
| Crude Oil + 0.4% EVA | 4.23 | 0.1252 | 4.09 | 0.1210 | 3.98 | 0.1178 | 3.70 | 0.1095 | 3.56 | 0.1053 |
| Crude Oil + 1% EVA | 4.69 | 0.1388 | 4.35 | 0.1287 | 4.05 | 0.1198 | 3.85 | 0.1139 | 3.69 | 0.1092 |

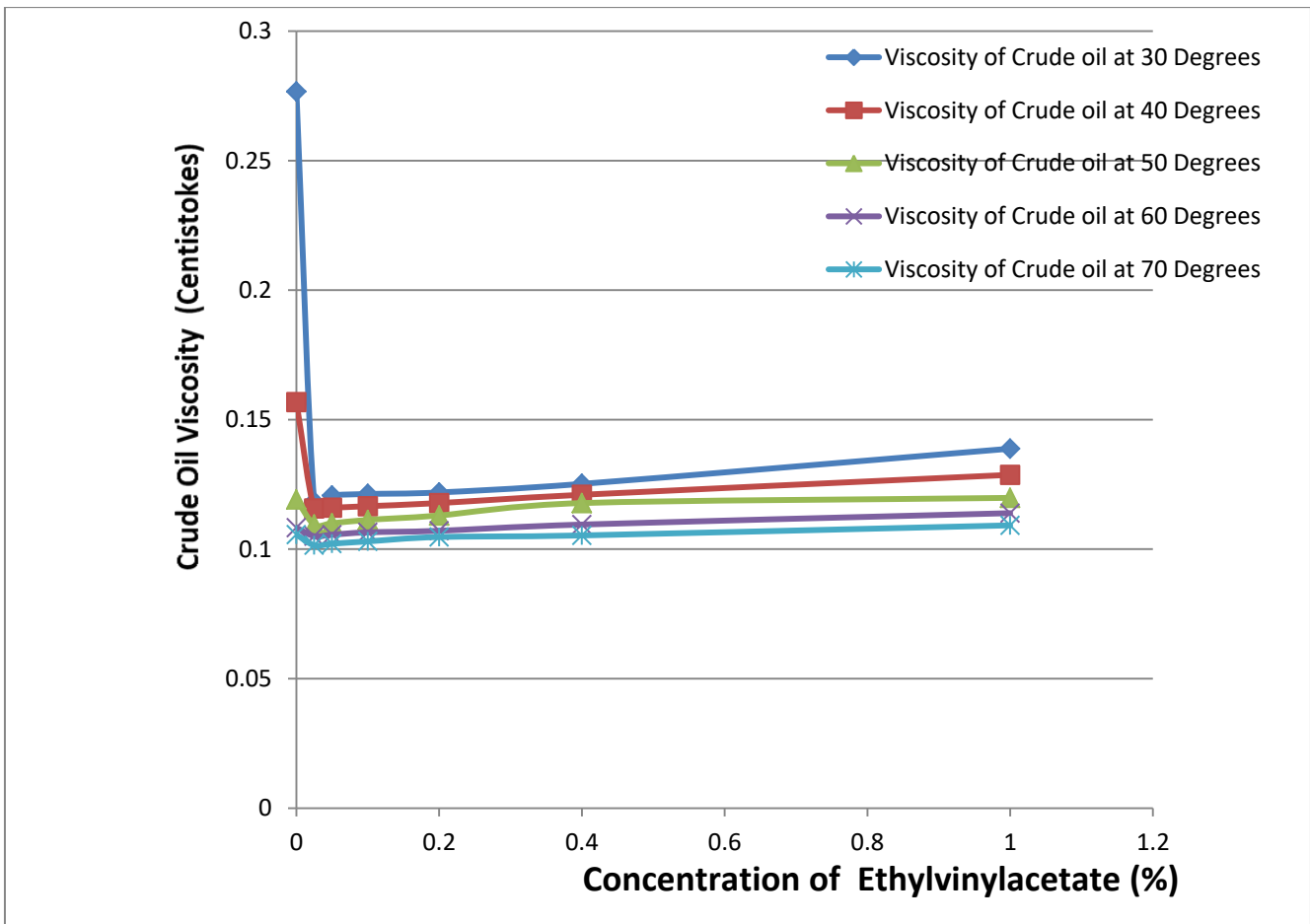


Fig. 4.4 Graph of Viscosity against Concentration (EVA) at Different Temperatures.

