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An Overview on Most Effective DRAs in Crude Oil Pipelines

Abstract- *The flow of crude oil in pipelines suffers from a problem of fluid flow pressure drop and high-energy consumption for pumping especially in low temperatures environment. Flow can be enhanced using viscosity either reduction or drag reduction techniques. Drag reduction is considered as the most effective and most applicable method. The technique contributes in reducing the frictional energy losses during the flow by addition of little doses of materials knowing as drag-reducing agents. The present work focuses on more recent and most applicable drag-reducing agents used in crude oil flow enhancement via pipelines.*

Keywords- *Crude oil, Drag reduction, Flow enhancement, Fibers, Polymers, Nanomaterials.*

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1. Introduction

When fluids are transported through a pipeline, a decrease in fluid flow pressure is usually occurs because of high friction involved between the wall of the oil pipe and the fluid. Because of this decrease in pressure inside the line, fluids are transmitted below suitable pressure to obtain the required productivity. In order to achieve desired flow rates across the pipeline, more pressure must be applied because with increased flow rates also increases the difference in pressure. However, there are limitations regarding pipeline design leading to reduce the amount of pressure that can be used. Problems associated with decreased pressure are compounded when fluids are transported over long distances. Such decrease leads to inefficiency thus increases the volume of equipment and operating costs [1,2]. To overcome the problems associated with low pressure, many industries use additive materials in flowing liquids. When the fluid flow in the pipeline is disturbed, it can be here used a material that is highly capable of reducing the losses resulting from the reduced flow pressure. The function of these additions is in suppressing the evolution of turbulent vortices resulting in an increase in flow rate under steady pumping pressure. It is known as polymers, fibers, surfactants and nano materials used as drag reducers operate especially in hydrocarbon fluids. Each type of drag-reducing agent (DRA) has diverse techniques to decrease

the drag within the pipeline system. Although still efficiently founded, drag-reducing agents are thought to work in several ways like turbulence repression, expansion of laminar domain limit to maximum Reynolds Number, near wall flow modulation, and friction detraction in totally advanced turbulence flow [3-5]. The aim of the present review is to survey the studies relating to the methods of reducing the drag in the oil pipelines and review the materials that are used as efficient drag reducers. The working mechanisms of each material are also included.

2. Drag Reduction working Mechanism

Drag reduction is known as a transport phenomenon where a tiny amount of additive material may reduce the friction factor of the fluid flow. The function is to increase the capacity, and decrease the power required for oil pumping through active agents, defined as Drag Reducing Agents (DRAs). Drag reduction (%DR) known as the ratio of pressure drop value (ΔP) without additive to pressure drop value (ΔP) with additive, as shown in Eq. (1) [5,7,8].

$$\%DR = (\Delta P - \Delta P_{DRA}) / \Delta P \times 100 \quad (1)$$

Where ΔP is the pressure drop without drag reduction additives, and ΔP_{DRA} is the pressure drop measured when using a drag-reducing agent. The working mechanism of DRA additives can be classified as:

- Polymer using as a drag-reducing agent by dampening the figuration of eddies so the turbulence can be reduced, as inferred by many researchers [9-11]. It has also observed that polymer execution impacted by secondary factors, such as the influence of concentration, pipe size and geometry, molecular weight, flexibility of chain, and flow rate [5,12].

- Fibers are applied to decrease the drag without causing any problems related to environmental pollution because it does not react with any material and does not produce toxic materials. Neighboring fibers in suspension interact and entangle even at minimum populations and can create bunches or structures that conduct differently from the individual fibers. Fibers triangle at middle concentrations to create three-dimensional structures or networks which in fluid suspension can change the transfer characteristic of the suspension [6,13].

- Surfactant additives reducing the drag inner the pipeline by forming micelles because of interaction between polar and nonpolar molecules of surfactant and oil. These micelles will aid in decreasing the flow turbulence by working as an impact absorber that minimizes generation of eddies [14].

- Nano fluids contain very small particles that are in a nanometer. These particles collide in base fluid as suspension. Nano fluids differently act as a drag reducer in comparison with surfactants and polymers. Nanofluid reduces the drag inside a pipe by means of surface modification method. Nanoparticle resides in crevices along the pipe inside wall, and then the pipeline becomes smoother for liquid flowing. The smoother wall the lower turbulence of the flow as it will reduce Reynolds Number (Re). This is attributed to wall roughness reduction inside the pipe. The more applicable nano-fluid used as a drag reducer is Nano-Silica. It is approximately cheap and easy to prepare, it proved to be a good drag reducer applied for crude oil and other fluids [5,17].

