Chapter

Activated Flooded Jets and Immiscible Layer Technology Help to Remove and Prevent the Formation of Bottom Sediments in the Oil Storage Tanks

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Abstract

Two flooded jet methods of tank bottom sediments caving based on either screw propeller generation or nozzle jets generated with entering crude head oppose each other. The comparison is not advantageous for the first one. Exceptionally if crude oil contains some concentration of high molecular weight polymer which can perform Drag Reduction. In this case, the jet range increases by many times, thus, upgrading the capability of caving system. Preventing the sedimentation of crude oil heavy components may be put into practice with Immiscible Layer Technology. Before filling the tank with crude oil, some quantity of heavy liquid, that is immiscible with all the components of crude oil, is poured into the tank. The most suitable/fit for purpose and available liquid is glycerin. Neither paraffin and resins, nor asphaltenes can penetrate through the glycerin layer to settle down at the tank bottom because of its density, which is equal to 1.26 g/cm^3. Instead, sediments are concentrated at/on the glycerin surface and when it is heated in external heat exchanger all the sediments ought to move upwards with the convection streams. Thus, no deteriorate sediment is formed in the tank bottom.

Keywords: crude oil, storage tank, residue, sludge, sediments, crude heavy components, flooded jet, washing out, drag reducing agents, immiscible heavy liquid, glycerin, external heat exchanger, convection streams

1. Introduction

Long-term crude oil storage in the tanks, as well as transportation by tank wagons and tankers, is accompanied by agglomeration and precipitation of water, inorganic impurities, paraffin, resins and asphaltenes. Organic part of the sediment is a product of crude oxidation that occurs in the course of oil contact with air and is followed by condensation reactions. Inorganics and water are caught into oil during production and transportation. Temperature drop in the tank makes some of the heavy components of crude oil insoluble. They gravitate onto the bottom in aggregate with inorganics and water. Bottom sediment reduces effective tank volume, promotes corrosive action, complicates oil transfer and water drain out. As heavy crude fraction is growing step by step in the whole production volume, the problem of bottom sludge in the oil storage tank will enhance.

2. The bottom residue washing out technologies

Mechanical methods of sludge disposal usually include scraping and auger techniques. In complicated cases, a technological pass-through is made for a robot-machine [1]. The personnel in this case must work using supplied-air respirators. As mechanical cleaning is accompanied by a number of problems, such as pretreatment, degassing, manual labor in gas hazard conditions, oil sludge disposal, all of which making it rather expensive and time-consuming, it is only applied in the case of maintenance shutdown or tank repurposing.

Now Transneft Company makes extensive use of screw propellers, both for caving bottom deposits and prevention of their accumulations. They are fixed in a manhole of a tank first circle and make a flooded jet of oscillating direction within the sector of about 60° in a plane parallel to the tank bottom [2]. However, this method has downsides, the biggest of which is quite large energy consumption that makes the use of "Diogen" screw propeller for prevention of bottom sediments formation not feasible. Other disadvantages [3]: peripheral propeller location, i.e. at the tank wall, which reduces the efficiency of the impact on the bottom area close to the opposite wall, as well as the occurrence of vibrations and increased stress in the welded joint of the inlet-distribution nozzle. In addition, in the case of high-viscosity oil, mixing can be difficult due to reduced mixing efficiency. Purely mechanical cleaning methods are complemented, if necessary, by physical and chemical methods, which allow for more comprehensive disposal of heavy oil components. Among such methods are the action of solvents, reagents and heated oil [4]; warm water containing surfactants [5], etc. As a result of this action, deposits are heated, liquefied and homogenized with subsequent separation of hydrocarbons by means of filter presses [6], centrifuges [7], and other methods. However, almost always after hydrocarbons are removed, solid residues are buried, which has an adverse impact on the environment. The cleaning procedure involves emptying and decommissioning of the tank for a period of two to seven weeks depending on the tank volume, amount of sediments and season of the year.

3. Prevention of bottom sediments' formation

As a rule, it is more beneficial to prevent the formation of sediments rather than to clean the already settled ones. For these purposes, for instance, a tank can be equipped with either jet hydraulic mixers (**Figure 1**) or a washout unit where the inlet nozzles fit with washout heads that generate flooded crude oil jets directed along the tank bottom. One of the options for washout heads is a plate lying on the tank bottom that, when being subjected to crude oil pressure, elevates, thus, forming a fan-shape jet.

Both washout systems are characterized by cost efficiency due to the use of the part of potential flow energy in the pipeline section preceding the tank inlet and quite high hydrodynamic capacity exceeding the capacity of propeller type mixers. Let us focus on washout heads system, the efficiency of which, as shown in paper [8], can be significantly enhanced without additional capital investments and which can be used not only to prevent tank bottom sediments formation but also for tank cleaning.