(from 3.2.1.5)

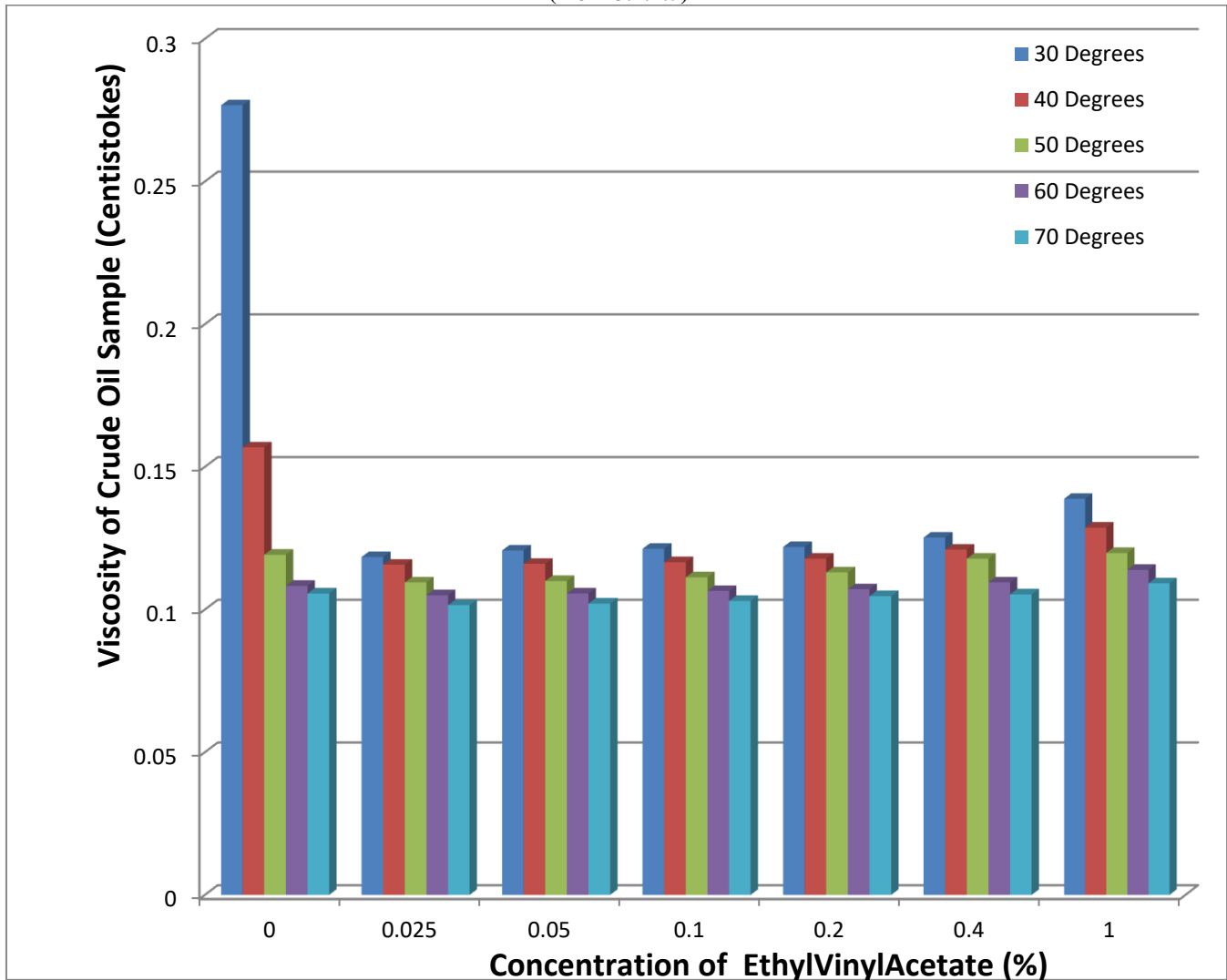


Fig. 4.5 - Chart of Viscosity against Concentration (EVA) at Different Temperatures

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Discussion

Effects of Triethanolamine (TEA) on Crude Oil Viscosity at different (TEA) Concentrations and Temperature

At room temperature of 30°C, when 0.025% of TEA by volume was introduced into the raw crude oil sample, there was a sharp reduction/decrease in viscosity from 0.2767 to 0.1124 centistokes. At subsequent higher percentages of TEA introduction to the crude oil, there was a progressive increase in viscosity but not up to the viscosity of raw crude oil, even up to 1% TEA introduction. This confirms an appreciable flow improvement/transport of the crude oil with TEA injection, keeping the optimum volume percent of injection at about 0.025% and may be below as shown in the table 4.1. This agrees with the works of (H. Soni & Bharambe, 2006), postulating that the polymeric additives at different doses are effective to depress pour point and

improve flow of the crude oil up to 9°C with 500 ppm of doses.

Similar results were also obtained at higher temperatures, except that there was a further reduction in viscosity by one step or two as the temperature increases pegging the optimum concentration of the flow improver (TEA) this time at 0.05% by volume. Many temperatures were sampled and several percentage concentrations of improver injections were tested for, to serve as a check and confirmatory influence and similar trend or results were observed in each case. Furthermore, the initial drop in viscosity of the crude oil is more at room temperature (30°C) (where efficiency of the DRAs are manifested before the interference of temperatures) than at other higher temperatures.

From the graph of viscosity against concentration using TEA as flow improver, figure 4.1, the following observations and inferences/interpretations were obtained:



