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Study of Modern Methods of Removing Deposits Formed in Oil Equipment and Pipes

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Abstract: In the research study, the causes of asphaltene-resin-paraffin deposits, which are very difficult to solve, are analyzed in the field of petrochemicals, the damage they cause and, most importantly, the ways to deal with them. These deposits can be found in formation rocks, transport pipes, and wells both inside and outside of them. These deposits eventually cause problems with oil production and lower productivity. Submarine pipes carry the oil from Azerbaijan's offshore oilfield to a highly advanced station for collection, processing, and transportation. Once it has gone through the first mechanical, water mixing, and demulsification processes, it is pushed to terminals situated near the coast. During pipeline transit, indicators of oil quality may change and deteriorate. This is typically caused by belt contamination. One of the most modern methods, "Pigging operation", was extensively researched, calculation of Differential pressure, Back pressure, PIG speed excursion, and various mathematical modeling methods of this process were considered (mainly Gas flow model, Liquid flow model). As a result, the most appropriate model was proposed.

Key words: ARPD; pigging process; precipitation; wax; modeling.

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Introduction

It is well known from global experience that pipelines used in the collection and transportation of oil mixtures for oil and gas extraction commonly experience blockages and macroscopic solid phase deposition. These deposits may be found in transport pipes, within or outside of wells, as well as in formation rocks. Over time, these deposits result in issues with oil production and decreased productivity [Кел22, Man21, Shi21].

It's well known that the physic-chemical and rheological characteristics of the oils produced in Azerbaijan range greatly. The oil extracted from Azerbaijan's offshore oilfield is transferred to a sophisticated collection, preparation, and transportation station via undersea pipes. It is pushed to terminals located along the coast after undergoing the first mechanical, water mixing, and demulsification procedures. Indicators of oil quality may fluctuate and degrade during pipeline transit. The usual cause of this is belt contamination [Pal16].

One component of crude oil called asphaltene has been known to cause serious issues both during production and during the transportation of the oil from a reservoir. One of the most intricate parts of the oil is this solid component, which has a variety of molecular makeup and shapes. The reservoir will go through multiple stages for asphaltene, starting with its stability phase and ending with its deposition in the pores, wellbore, and facilities.

Asphaltene deposition is the process whereby asphaltene aggregates are attached to the surface. Depending on the interaction between the surface and asphaltenes, they may adsorb on the surface [Kel23, Far05].

Changes in the chemical composition, temperature, and pressure of crude oil can lead to the deposition of asphaltene. The deposition of asphaltene is also influenced by electrical and other variables.

By causing the dispersion of asphaltic material to flocculate, the use of hydrochloric acid for well stimulation can also harm the formation.

The producing well's downhole tube yielded deposited organic material that included wax, resin, and asphaltene. High molecular weight paraffins found in most crude oils have the potential to solidify into a wax phase at low temperatures. Unlike the creation of asphaltenes, wax is primarily formed by temperature drops. Wax thus frequently gathering in one area of production well more than others. However, it was discovered from the gathered material that asphaltene precipitation can also be caused by wax production. Wax precipitation has the potential to clog transfer pipes and produce wells. In places where oil is produced, this issue is far more severe [Vin06, Man21b, Bar00].

The problem's solution depends on the ability to predict wax formation, which is necessary for petroleum refining process design. forecasting the generation of wax in crude oil using thermodynamic modeling is less complex than forecasting the precipitation of asphaltene.

The chemical components of wax and the process by which it forms are well understood. The process of wax production is reversible. The wax phase will melt and dissolve into the oil as long as the temperature rises to its initial level. One can use thermodynamic phase equilibrium criteria to forecast the development of wax. The wax process presents the sole challenge [Man21b].

In this study, both the causes of the formation of asphalt-resin-paraffin deposits and ways to combat them are analyzed. At the same time, the authors considered their works [Рза24, Ras25].