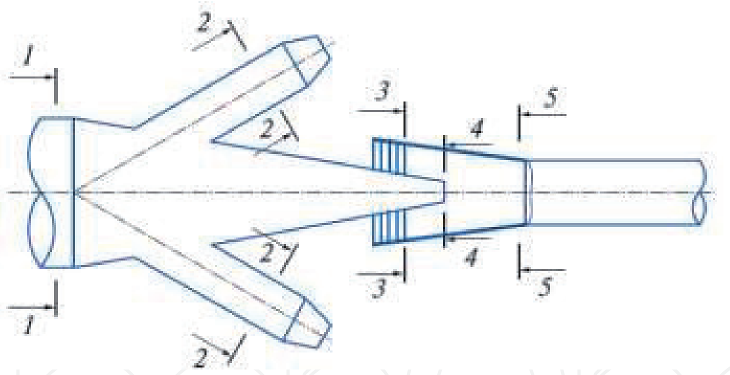

Figure 1.
Diagram of cross sections of mixer for calculations: 1 – Supply nozzle; 2 – Lateral nozzles; 3 – Confusor; 4 – Central nozzle; 5 – Inlet to the mixing chamber.

Under standard operational conditions, areas covered by washout heads should overlap. However, in the case of low oil pressure or if a head gap gets clogged, the areas of coverage of fan-shaped jets do not overlap and stagnation zones are formed where a build-up of bottom sediments occurs. In our case, for a number of reasons, sediments occupied about 20% of the useful volume of the tank. And activation of flooded jets of oil, coming out of washout heads, was attempted to be made through injection of high molecular weight oil soluble polymers into the pipeline section preceding the tank inlet [8].

It is known that polymer additives capable to reduce the hydrodynamic resistance of liquids, when introduced into the flow, significantly increase the compact part of flooded and free jets. Increase in the range of open jets is used, for example, in firefighting and water jet rock destruction. In the latter case, the aqueous polymer solutions perform similarly to sand slurries that have abrasion wear effect on perpendicular plate [9] due to polymeric associates present in the solution [10]. The size of such supermolecular features, according to the authors, is about 1 mm, and their relaxation time is about $1 \cdot 10^{-3}$-$1 \cdot 10^{-2}$ s. Associates behave like drops of ordinary fluid in deformation processes with characteristic time exceeding the aforementioned time. If the deceleration time is much shorter than their relaxation time, associates behave like solid particles. Analysis of thin sections of washout zones in metal plates treated with high-speed jets of aqueous polymer solutions indicate in favor of the impact nature of their destruction.

Something similar can occur in the flooded oil jets upon introduction of linear polymers molecules of high molecular weight into the flow: length of the compact part of a stream considerably increases, thus, the action area of a washout head increases by several times. On the other hand, in a compact part of jet, macromolecules and their associates, being guided by the flow, can form anisotropic structures of “thread” or “needle” types. Such inclusions, when encountering a perpendicular obstacle, at sharp braking may act as solid particles of an elongated shape that “dig” the sediment layer (**Figure 2**).

An additive of high-molecular octene-decenoic copolymer earlier used in experiments to increase the capacity of oil pipelines, was used as an activator for flooded jets. The copolymer solution in naphta was applied, because it takes a short time to get a mixture with oil flow. Sediments were washed out according to the scheme shown in **Figure 3** (here 1 - tank; 2 - washout heads; 3 - container with polymer solution; 4 – dosing pump; 5 - extraction pump).

Check gauging of the level of sediments made at five points - at the metering manhole, three inspection and one central manhole - showed that the average level in the first tank made 195 cm, and in the second tank - 206 cm, while the whole

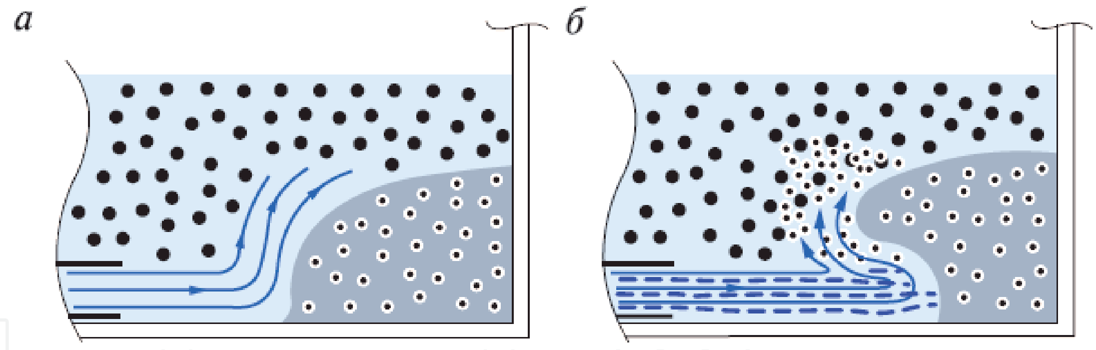

Figure 2.
Presumable picture of the flooded jet action without the polymer (a) and in the presence of the polymer (б).