The crude sample reveals initial sharp drop (by wide range) in viscosity for all temperatures (especially with lower temperatures) before rising with increased concentration of TEA for the same temperature. This indicates that TEA considerably qualifies or does the job of a flow improver with the overriding effect of temperature since room temperature was also used in the experiment as control in this case, affirming the observation of (Popoola et al., 2015) and (Taiwo et al., 2012), who were unanimous that TEA is a very good flow improver.

Again, the lower temperatures (30°C and 40°C) recorded sharper or higher viscosity inferring that in the absence of the overriding effect of temperature, TEA performs very well in improving flow properties of (the) crude oil.

Furthermore, after the initial long range sharp drop in viscosity for all cases to a minimum point, there is also a quick rise in viscosity on continued addition of TEA to each of the samples. This implies that there is an optimum point of concentration of the chemical in its results after which further concentration of TEA begins to increase viscosity instead of dropping it in concordance with (H. P. Soni et al., 2005), who asserts that crude oil responds differently with the same additive at different doses, as a result of changes in rheological properties of the crude oil.

Figure 4.1 shows that this optimum point of flow improvement result vis-a-viz viscosity is different for each sample of different temperature (though within a close range). This observation is purely an influence of higher temperature on both viscosities of crude oil and the DRA (TEA), since each line has the same composition at each point with only temperature varied.

Rate of return of the viscosity slows down drastically after quick rise and gradually tending towards a constant viscosity on further addition of the TEA. This follows the opinion of (Jafari Behbahani, 2014), that relation between pour point decrease and polymeric flow improver concentration is not linear. Hence, without appropriate calculation and realisation of the minimum point, there is an imminent material or resources waste (chemical, labour, time, etc.) as further addition works in the negative of the targeted result and then tends to a useless effort. All conditions of temperature followed the same trend.

