MIKOVINY SÁMUEL
DOCTORAL SCHOOL OF EARTH SCIENCES

Head of Doctoral School:
Dr. h.c.mult.Dr. Ferenc Kovács
Member of the Hungarian Academy of Sciences

PhD Theses

OPTIMIZATION OF PARAFFIN REMOVAL FROM THE ALGYO-SZAZHALOMBATTA CRUDE OIL TRANSPORTING PIPELINE

by

FARAG MOHAMED ABDUMULA
Petroleum Engineer

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Geotechnical System and Process Engineering

Research Institution:
University of Miskolc
Petroleum Engineering Department

Scientific Supervisor
Dr.Takács Gábor

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I Introduction

Crude oil is a continuous mixture of hydrocarbons components. If the temperature is decreased the heavy hydrocarbons' solubility may be sufficiently reduced to cause precipitation of these components in the form of solid wax crystals. Waxy crudes cause problems in transportation through pipelines, particularly during winter. If the oil is cooled during transportation, the wax crystals tend to deposit on the colder pipe wall. Wax deposition leading to an increase in roughness and loss of effective diameter, will increase pressure drop. If these deposits get too thick, they can reduce the capacity of the pipeline and cause problems during pigging. Wax deposition in process equipment may lead to more frequent shutdowns and operational problems. In extreme cases, wax crystals may also cause a crude oil to gel and lead to problems of restarting the pipeline.

As the phenomenon of wax deposition in crude oil pipelines is of great relevance to the petroleum industry, there has been considerable work done on both real and model oil pipeline systems in an effort to gain insight into the deposition process itself. It is generally believed that a thorough understanding of the mechanisms behind wax deposition will enable researchers to predict the growth and evolution of an incipient wax layer, allowing for the development of additives and surface treatments which will be more successful in hindering wax deposition.

II Objectives of the Thesis

The crude oil produced at Algyo Field is transported through the Algyo-Szazhalombatta pipeline to the refinery. To improve the transporting conditions, the crude is mixed with gasoline. The high paraffin contents of the crude cause heavy paraffin deposition on the pipe wall. This paraffin precipitation increases the transporting costs and finally can totally stop the transportation. In this project, deposition of wax on the wall of oil pipelines is regarded as a problem since the tube diameter is reduced. Consequently, more power is needed to force the same amount of oil through the system.

All derivations to describe the growth of paraffin deposition are related to a small ? L section of the pipeline where paraffins from the transported oil deposit on the pipe inside wall. In order to describe the growth of the deposition thickness, the measured pressure drop occurring in the given pipe section needs to be known. Based on measurements made just after the last pigging operation, the relative roughness of the paraffin layer is calculated. It is easy to see that this roughness is also valid at any other time, since the pipe inside wall can never be made completely clean and a layer of paraffin is always present in the pipe.

Using a logic similar to the one given previously, the inside diameter of the pipe section at discrete times after the pigging operations needs to be calculated from pressure drop data. The task is accomplished using the calculation model developed in this dissertation.

To describe the time variation of the paraffin layer thickness, and consequently the pipeline's inside diameter, a calculation model is developed which is based on measured pressure drops vs time. The proposed calculation of the additional pressure drop due to paraffin deposition and the economic interval for the next pigging process has to be described as well.

III Main Scientific Approaches

1. Crude Oil Measurements

1.1 Material

Two crude oil samples from both Algyo and Kiskunhalas were taken to be examined for their properties.

1.2 Thixotropy and Flow Curves

For the oils studied, the shear stress at discrete shear speeds was measured for a longer period of time. For each kind of fluid the

thixotropic checking was made, by testing both of the oils under soil temperature of 5°C and a slightly higher temperature of (20°C). Measurement results proved that oils do not exhibit thixotropic behavior. Laboratory measurement showed that both the Algyo and Kiskunhalas oils are Non-Newtonian fluids with pseudoplastic behavior.

1.3 Density

The density of the two samples was measured at two different temperatures, to be able to determine the density-temperature function of the oils which was considered to be linear.