3. Industrial Drag-Reducing Agents

The industrial DRAs can be classified into four categories as they used by researchers:

1. Polymers

The addition of small quantities of high molecular weight polymers in the liquid stream causes a massive decrease in the friction at the pipe wall [16]. In 1949, Toms reported unusually low friction factors for dilute solutions of poly (methyl methacrylate) in monochlorobenzene. He firstly published drag reduction data, which was later

named as the "Toms effect". While Tom has been reported that turbulent drag reduction can be achieved using polymer additives, however, there are a lot of researches focuses on this phenomenon, including theoretical, experimental and numerical approaches [17,14]. Polyethylene oxide (PEO) has a linear and flexible structure, which is used as a drag reducer in the water system. The maximum DR % was 50% with a concentration of 20 ppm [18]. In addition, the PEO was used as a DRA in water-oil flows; the maximum DR % was about 65% with a concentration of only 10–15 ppm [19]. While polyacrylamide (PAM) solutions widely used as DRA in water at 1000-ppm concentration and rectangular pipe have length 11m to give DR% of about 58% [20]. A hydrolyzed polyacrylamide (PAMH) was studied in water, The main part of the setup consists of a smooth straight pipe of Plexiglas with a length of 34 m and an inner diameter of 40.37 mm. this experience showed the highest DR of 70% obtained with 435ppm and Re No. of 10805 [21]. The influence of polyacrylamide (PAM) was studied as a drag-reducing polymer on flow of Iraqi crude oil in pipelines, five concentration of PAM (10,20,30,40,50) ppm and pipes made of carbon steel with 3 m in length and different inside diameters (0.0508, 0.0254 and 0.0191 m) was used. Maximum drag reduction was 40.64%, which was achieved with 50 ppm of PAM polymer flowing in straight pipes of 0.0508 m I.D [22]. Most of the experimental studies in laboratory and commercial scale are devoted to using polyethylene oxide and polyacrylamide because of their low cost and availability. However, many previous works showing the solution behavior is available [23]. The widely used biopolymer is Xanthan gum (XG) , the results showed that when using of XG in water flow pipe a percentage drag reduction of 35% was achieved with a concentration of 200ppm in a rotating disk apparatus[24,25]. The other biopolymer that is greatly available as a commercial drag reducer is sodium carboxy methylcellulose (CMC), maximum DR% was 22% by using 500ppm of CMC in the water and the flow system consists of a test section that is 6 m of (PVC) pipe with 46 mm inner diameter [26]. Polyisobutylene (PIB) are highly olefin hydrocarbon polymers, consist of long, straight chain macromolecules including only chain- end olefin bonds. This molecular structure leads to be inert with higher chemical subsidence and opposition to chemical or oxidative attack, and it has high solubility in organic solvents. All grades of polyisobutylene are a mixture of molecules of

varies sizes [27]. PIB was used in pipelines as drag reducing agent with different types of solvents such as crude oil, the result showed that maximum drag reduction was 40% with a concentration of 30ppm, 45%DR% at 18ppm, and 22.23% DR% with 50ppm respectively [28-30]. Kerosene was used also as a solvent, it represents that maximum DR is about 9% with 50 ppm [31].

II Fibers

The drag reduction in turbulent tube flow by the addition of fibers has several practical applications. Numbers of studies have been done by Vaseleskiet al. [32] and Lee et al. [33]. They studied turbulent drag reduction in a homogeneous mixture of polymeric solution and fibers. Their results indicated a maximum drag reduction of 95%. They further observed that the polymer possesses the ability to augment the drag reduction when mixed with fiber suspension, although no reduction of the drag is achieved with polymer alone. The addition of fibers to a degraded polymer solution leads to increase the percentage drag reduction more than use degraded polymer alone. Lin et al. [34] Investigated the effect of distribution of fiber suspension in Newtonian fluids. They proved the ability of suspended fibers to suppress the turbulence. The flow rate is considerably increased at the same pressure drop due to the relatively lower turbulent intensity with fiber suspension. In addition to the coconut, fiber shown in Figure 1 develops the DR% of the following suspensions. PVC pipe was used with three divers internal diameter (0.0127, 0.0254 and 0.0381 m) and the pressure drop is taken at four divers points of 0.5, 1.0, 1.5 and 2.0 m long. DR% was exhibited to rise by rising the additive concentration reaching ultimate amount at 55.58% with concentration up to 250 ppm of fiber in water [6].