1. EXPERIMENTAL PART

1.1. Asphaltene precipitation models

Prediction and modeling of asphaltene precipitation is based on either solubility theory or colloidal theory [Bar00, DeK07, Bog78].

1. Solubility approach.
   - 1.1. Regular Solution Theory.
   - 1.2. Flory-Huggins Theory.
   - 1.3. Scott–Magat Theory.
   - 1.4. Equation of State (EoS) Models.
     - 1.4.1. Cubic Equation of State.
     - 1.4.2. Statistical Association Fluid Theory (SAFT).
     - 1.4.3. Cubic-Plus-Association Equation of State.
2. Colloidal approach.

The most widely used EoS model for asphaltene prediction is the Statistical Associated Fluid Theory (SAFT). SAFT was developed by Chapman et al. by extending Wertheim's thermodynamic perturbation theory to mixtures. In the form of residual Helmholtz Free Energy (A^{res}), the SAFT EoS is defined. Three terms make up the residual free energy: $A^{segment}$, $A^{chain\ formation}$, $A^{association}$ [Bar00, DeK07, Bog78]:

$$A^{res} = A^{segment} + A^{chain\ formation} + A^{association}.$$

Using chain molecules as an example, Gross and Sadowski applied the perturbation theory to generate an expression for the segment term. Since the reference fluid in the model proposed by Gross and Sadowski was composed of chain molecules rather than spherical molecules, it was given the term Perturbed Chain-SAFT (PC-SAFT). The PC-SAFT EoS requires three parameters as input [DeK07]:

- segment number (m);
- segment diameter (σ);
- segment energy parameter (ε/k).

The presence of paraffin hydrocarbons in crude oil is one of the primary factors impacting processing facilities and tanks during the pipeline transportation of oil.

Waxy crude oils (WCOs) are mineral oils with high molecular weight paraffinic components (from C17on) that have the potential to separate into a wax phase below a temperature known as the "Cloud Point," (denoted by T_{cloud}) which can lead to a number of serious issues when transported via pipelines.

Without a doubt one of the most important is the development of a solid deposit (wax deposit) on pipeline walls. This phenomenon is important to the oil business because it might cause a line to become entirely or partially clogged, which would lower or cease production [Sha05].

1.2. Removing methods

During the transportation of oil, deposits of both organic and inorganic materials can be built up in pipes and equipment, which can seriously compromise flow assurance. These deposits can result in a number of flow issues, including decreased flow rates, higher pressure dips, and even total pipeline blockage, which can be extremely costly and dangerous. Therefore, in order to guarantee seamless and continuous oil transportation, efficient and effective procedures for eliminating these deposits are essential. Paraffin accumulation is one of the most prevalent types of deposition and can happen in conjunction with asphaltenes and resins [Roh95, Lot10, Kel23b, Kel17].

In offshore facilities, the production system entails the flow of oil from the reservoir to the well, via the undersea flowlines, and finally to the oil platform. The oil is transferred to the refinery for additional processing once it has been prepared and processed. The oil's temperature fluctuates several times during this operation. For example, the temperature of the oil might drop dramatically as it approaches the bottom, possibly to 4 °C or below, as consequence is observed a decreasing in paraffins solubility, leading to the precipitation of paraffin deposits and potentially causing blockages in the pipes [Lot10].

An essential step in petroleum products, such as crude oil and refined goods like diesel and jet fuel, is wax crystallization. This process takes place when the petroleum product's temperature falls below a particular threshold, which prompts the product's waxy molecules to begin crystallizing. The cloud temperature, sometimes referred to as the wax appearance temperature (WAT), is the temperature at which this process starts [Sou20]. The waxy molecules in oil start to crystallize when the temperature of the petroleum product in a pipeline falls below the temperature at which wax appears. These crystals may develop and stick to the pipeline's surfaces in the event of additional temperature dips, resulting in deposition. The bulk of the flow or the tube walls may experience this deposition.