2. Friction Factor and Pipe Roughness for a Clean Pipe

One basic problem of frictional pressure drop calculations is that the roughness of the pipe inside wall must be known. In our case the pipe inside is always covered by a paraffin layer and the steel material of the pipe is never exposed. This is due to the fact that pigging operations usually use a pig whose outside diameter is considerably smaller than the pipe ID. It follows from the nature of pigging technology that the pipe can never be completely cleaned from paraffins and a clean pipe, as used in the following, only means that the paraffin thickness is reduced to such a level which is allowed by the pigging operations.

It can now be concluded that the actual roughness of any pipeline with a paraffin inside layer never equals that of the original steel material. The actual roughness can be a function of the paraffin's behavior, the shape and surface conditions of the pig used, etc. For our purposes it is sufficient to assume that the roughness of the paraffin layer must be the same before and after pigging operations.

The determination of the relative roughness of the paraffin layer in oil pipelines is proposed as follows. If the frictional pressure drop in the given pipe section is known, then, based on the Darcy-Weisbach equation, the friction factor can be evaluated. From this the ratio k/d is found from the BNS formula used for flow of non-Newtonian flow of pseudoplasic fluids. All calculations are done with pressure drop data measured at a time following a pigging operation thus ensuring that the conditions for a “clean pipe” are met.

The derivation of the proposed calculation model is started from the Darcy Weisbach equation:

$$\Delta P_f = l \frac{v^2 l r}{2d_i^{\,2}}$$

In case of a clean pipe wall (original pipe diameter) the friction factor can be expressed from this equation. The pipe roughness can be determined from the BNS equation, used for Non-Newtonian fluids with pseudoplastic behavior

$$\frac{1}{\sqrt{l}} = -2\lg\left[\frac{10^{\frac{-b}{2}}}{N_{\mathrm{Re}\,pp}^{\frac{1}{n}}\, l^{\frac{2-n}{2n}}} + \frac{k}{3.715 d_i}\right]$$

The relative roughness of the pipe will be as expressed from the previous equation:

$$\frac{k}{D} = \left(10^{\frac{1}{-2\sqrt{l}}} - \frac{10^{\frac{-b}{2}}}{N_{\mathrm{Re}\,pp}^{\frac{1}{n}}\, l^{\frac{2-n}{2n}}}\right)3.715$$

3. Development of a Mathematical Model to Describe the Influence of Paraffin Deposition on Pipe ID

The aim of the mathematical solution is to determine the pipe internal diameter (affected by paraffin deposition on the pipe wall) for a given pipe section if the pressure drop occurring in the pipe

section is known. During the process it is assumed that the absolute roughness of the pipe does not change during the transporting, and equals that determined for the clean pipe (after pigging). The temperature of the pipe increment is considered to be constant.

The basis of the mathematical solution is the general friction drop equation:

$$\frac{\Delta p_f}{\Delta l} = l \frac{v^2 r}{2d_i^{\,2}}$$

The left hand side of the equation represents the friction gradient which is known from the measurement. The right hand side of the equation contains the internal pipe diameter (d_i). So, normally it is easy to express (d_i) from the equation. The main problem with this is that the velocity (v) and friction factor (l) are function of the internal pipe diameter (d_i) as well. To solve this problem we have to find an equation with which (v) and (l) are expressed as functions of (d_i).

The equation I derived to describe the influence of heavy deposits on the pipe wall is the following

$$d_i^{\frac{5}{2}} = \frac{1}{-2a_3\lg\left(\frac{10^{\frac{-\text{ß}}{2}}}{d_i^{\frac{n+2}{2n}}\, a_4} + \frac{k}{3.71 d_i}\right)}$$

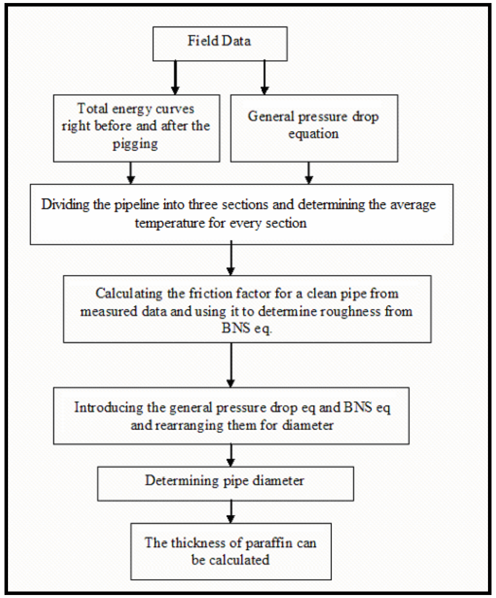
The equation derived is a non-linear function of pipe internal diameter (d_i). The solution of this equation gives the actual or affected pipe ID for a measured pressure gradient.