Hayder et al. [35] showed paddy husk fiber, which also reduced the drag in pipes by up to 32%. Paul et al. [36] used Micro fibrillated cellulose (MFC) in water with of cylindrical PVC pipe , tow pipe inner diameters 45mm and 57mm, and long 3m flow rates ranging from 300 – 1000 l/min and MFC concentration between 0.02 – 0.2% . The turbulent drag reduction was found to increase in both pipes with flow rate and with MFC concentration up to a maximum at 0.15% concentration by mass, after which it was found to decrease. A maximum drag reduction of approximately 9% was observed in each pipe, but, in the 57mm, the flow of 0.02% MFC suspension was found to increase the turbulent drag at lower flow rates. Takuya et al. [37] also revealed that Bamboo fiber suspensions with

average length of 1.19 mm and average diameter of 13.3 μ m, The measurement part of pressure drop were made from acrylic pipe with inner diameter of 5, 10, and 15 mm and other pipes were made of stainless steel reduced drag by up to 20%. Warashina and Ogata [38] shown that the drag-reduction effect appeared to be due to the formation of networks of tangled fibers of nata de coco, nata de coco fiber minimized drag by up to 25%. when the concentration is 50 ppm in water flow tube. Amir et al. [39] used polyacrylonitrile fibers of larger lengths (6 mm) demonstrated minor and a rectangular pipe with 6m length are used, drag-reducing effects (up to 3%). Ahmed et al. [40] used Kenaf core pulp fiber DR increases to about 5.09% at concentration 0.6%.wt. Gharehkhani, Samira et al. [41] added a small amount of fiber to water , the maximum drag reduction of 24% occurred at 0.6 wt.% concentration and pipe diameter of 40 mm. Wulandari et al. [42] applied coconut fiber suspension in water with circular pipe ID 38 mm, mm, it can be concluded that the coconut fiber suspensions have an effect on the drag reduction about 7.6% with concentrations 1000 ppm.

III. Surfactants

Surfactants are unit compounds that reduce the physical phenomenon of a fluid, the interfacial surface tension between two liquids, or that between a liquid and a solid. Surfactants might work as detergents, wetting agents, emulsifiers, foaming agents, and dispersants. The drag-reduction mechanism by surfactant additives is still not fully understood, but it is mostly approved that drag reduction is related to network structures named micelles, in the surfactant solution. These network structures appear elasticity and prohibit the formation of turbulence and thus lower frictional drag [31].



Figure 1: Coconut fiber powder [6]

Among the surfactants used for drag reduction, cationic surfactants such as, Cathy tri methyl ammonium chloride (CTAC), CH₃ (CH₂)₁₅ N (CH₃)₃Cl, and stearyl tri methyl ammonium chloride (STAC), CH₃ (CH₂)₁₇ N (CH₃)₃Cl, and sodium salicylate (NaSal) have been most widely

used as the drag-reducing additives [12]. Bewersdorff [34] had stated, that with the increasing the flow rate, the micelles start to align with the flow direction (with increasing DR finally, it becomes totally parallel to flow direction as shown in Figure 2. The disadvantage of this type of additives is that the surfactant drag-reducing additives require higher concentration (i.e. 2000 ppm) if it is compared with high molecular weight polymeric additives (about 50 ppm). This will lead to higher costs. Musaabet al. [45] studied the drag reduction efficacy of Sodium Di-octylsulfosuccinate (SDS), Sodium dodecyl benzene sulfate (SDBS), and Sodium lauryl ether sulfate (SLES) with diesel fuel in a rotating disk apparatus is investigated, the result showed that the maximum drag reduction achieved was 29.5% for Sodium lauryl ether sulfate (SLES) at 1100 RPM and 1000 ppm.