More so, the orientation of the graph of figure 4.1 reveals that at higher temperature (from 60°C upwards), there is a convergence or closeness of behaviour in the samples i.e. the higher the temperature, the more similar the behaviour of the flow improving process. This is suggestive that there might be convergence or optimum temperature point at which further increase in temperature will have no effect.

At 60°C (which is double of the room temperature used that widely behaved differently), there is a more pronounced second irregular behaviour more than others including 70°C. The second drop or slowing down of increasing viscosity, which is not very noticeable in others was more significant around 0.1% to 0.35% concentration of TEA from where it

later went higher than 70°C line as ordinarily expected from the overriding effect of temperature confer figure 4.1. But then, this second optimum point for 60°C is of little or no significance for three reasons: it is happening at a higher concentration of drag reducing agent than the first optimum point which translates to material waste, happening at a higher temperature which means waste of energy, and, above all, the initial optimum point gives a better improvement/flow in the viscosity. This value may also be a result of random error in measurement.

From the variation observed with the sample at room temperature serving as control against other higher temperature samples, it is clear that a combination of the DRA (TEA) and increased temperature gives better result as seen from the highest and lowest values of viscosity achieved across the temperatures viz: 0.0944(at 70°C) and 0.1124(at 30°C), which aligns with the opinion of (Abney et al., 2003) that a combination of two or more treatment methods gives more efficient result.

The steep/sharp rise in viscosity immediately after the minimum point drop in viscosity (figure 4.1) especially in the absence of heat, indicates that once the optimum point is missed, the negative result ensuing immediately after the optimum point is far disadvantageous in terms of waste of resources, time, energy and then reversal of better flow improvement already achieved.

Higher temperatures are considerably inhibitory to this reverse negative action when compared with the rate at room temperature following the large gap from the graph. This means higher temperature degrades TEA, and (Shenoy, 1976) agrees with this finding that degradation can occur on the polymers during the flow due to pressure and temperature.

Note: Room temperature conditions of the experiment pegged at 30°C is invariably the outside environmental seasonal temperature in most countries especially the tropics and temperate regions for consideration in pipelines.

Effects of Ethylvinylacetate (EVA) on Crude Oil Viscosity at different Concentrations and Temperature

At room temperature when 0.025% by volume of EVA was injected into the crude, there was also a sharp drop in the viscosity of the crude even though the drop for EVA was less than that of TEA. The same trend as in TEA also followed after the first sharp drop, then at subsequent higher percentages of EVA injection, the viscosity began to rise gently unlike with TEA and continued that way but never up to the viscosity of raw crude only.

Room temperature readings were suggestive that the smaller the percentage EVA injected, the lower the viscosity.

Each condition of temperature also shows an initial drop in viscosity to a minimum point (viscosity) before rising again. This implies also that EVA is a good flow improver.

All the conditions of temperature dropping and rising simultaneously indicates that with the chemical, there is also

an optimum concentration point for best result as temperature alone is expected to continuously drop viscosity or at least remain constant with further increase in temperature.

Though unarguably, temperature has an overriding effect here also, it is evident that the EVA showed its power to reduce viscosity or improve flow at the condition of room temperature pegged at 30°C.

More so, the effect of temperature seems not to be much felt as the graph line of 30°C (room temperature) dropped viscosity with chemical (EVA/improver) alone closely as much as higher temperatures could offer.

All temperature conditions with EVA as improver followed the same trend, although they maintained different optimum points. In any case, they are of very close range or approximately the same optimum point. Hence, high temperature does not degrade EVA as seen with TEA.

Higher temperature is not inhibitory with EVA as there was no much gap between the lines.

Figure 4.4 also show different optimum points indicating influence of temperature alone since same composition applies in each graph line as was the case with TEA.