3.1 Determination of the Waxy ID of the Pipeline

For the determination of the waxy oil pipeline diameter I developed a calculation model, the main steps of which are given in the following:

- Calculation of the total energy curves indicating the point where paraffin starts to precipitate.
- Dividing the pipe length studied into three sections according to received measured data.
- Using the general pressure drop equation for the determination of friction factor in case of clean pipe as well as the roughness of the pipe from the BNS equation.
- Rearranging both the general pressure drop equation and the BNS for the determination of pipe diameter.

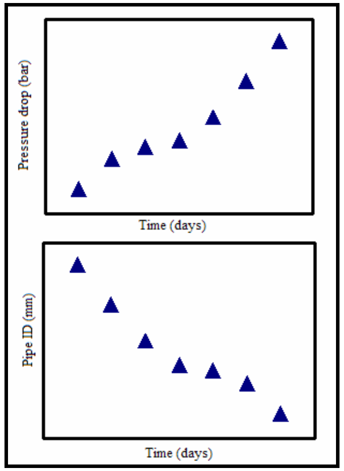
The following flow chart describes the suggested method



4. Calculating the Pipe ID-Time Function

The pressure drop in the pipeline changes with time, as time increases, the pressure increases, too. This leads to a reduction of the

internal pipe diameter as shown in the following figure. The figure schematically describes the influence of time on the pressure drop.



Influence of time on the pressure drop and pipe ID.

Since the equation derived determines the pipe diameter as influenced by paraffin deposition at a given time only, a procedure is applied here to find how the pipe diameter changes with time. By applying the previous equation for different times, (using measured pressure drops after the pigging operations), the variation of pipe diameter in time is found.

To obtain intermediate estimates and to provide a simplified version of a complicated function, the discrete points on the pipe ID vs. time figure are curve fitted. Based on my calculations, the functions best fitting of the data for pressure drop and pipe diameter have a general form as given below:

$$\Delta p = A\ \exp(b\,t)$$

$$ID = C\ \exp(d\ t)$$

5. Pressure Drop Due to Paraffin Accumulation

Deposition of paraffin entails an increased pressure drop in the pipeline. This continuously increases the power required to transport the oil through the pipe. Pressure drop increases with time and a correlation was also developed, using the best-fitting equation found there.

The pressure drop in case of a clean pipe wall (Δp_c) is calculated using the original diameter and is a constant value. But, the pressure drops for the influenced diameter (Δp_{in}) values vary with time because the pipe ID varies with time as shown in the previous section. So, pipe diameters are calculated from equation as function of time and the pressure drops belonging to these diameters are also calculated. The time dependent additional pressure drop (Δp_{add}) can be determined as shown in the following equation:

$$\Delta P_{add}(t) = \Delta P_{in}(t) - \Delta P_c$$

Values of Δp_{add} (t) are discrete values. Later, for iteration we need Δp_{add} (t) as a real function of time. Curve fitting was used to get this function. I found that a function of the following form gives good results for fitting:

$$\Delta P_{add} = E \exp(f\ t)$$

6. Calculation of the most Economic Pigging interval

For the determination of the most economic interval I had to compare the cost of pigging operations with the additional cost due to additional pressure drop. The optimum time for the pigging is when the cost of pigging is equal to the additional transporting cost due to paraffin deposition. Substituting the cost of pigging into this equation the economic time interval can be expressed. A graphical solution was used to determine the economic interval. In a time-cost coordinate system the curve calculated from work equation is plotted as well as one pigging operation cost in the horizontal line in this

coordinate system. The intersection of the two curves determines the most economic interval for the pigging operation.