IV. Nanomaterials

By adding Nano particles, the properties of the base liquid can be tuned to the optimum grade. Generally, these particles are in a suspension generate in the fluid phase (oil, water or traditional fluid mixture) in the low volumetric fractions. Pouranfardet al. [46] studied the impact of concentration of Nano fluid on drag reduction into a horizontal pipe. They found that the drag reduction in swish pipe was decreased but in rough pipe at constant operation conditions and drag reduction share will increase with rising the Nano fluid concentration up to pure gold. The results verified that once the concentration of Nano particles was terribly tiny; there was not enough nano-SiO₂ for smoothing the tube surface. In distinction, because the Nano fluids concentration has risen, the number of Nano particles smoothing the tube surface has risen. Muhammad and Mohamad [47] showed that

Nano-size of CMC has maximum drag reduction and flow improvement as compared with normal-size CMC. It has been shown that: 44% - 48% increase in drag reduction was achieved at low flow rates, and 16% - 18% increasing in drag reduction at high flow rates. Norouzi et al. [48] used ZnO nano particles. The results indicated a reduction of 80% in drag force of the treated fabric in the optimum conditions of pre-treatment with 10% zinc nitrate (Zn(NO₃)₂) and 5% sodium hydroxide (NaOH) at 130 °C for 1 h. [49] studied the effect of Al₂O₃nanoparticles flows through the spiral pipe on drag reduction in turbulent flow conditions. The result showed that maximum DR rate is 38% with a concentration 300 ppm. Akindoyo et al. [4] used Carbon Nanotubes (CNT) with Xanthan gum (XG) as a drag reducer in water flow pipe and 50% drag reduction was achieved. Table 1 summarizes the previous studies regarding the usage of various drag reducing agents in crude oil pipes and in water as a fluid.

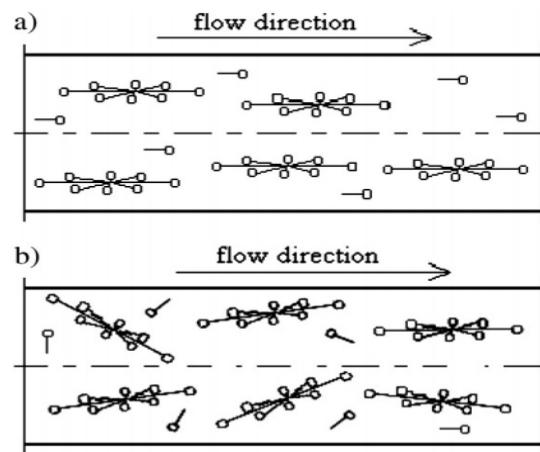


Figure 2: Drag reduction mechanism [33].

Table1: Summary of drag reduction studies

| Researchers | System | Drag reduction agent (DRA) | Results |
|-----------------------------|-----------|--|--------------------|
| Sohn et al. [24] | water | xanthan gum | 35%DR at 200ppm |
| Figueredo and Sabadini [18] | water | poly(ethylene oxide) (PEO) | 50%DR at 20ppm |
| Mowla and Naderi [29] | Crude oil | Polyalpha-olefin (Polyisobutylene) | 40%DR at 30ppm |
| Marmy et al. [6] | Water | coconut fiber | 55.58%DR at 250ppm |
| Warashina and Ogata [38] | water | nata de coco fiber | 25%DR at 50ppm |
| Akindoyo et al. [4] | water | Carbon Nanotubes (CNT) with Xanthan gum (XG) | 50%DR |
| Musaab et al. [45] | water | Sodium lauryl ether sulfate (SLES) | 29.5%DR at 1000ppm |
| Yanuar et al. (| water | Al ₂ O ₃ nanoparticles | 38%DR at 300ppm |

Conclusions

Drag reduction is considered as the most effective and most applicable method to reduce frictional losses and pressure drop inside the pipes. The technique contributes in reducing the frictional energy losses during the flow by addition of drag-reducing agents like fibers, polymers, surfactants, and Nano materials. Polymers are widely used as effective reduce drag agents, but it is exposed to degradation. Surfactants prohibit the formation of turbulence and thus lower frictional drag. Fibers are almost natural materials, so it is more suitable to be used in crude oil pipelines. Nano materials are efficient in combining with polymers, but it considered as costly material in comparison to other drag-reducing agents.

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