EVA also showed a tendency to constant viscosity by the line orientation with a seeming higher gradient towards higher concentration but didn't have an initial steep rise as with TEA. If this happens (constant viscosity on increased concentration), it means either the DRA (EVA) is useless at higher concentration due to perfect blending with bulk crude components or it becomes inhibitory to its own action at higher concentration (because the quantities are still in parts per million).

Missing the optimum point in the case of EVA is not as deadly in terms of wastes as with TEA due to the gentle initial gradient of the graph lines.

EVA did not appear to be affected by higher temperature/heat as with TEA hence the graph line of room temperature (30°C) and other temperature are similarly close to each other except for the overriding effect of temperature. Combination of EVA with higher temperature also gave better results in terms of flow improvement as from the highest and lowest values of viscosity achieved across the temperatures, viz: 0.1015(at 70°C) and 0.1184 (at 30°C).

Convergence of the different temperature lines with EVA started from the beginning and began to disperse at higher concentrations. This means higher concentration of EVA promotes reverse improver action irrespective of temperature.

Comparison between TEA and EVA as Flow Improvers

General comparative efficiency between TEA and EVA reveal that even though both improvers reduced viscosity of the crude oil, TEA showed more drop at room temperature and at 0.025% concentration, but from the immediate next step of 0.05% DRA in crude oil, EVA began to do better result (lower viscosity) which it maintained throughout. This

implies that outside the optimum point of TEA at room temperature, and at higher concentrations of EVA and TEA, TEA raises viscosity (backward action) more sharply than EVA.

Differences:

1. TEA seem to have a converging optimum point at about 0.1centistokes and 0.025 – 0.05% concentration while EVA does not really seem so, rather, just showing independent drop in viscosity at different minimum points for all temperature conditions.
2. There is wider range or gap in the mode of rising viscosity after the optimum point with TEA for different temperatures even for the same concentration, whereas EVA followed a close range in-between different temperatures at the same conditions and concentration after optimum point.
3. Using room temperatures for the two additives (TEA and EVA) as reference points at 0.025% concentration of each to the same volume, TEA (though more viscous than the crude oil) proved to be a better flow improver at their optimum points having 0.105centistokes against EVA having 0.1157 centistokes. The same was also observed at the apex temperature of 70°C (TEA at 0.025% concentration = 0.0997, and EVA = 0.1015centistokes at 0.025%).
4. It is more disadvantageous to miss the optimum point with TEA (as the viscosity will rise back sharply/steeply) than missing the optimum point of EVA (which raises backward viscosity gently). And hence, missing optimum point is costlier with TEA than EVA.
5. Heat degrades TEA but not EVA hence inhibits reverse viscosity.
6. Increasing concentration of EVA promotes reverse viscosity drop and not heat like in TEA, hence temperature does not degrade EVA.
7. TEA separates with high distinction into low and high temperatures but EVA behaved fairly uniform irrespective of the temperature.
8. Second kink/depression in TEA is totally absent in EVA.

Similarities:

1. Both EVA and TEA all dropped the crude oil viscosity tangibly and rose on extra injection of additive beyond their minimum point.
2. Given the same physical conditions of temperature, pressure, constituent/composition, etc, the two DRAs all dropped viscosity of crude oil to an optimum point of about ± 0.1 centistokes at around DRA concentration of 0.025% in the crude oil, although seen to drop further at lower concentration of improvers following the trend.