IV Theses

Based on the results of my experimental and theoretical work I claim the following scientific findings:

1. My rheological measurements proved that none of the Algyo or the Kiskunhalas oils exhibit thixotropic behavior.
2. My measurements and their evaluation showed that the crudes transported in the pipeline investigated are Non-Newtonian and pseudoplastic fluids.
3. I clearly identified the influence of paraffin deposition on the operation of the pipeline from the analysis of the total energy curves calculated along the pipeline length. The influenced segment is situated between the 20 km and 78 km pipe sections.
4. I developed a calculation model for the determination of the pipeline's relative roughness at any pipe section. It is valid for the flow of pseudoplastic fluids and requires the measurement of the actual pressures along the pipeline only.
5. For the flow of pseudoplastic fluids in rough pipes I derived the appropriate formulas for the determination of the inside pipe diameter affected by paraffin deposition. The developed calculation model's input data are the measured flowing pressures vs. pipeline length. I fully justified the assumption of a constant roughness for pipeline sections influenced by the paraffin deposition.
6. I developed a correlation, based on industry measurements, to describe the time change of the pipe inside diameter affected by the deposited paraffin layer.
7. Based on a simplified economic analysis I demonstrated how the crude transporting costs increase with time due to the increased amount of paraffin accumulated on the pipe inside wall. The economic model allowed the determination of the optimum pigging interval for the pipeline investigated.

Nomenclature

?P_f	pressure drop (Pa)
l	friction factor
v	velocity of fluid (m/s)
l	pipeline length (m)
d_i	internal pipe diameter (m)
r	fluid density (kg/m^3)
ß	rheological index factor
k	pipeline roughness (m)
K	consistency index
N_{Repp}	pseudo plastic Reynolds number
?P_{add}	additional pressure drop due to paraffin deposition (Pa)
?P_{in}	pressure drop in case of influenced pipe (Pa)
?P_c	Pressure drop in case of clean pipe diameter. (Pa)
A, b	constants
ID	Internal pipe diameter (m)
C, d	constants
T	time (day)

V Publications

1) ABDUMULA, M. Farag: “Paraffin Deposition in Algyo-Szazhalombatta Transporting Crude Oil Pipeline in Hungary” 25th International Petroleum Conference and Exhibition. Hungary – Balatonfured 2002, October 10. P13
2) ABDUMULA, M. Farag: “Rheological Behaviour of Crude Oil Transported in the Algyo-Szazhalombatta Pipeline” 25th International Petroleum Conference and Exhibition. Hungary – Balatonfured 2002, October 10. P. 1.
3) ABDUMULA, M. Farag: “An Experimental Approach to Prediction of Paraffin Flocculation” PhD Students Forum. Hungary –Miskolc, 2002, November, 6. PP.1-7.

4) ABDUMULA, M. Farag: “Paraffin Formation and Inhibition” PhD Student Forum, Hungary- Miskolc, 2003, November, 6. P3.
5) ABDUMULA, M. Farag:” Influence of Paraffin Flocculation in Crude Oil Transported Pipelines with Economic View of Pigging Process”1st International Conference and Exhibition in Oil Field Chemicals. Libya-Tripoli, 2003. December.8-10. P. 28.
6) ABDUMULA, M. Farag:” Wax Precipitation in Crude Oil Transporting Pipelines”. The Micro CAD International Scientific Conference Hungary – Miskolc, 2004, March. PP. 1-6.
7) ABDUMULA, M. Farag:” Heavy Hydrocarbon Testing Methodology” The Micro CAD International Scientific Conference Hungary – Miskolc, 2004, March.PP.7-13.
8) ABDUMULA, M. Farag:” Crude Oil Pipelines Inspection” Technology of Oil and Gas Forum and Exhibition (TOG 2004), 2004, June, 28-30, Libya - Tripoli
9) ABDUMULA, M. Farag: “Treatment of crude oil pipelines by using Additives and Chemicals” Intellectual Service for Oil and Gas industry, Volume 3, Ufa-Miskolc, 2004, ISBN:5-97855-0017,.PP.136-141
10) ABDUMULA, M. Farag: “Fundamentals of Oil and Gas pipeline Pigging Technology” Intellectual Service for Oil and Gas industry, Volume 3, Ufa-Miskolc, 2004, ISBN: 5-97855-0017, PP.160-165.