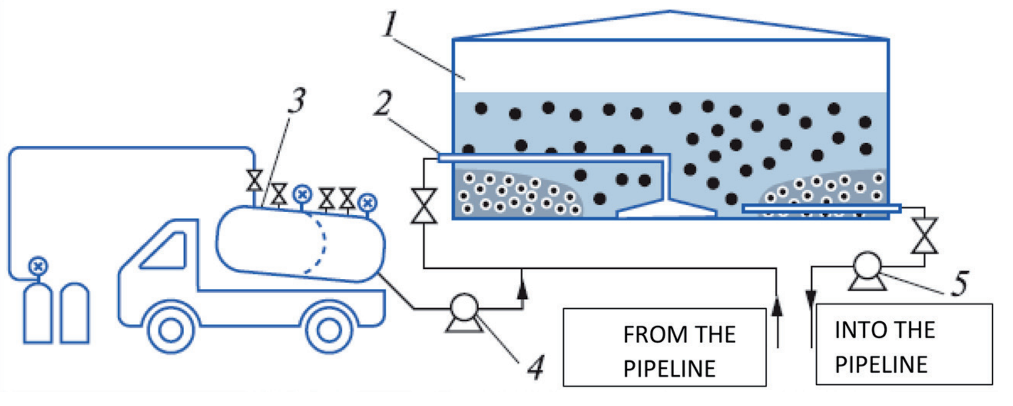

Figure 3.
Scheme of the bottom sediments washout by polymeric activators of flooded jets.

height of the tank was 1000 cm. The washout was carried out in a flow regime, i.e., when oil was simultaneously pumped into and out of the tank. The oil rate was about 2000 m^3/hour. The level of oil above the sediment level was kept within the range of 1 to 1.5 m. The control 12 hour washout with clean oil performed through the washout heads gave practically no changes either in the height of the sediment level or in the oil composition at the inlet and outlet of the tanks.

The polymer solution was dosed into the receiving pipeline at a distance of 200 m from the tank, the polymer concentration in oil was about 50 ppm (parts per million). The beginning of dosing was accompanied by the growth of water presence in oil at the outlet of the tank: at an average concentration of 0.18% at the outlet, it exceeded 2%. It gave evidence of the dispersion of bottom sediments that contained water. In 10 hours the dosing of the concentrate was stopped, but the circulation regime was maintained for another 10 hours to complete the hydraulic transport of washed out sediments outside the tank. The tank was then filled with oil and allowed its contents to settle for 24 hours. The check measurements made after that showed that the sludge level after washing out made 80 cm. About half of the concentrate had been used.

In order to reach maximum efficiency, the second half of the concentrate was used to wash out the second tank. The cycle of works was repeated in the same order. The water content at the outlet reached 2.7%. Check measurements of sediment level made after cleaning showed an average value of 69 cm. Thus, as a result of the experiment, about 4000 tons of bottom sediments were removed and mixed with oil from two 20,000 ton vertical tanks. The cleaning procedure including preparation activities took ten calendar days. The interaction of the activated flooded jet with the sediments was so intense that the external tank wall warmed up to a temperature of about 40°C within the height of sediments location. Dissipation of mechanical energy of the "reinforced" jet into the heat energy, apparently, causes autoacceleration of the washout process due to softening the object under the impact of a flooded jet.

The following advantages of the considered cleaning method should be noted:

- useful settlement components are preserved;
- no soil contamination;
- simplicity of hardware design/equipment required;
- fire safety, as there are no works performed inside the tank;
- the tank is taken out of operation for a short time: the cleaning procedure itself takes about one week;
- no personnel are exposed to harmful fumes during the cleaning process.

The method of activation of oil flooded jets can be used both for tank cleaning and prevention of bottom sediments accumulation.

4. Immiscible layer

The idea of an immiscible layer is a separate topic, as it offers a fundamentally new approach to the prevention of bottom sedimentation [11]. It is suggested to use a layer of a heavy liquid covering the bottom of the tank and preventing the settling of heavy oil and water components.