Shear dispersion, gravity sedimentation, Brownian diffusion, and molecular diffusion are some of the potential processes underlying paraffin deposition [The18]. A solid deposit forms on the pipeline surface as a result of paraffin molecules diffusing from a high concentration area to a low concentration area. This process is known as molecular diffusion. There have been various techniques studied to control paraffinic deposits in pipelines. These treatments can be broadly categorized into five types: mechanical, thermal, bacterial, chemical, and coating [Sun19, Yaa13, Rot12, Wan08, Xia12]. Mechanical treatments are one of the most used and oldest method of removing paraffinic deposits, especially in the early stages of deposition.

Involves physical methods such as pigging, scraping, or jetting to remove the deposits from the pipeline. WAT indicates that temperature significantly affects deposition. Thermal techniques can be used to stop and lessen deposition. The application of thermal insulation, which is less expensive than heating the pipeline, is one economical technique to stop deposition. It is possible to employ a variety of thermal procedures, such as electric pipe heating and the injection of steam, hot oil, and hot water.

Biological treatments, that involve the use of microorganisms, have also been proposed for removing paraffinic deposits [Kel23]. However, still application limitations are observed [Kel23, The18, Wan08, Xia12].

Another technique for getting rid of paraffinic deposits in pipes is the chemical procedure. Chemicals that dissolve or scatter paraffin molecules are used in this procedure to facilitate their removal or pipeline passage.

Solvents are a frequent chemical used for this purpose since they may dissolve paraffin deposits and restore the flow capacity of the pipeline. It is possible to utilize a variety of solvents, such as oxygenated, aliphatic, and aromatic solvents. However, the makeup of the paraffinic deposits and the operational circumstances of the pipeline may affect how effective solvents are. Even though they are widely used in industry with high efficiency, the use of solvents poses several risks and challenges. One major concern is the potential harm to the environment. Most solvents used in paraffin removal are toxic and can have adverse effects on the surrounding ecosystem.

1.3. Pigging operation

Pigging, as used in pipeline transportation, is the process of carrying out different maintenance tasks utilizing pipeline inspection gauges or devices, sometimes known as scrapers or pigs. This is accomplished without halting the product's pipeline flow.

These operations include but are not limited to cleaning and inspecting the pipeline. This is accomplished by inserting the pig into a "pig launcher" (or "launching station") – an oversized section in the pipeline, reducing to the normal diameter. The launching station is then closed and the pressure-driven flow of the product in the pipeline is used to push the pig along the pipe until it reaches the receiving trap – the "pig catcher" (or "receiving station") [The18] (Fig. 1).

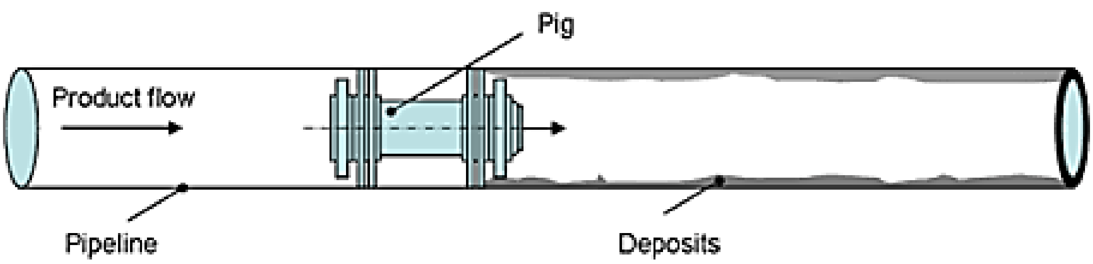

Fig. 1 The scheme of pipeline pigging [The18]

In the oil sector, pigging is used to clean big diameter pipes. However, as plant operators look for ways to save costs and boost efficiency, fewer continuous and batch process facilities are using pigging systems with lower diameters [Sun19].