3. The two DRAs reverse viscosity at higher concentration points to the fact that either they gather the wax back with or without themselves (especially TEA) or they become immiscible compounds with wax thereby allowing the wax to nucleate back.
4. Both cases (DRA/chemicals) after the fall and rise in viscosity seem to tend towards maintaining a constant viscosity (averagely) at higher concentration of the additives (about 1%) given the limits of this experiment or a kind of asymptotic behavior.
5. Both DRAs compete favourably close with temperature, though it maintains an overriding effect.
6. The two DRAs overruled the influence of further heat and evoked a reverse viscosity trend as temperature alone would have continued reducing viscosity or remain constant at most.
7. They both have optimum concentration points beyond which wastes sets in in terms of material, energy, time, etc.
8. Temperature has an overriding effect in both cases of the DRAs.
9. Both varied in minimum/optimum points at different temperatures and are still closely related.
10. The two DRAs showed similar trend of fall, rise, divergence and tendency to constant viscosity at higher concentration.
11. Both also behaved in similar manner under the influence of temperature.
12. Missing optimum points in both cases gives/spells immediate losses.
13. Combination use of each of the DRAs with higher temperature/heat proves a better result.

III. CONCLUSION

In this research, chemical additive has presented itself as a very good and more efficient option for improving flow of heavy crude oil, especially in pipeline transport more than pigging, heating or other temperature means.

In this comparative study, the following can be inferred: both chemicals; triethanolamine (TEA) and ethylvinylacetate (EVA) are good flow improvers in crude oil. However, triethanolamine proved to be a better improver than ethylvinylacetate under the same and given conditions of the experiment.

More so, each has its own comparative advantage with regards to its optimum quantity and condition. And the essence of using volume percent of improver as a veritable measurable index for efficiency comparison parameter is because the volume of improver chemical is directly linked with cost and convenience. Furthermore, it can be applied by scaling to any quantity higher or lower of fluid system.

It is worthy of mention here that no chemical reaction is involved in the use of these two chemicals as no new substances or change was observed rather it followed

physical interference with the crude as reported earlier from literature, rather the DRA co-crystallizes with the wax forming from a nucleus site, since wax is the major cause of flow inhibition in a fluid system such as these.

RECOMMENDATIONS

From this research work, I therefore recommend the use of the two chemicals as flow improvers following the foregoing arguments especially from the action of the DRAs at room temperature comparable to or even more than what heat offered at higher temperature when heat cost is taken into consideration.

- 1) Further research is needed in this area to see if lower percentage volume/concentration of improver/DRA (both for the ones used, TEA and EVA or others) injection less than 0.025% will further lower viscosity i.e. further improve flow thereby establishing new minimum point thereby engendering even cheaper resource use.
- 2) The government should support research in this area as it forms the main stay of our economy, by way of research funds and grants and also provision of well-equipped ultra-modern laboratory facilities to ensure ease of precision and accuracy with research findings.
- 3) I also recommend the use of these organic chemicals as against heat because they are less hazardous, more environmentally friendly by virtue of their organic nature; while heat and other processes bring about global warming and environmental degradation.
- 4) A national repository of research findings in the sciences is highly recommend especially in this all important petroleum industry being the base of our economy.

CONTRIBUTION TO KNOWLEDGE

Findings from this research have added to existing knowledge in the following ways:

1. There exist great similarities between the two chemicals: EVA and TEA in enhancing flow properties of crude oil.
2. The performance of triethanolamine proves a better flow improver/drag reducing agent at room temperature and higher at concentration of additives lower than 0.05% by volume than Ethyl Vinyl Acetate
3. If the system of the crude oil experiences increase in temperature beyond room temperature, may be due to its operations or by design, EVA will give a better result at such condition.
4. When it is intended to diminish viscosity (enhance flow) of oil crude by TEA (Triethanolamine), 0.025% by volume concentration of TEA in relation to the crude is to be used and not more, as more than this will increase viscosity (reduce efficiency and utility) from optimum volume/condition (although there are chances



to argue that even lower concentration of the DRAs will do better).

5. When the use of improver is intended outside calculated optimum point and at higher temperature than room temperature, EVA (Ethyle Vinyl Acetate) should be used but not more than 1%. This is because the rise after optimum point with EVA is gradual unlike TEA which sharply rises immediately after optimum point but after about 1-2% volume additive the rise in viscosity becomes substantial even though still better/lower than with TEA.

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