Immiscible layer fluid should meet three requirements: it should be immiscible to oil hydrocarbons; it should have a greater density than oil and its boiling point should be high enough. Polyatomic alcohols are most suitable for this role. Of these, glycerin (**Figure 4**) is the most applicable for it is available and has a density of 1.26 g/cm^3. Asphaltenes that is the heaviest component of crude oil has a density not more than 1.1 g/cm^3.

The liquid circulates through an external heat exchanger that maintains the immiscible pad temperature sufficient for thermal convection of the lower oil layers (**Figure 5**). In this case, heavy asphaltenes will not accumulate on the glycerin surface, and, due to thermal convection, will be distributed along the bulk.

The water proposed for the role of such a liquid [12] is not quite suitable due to corrosion activity and low density: heavy resins and asphaltenes with a density of about 1.1 g/cm3 will penetrate through the water layer and settle on the bottom.

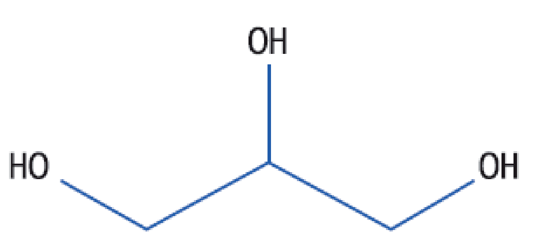

Figure 4.
Structural formula of glycerin.

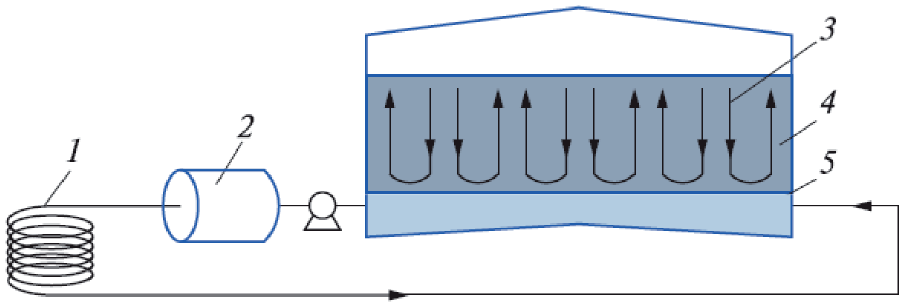

Figure 5.
Diagram of oil tank with immiscible layer.

Glycerin is not mixed with oil hydrocarbons and has a density of 1.26 g/cm3. Water and inorganic impurities enter the glycerin layer. Dissolved moisture is periodically removed from the glycerin by an external drying device (not shown in **Figure 5**). As far as mechanical impurities are concerned, they will be retained within the viscous glycerin for some time, and provided quite intense circulation, most of them will be collected at the external filter. Glycerin does not cause corrosion and its high density will protect the bottom of the tank from asphaltenes and resins settling.

The bottoms of oil tanks with the capacity of more than 5 thousand tons have, as a rule, a conical shape with a slope from the center of 1:100. The height of the immiscible layer should exceed the height of the bottom cone in the preferred case by at least 10 cm, so that the whole surface is covered with heavy immiscible layer fluid (see **Figure 5**). Based on this, the minimum glycerin volume for a 20 thousand tons tank should be 292 m^3, for a tank of 50 thousand tons - 875 m^3. The maximum volume of the hydraulic cushion is calculated from the economic feasibility: on the one hand, the formation of sediments and corrosion of the tank bottom are prevented, on the other hand, the layer volume is the "dead volume" of the tank cut off from the commodity transactions. The level of the distribution nozzle should also ensure that glycerin does not get into the pumped out oil.

All manipulations with the immiscible layer liquid can be carried out at external devices without tank shutting down from operation, and the complete set of the equipment on glycerin heating and cleaning can be used for handling of several tanks.

Glycerin is non-toxic and dissolves water together with salts. Moreover, its cost is not high, as it is a waste of biodiesel production from vegetable oils. Currently, a kilo of glycerin costs about $1 and there is a downward trend in the cost.

This method of preventing the formation of bottom sediments can multiply the period between tank cleanups and the lifetime of the tanks. Accordingly, losses of heavy oil fractions will reduce, and operation of the tank farm will be more efficient and environmentally safe.

5. Conclusion

Bringing into development of bituminous oil fields leads to "weighting" of oil pumped through the main oil pipelines. High viscosity oil has an even greater tendency to form sediments during storage. The use of heated tanks partially solves the problem, but is associated with high energy consumption. Forced circulation screw devices can be ineffective in a highly viscous medium. In this regard, the research described in the article may be useful for solving the problems that arise.

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