Pigging can be applied to nearly any part of the transfer process, such as blending, filling, or storing systems. Pigging systems are used in businesses that deal with a wide range of goods, including paints, lubricants, chemicals, food products, cosmetics, and toiletries.

Pigs are employed in paint or lubricant mixing to empty pipes into product tanks and clean pipes to prevent cross-contamination (or sometimes to transfer a component back to its tank). Pigging is often done at the start and finish of each batch, although occasionally it is done in the middle, for example, when making a premix that will be used as an intermediary component [The18, Sun19, Yaa13, Rot12, Wan08, Xia12, Kel23c, Fin18, Duf16].

Pigs are also utilized in the gas and oil industries for pipeline clearing or cleaning. Pipelines are inspected by intelligent or "smart pigs" to determine their status and to stop leaks, which can be dangerous or bad for the environment. They often don't stop production, however when the pig is taken out, some produce may be lost. They can also be used to clear liquid slugs from multiphase gas/liquid pipelines and separate various products in a multiproduct pipeline [Fin18].

The pipeline must be built with pigging in mind from the beginning. The pipeline cannot be conventionally pigged if it has topological modifications, such as diameter alterations, butterfly valves, instrumentation, tight bends, pumps, or decreased port ball valves. Alternatives like Ice Pigging may be used in these situations. Full port (also known as full bore) ball valves function flawlessly because the ball opening's inner diameter matches the pipe's [Kel23c].

Intelligent pigging is a method for examining the inside of oil and gas pipelines while they remain in operation. A smart device, known as a pig, moves through the pipeline to gather information on issues like corrosion, cracks, and the thickness of the pipe walls. This approach enhances safety, prevents leaks, and increases the overall efficiency of pipeline systems [Kel23c] (Fig. 2).

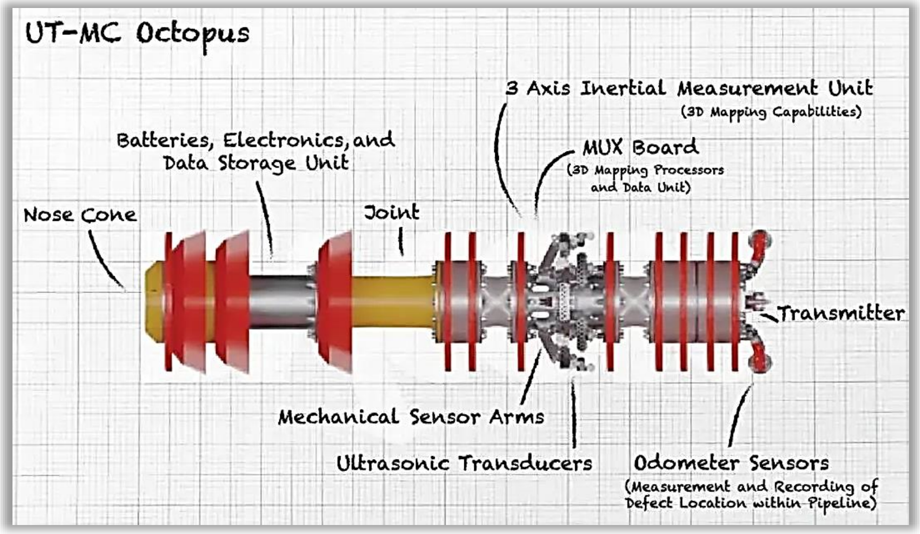

Fig. 2 Intelligent Pigging PIG Components [Kel23c]

Pigs function similarly to a pipe-cleaning squeegee, but instead of being pushed through the pipe on a wire, the projectile and product are pushed through the pipework using pressured air, nitrogen, or water. The product can be forced out at the end of the line or, if necessary, returned to the holding tank.

The projectile design is specified by processing engineers using:

- product viscosity;
- system line size.

Pigging is performed throughout the lifecycle of a pipeline from pre-commissioning all the way through to decommissioning. The most common uses of pigging are routine cleaning, maintenance, and inspection of the asset's internal characteristics. Launchers and receivers are installed at the beginning and at the end of the pigging section allowing for the insertion and removal of the pig. Differential pressure is used to propel the pig through the pipeline.

1.4. Pig Propulsion

Differential Pressure (DP): Differential pressure represents the difference in pressure between two points. In pigging differential pressure is used to show the difference in pressure in the pipeline in front of and behind the PIG:

Pressure at the Rear of the PIG bar(g) – Back Pressure bar(g) = Differential Pressure (dP),

7 bar(g) – 5 bar(g) = 2 bar(g) dP.

Back Pressure (BP): Back pressure, also known as backpressure, is the resistance in a pipe that acts in the opposite direction of the flow. Back pressure in pigging refers to the force or pressure in a pipeline that is acting against the PIG. The pressure behind the pig, which is employed to force it through the pipeline, is sometimes mistaken for back pressure.

PIG Speed Excursion: In pigging, a "peed excursion" is when the PIG accelerates suddenly because of irregularities and variations in pipeline pressure. Speed excursion is mostly caused by gas compressibility. Gas is compressed as pipeline pressure rises until there is sufficient force to push past friction and move the tool. The pig accelerates quickly once it starts moving, but when the gas decompresses, the pressure on the pig also reduces quickly, causing the tool's speed to drop off quickly.

Probably the first researchers to present a study on pigging gas–liquid pipelines were McDonald and Baker in 1964. In their attempt to simulate the pigging phenomena, they used the assumption that a sequential steady-state approach could be applied. This resulted in several calculation mistakes because the standard steady-state two phase empirical correlations for both liquid holdup and pressure drop were employed inside each time step. Shoham and Minami [Sho96] examined the pigging operation's temporary aspects. They made predictions about the pressure drop across the liquid slug section that forms ahead of the pig, as well as the position of the pig and the liquid slug front regarding time. By assuming that the flow was steady and incompressible, Azevedo et al. [Aze01] simplified the answer. Nguyen et al. [Ngu01] presented a computer technique for calculating the dynamics of pigs flowing through natural gas pipes that makes use of the method of characteristics (MOC) and a regular rectangular grid.

2. Mathematical modeling

To simulate the pig motion in the pipe, the pipeline is divided into two sections. The upstream section is from the inlet to the pig, and the downstream section is from the pig to the outlet of the pipeline. The fluid can be either liquid or gas and it is considered to be Newtonian. Thus, the flow problem is governed by the conservation of mass, momentum and energy equations. The fluid flow equations were combined with a linear momentum equation for the pig.

2.1. Gas flow model

The mass conservation equation with an assumption of constant area can be written as:

$$\frac{\partial \rho}{\partial t} + u\frac{\partial \rho}{\partial x} + \rho\frac{\partial u}{\partial x} = 0, \tag{1}$$

where ρ, u, x and t are the density, velocity, distance and time, respectively.

The momentum conservation equation can be written as:

$$\frac{\partial \rho}{\partial x} + \rho u\frac{\partial u}{\partial x} + \rho\frac{\partial u}{\partial t} + \frac{F_f}{A} + \rho g \sin\beta = 0, \tag{2}$$

where p is the flow pressure, g is the acceleration of gravity vector, β is the angle of the centerline with the horizontal, A is the area and the friction force per unit pipe length is represented by F_f.

$$\frac{1}{\sqrt{f}} = 1.14 - 2\log\left(\frac{21.25}{\mathrm{Re}^9} + \frac{k}{d}\right), \tag{3}$$

where, k, f, d and Re are pipe wall roughness, friction factor, pipe diameter and Reynolds' number respectively. If Reynolds' number is less than 2000, the friction factor is $64/\mathrm{Re}$, between 2000 and 4000 the friction factor is 160.

The energy conservation equation can be written as:

$$\frac{\partial \rho}{\partial t} + u\frac{\partial \rho}{\partial x} + \gamma\rho\frac{\partial u}{\partial x} = \frac{qS}{A}(\gamma - 1) + \frac{F_f u}{A}(\gamma - 1) + + (\gamma - 1)u\rho g s, \tag{4}$$

where S is the perimeter of the pipe, q is the rate of heat inflow per unit area of the pipe wall, and γ is the ratio of specific heat.

2.2. Liquid flow model

For the flow of liquids, the flow is considered to be one phase and isothermal. The mass conservation equation with assumption of one-dimensional flow and a fixed area can be written as:

$$\frac{\partial \rho}{\partial t} + u\frac{\partial \rho}{\partial x} + K\frac{\partial \rho}{\partial x} = 0, \tag{5}$$

where, K is the Bulk modulus of elasticity of the fluid.

The momentum conservation equation can be written as:

$$\frac{\partial \rho}{\partial x} + \rho u \frac{\partial u}{\partial x} + \rho \frac{\partial u}{\partial t} + \frac{F_f}{A} + \rho g \sin \beta = 0. \quad (6)$$

2.3. Pig dynamics

The coupling of the pig motion with the fluid flow in the pipeline was obtained through a balance of forces acting on the pig. The force balance on the pig can be written as:

$$m_{\text{pig}} \frac{dV_{\text{pig}}}{dt} = (p_1 - p_2)A - m_{\text{pig}} g \sin \beta - F_c, \quad (7)$$

where, V_{pig}, m_{pig}, p_1 and p_2 are the pig velocity, pig mass, and the pressure on the upstream and downstream faces of the pig, respectively. The term F_c represents the axial contact force between the pig and the pipe wall which can be obtained from the shrink fit correlation given by Shigley et al. [Shi04].

$$F_c = \mu_f N = 2\pi r_{\text{pig}} L_{\text{pig}} \mu_f P_f, \quad (8)$$

where E_i and v_i are the changes in the radius of the pig, the modulus of the elasticity of the pig and the poison ratio of the pig.

Conclusion

The reasons for asphaltene-resin-paraffin deposits, which are extremely challenging to solve, are examined in the context of petrochemicals in the research study, along with the harm they cause and most important solutions. These deposits are present both inside and outside of wells, transport pipes, and formation rocks. Lower productivity and issues with oil production are eventually brought on by these deposits.

Extensive research was conducted on "Pigging operation," one of the most advanced techniques. Differential pressure, back pressure, pig speed excursion, and several mathematical modeling techniques were taken into consideration (primarily Gas flow model, Liquid flow model). Consequently, the best possible model was suggested (4), (6).

Finally, the force balance on the pig was calculated (7).

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МЕТАДАННЫЕ / METADATA

Название: Изучение современных методов удаления отложений, образующихся в нефтяном оборудовании и трубопроводах.

Аннотация: В исследовании анализируются причины образования асфальтосмолопарафиновых отложений, которые очень трудно устранить в области нефтехимии, наносимый ими ущерб и, что самое главное, способы борьбы с ними. Эти отложения можно обнаружить в породах пласта, транспортных трубах и скважинах как внутри, так и снаружи них. Эти отложения в итоге вызывают проблемы с добычей нефти и снижением производительности. Подводные трубы транспортируют нефть с морского месторождения Азербайджана на высокотехнологичную станцию сбора, переработки и транспортировки. После того, как она прошла первые механические, водные процессы смешивания и деэмульсации, она проталкивается на терминалы, расположенные вблизи побережья. Во время транзита по трубопроводу показатели качества нефти могут изменяться и ухудшаться. Обычно это вызвано загрязнением ленты. Один из самых современных методов, «операция скребка», был широко исследован, был рассмотрен расчет перепада давления, противодавления, отклонения скорости скребка и различные методы математического моделирования этого процесса (в основном модель потока газа, модель потока жидкости). В результате была предложена наиболее подходящая модель.

Ключевые слова: АСПО; процесс очистки; осаждение; вязкость; моделирование.

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