Analysis Of Pressure Transverse Between Pump Stations Of Fula Pipeline Under Different Operation Scenarios

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Abstract: Different operation scenarios generate different thermal and hydraulic conditions of pipelines. The most important concept describing the hydraulic condition of any pipeline is the hydraulic gradient line which is defined as the pressure head loss for every unit of length of the pipeline. Emerging the hydraulic gradient line with the pipeline profile provides a real description of the pressure transverse between pump stations which turn in good evaluation of the transportation system (pump stations and pipeline) in term of the capability of the pump stations to transport the oil with a desired throughput. In This paper pressure transverse between pump stations of Fula pipeline at different operation scenarios has been analyzed using simulation results. The analysis has been done by using a computational model developed by the author. Thermal/hydraulic mathematical models have been employed to the computational model to take into account temperature dependency of fluid parameters.

Index Terms: Fula pipeline, friction pressure, hydraulics, transverse

Introduction

There are many methods for transporting crude oil from oil production fields to refineries or marine terminals. Compare with other transportation methods, pipelines are used most extensively because it is economical and the only feasible mean for transporting large quantity of oil or gas for long distance [1]. This superiority cannot be guaranteed unless proper design is carried on to achieve the optimum operation throughout the pipeline life. Oil and gas pipelines design and operation are normally achieved by using pipeline simulators which are developed by employing variety of mathematical models. Depending on the objective and complexity, pipeline simulators are divided into three categories: generic simulators, full scope simulators, and partial scope simulators [2]. Different mathematical models for pipelines design are available in open literature. These models are ranging from simple correlations to mechanistic models and used for different flowing media ranging from single phase to multiphase multi components fluids. For oil pipelines, the design is normally performed to simulate hydraulic conditions along the pipeline during operation. Examples of publications proposing mathematical models and calculation procedures used to simulate flow in pipelines are listed in Table (1).

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Table 1: Examples of publications discussing mathematical models of pipelines simulation

Transported medium	Objective of simulation	Publication
Oil	Temperature drop	[3]
Oil	Surge analysis	[4]
Gas condensate	Pigging simulation	[5]
Multiphase flow	Wave growth in slug flow	[6]

There were some attempts to employ selected mathematical models to design or simulate Sudanese pipelines. Mysara Eissa Mohyaldinn [7] has developed a computational code for simulation of hydraulic and thermal conditions during operation and shutdown of Higleig-PorSudan pipeline. Later on, Mysara Eissa Mohyaldinn [8] has adopted the same algorism and developed similar code for Fula oil export pipeline. Nasreldeen Sukaiman Ahmed [9] has performed hydraulic calculation and designed a proposed 185-km long pipeline from Higleig to Fula. In this paper the computational codes developed previously by the author is utilized to analyze different operation scenarios of Fula pipeline. The operation scenarios are selected based on the operation phases of the pipeline proposed in design step of the pipeline project. The simulation results indicate that the operating only initial pump station with maximum discharge pressure can generates flow rate of up to 15000 BOPD. For safe transportation of 40000 BOPD at least three pump stations are required. The 40000 BOPD can also be transported with two pump stations providing that the initial pump station is operated with maximum discharge pressure and another pump station should be located before 470 km.

Methodology

The calculations are performed using a predictive tool developed by the author. The predictive tool is user-friendly software performs the calculations in three steps as illustrated in the flow chart in Figure 1. The accuracy of the predictive tool has been discussed in Mysara [8]. In this section, the equations used in every step are discussed.

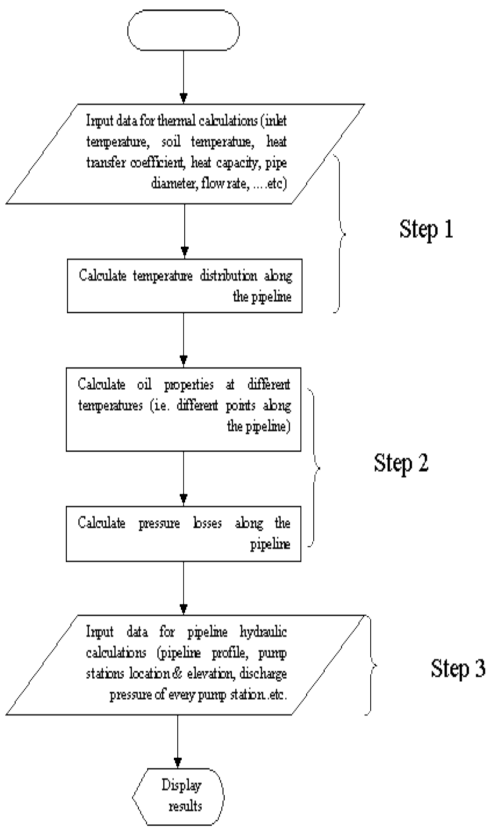

Figure 1: Calculation steps

Step 1

The total change of internal energy of oil moving through a pipeline is the sum of heat loss due to heat transfer from or to surroundings and heat gain due to shear action due flow. This can be expressed as follows:

$$\rho v \frac{de_{in}}{dx} = \frac{4}{d} q_n - \rho v g i \quad (1)$$

Where e_{in} is the internal energy per unit mas, ρ is the oil density (kg/m^3), v is the flow velocity (m/s), d is the pipeline internal diameter (m), q_n is the heat flux going through aunit area of the pipeline surface (W/m2) to or from the surroundings, g is the gravitational force m/s^2, i is the hydraulic gradient (m/m) (pressure loss per unit length of the pipeline). The values of ein and qn can be written as follows:

$$e_{in} = C_v T + const \quad (2)$$

$$q_n = -k(T - T_{ex}) \quad (3)$$

Where C_v is the heat specific in j/kg.k (assumed constant), k is the overall heat transfer coefficient in W/m2.k Substituting the internal energy and heat flux and assuming that hydraulic gradient is constant, the general equation for temperature distribution can be written as follows:

$$\rho C_v v \frac{dT}{dx} = -\frac{4k}{d}(T - T_{ex}) + \rho v g i_o \quad (4)$$

Solving the above equation considering temperature at x=0 is T_0 gives the following equation which allows calculation of temperature at any distance x

$$\frac{T_x - T_{ex} - T_\theta}{T_0 - T_{ex} - T_\theta} = \exp\left(-\frac{\pi dk}{C_v \dot{M}} x\right) \quad (5)$$

Or

$$T_x = (T_{ex} + T_\theta) + (T_0 - T_{ex} - T_\theta)\exp\left(-\frac{\pi dk}{C_v \dot{M}} x\right) \quad (6)$$

With

$$T_\theta = \frac{g i_o \dot{M}}{\pi dk} \quad (7)$$

By the end of step 1, the temperature at any distance long the pipeline (using a selected interval) is calculated. These temperature values will be used (in step 2) in conjunction with a selected empirical correlation to calculate the oil properties (viscosity and density) at the respected distance.

Step 2

There are numerous of empirical models that relating oil viscosity and oil density to the temperature. Equation (8) is used in this work to calculate oil density at any temperature using the density at 20 °C as a reference value:

$$\rho(T) = \rho(20) - (1.825 - 0.001315\rho(20))(T - 20) \quad (8)$$

Where ρ(20) is the density (kg/m^3) at 20 °C.

Although there are many published empirical equations relating oil viscosity with temperature, the practice in pipeline calculation is to develop an empirical equation for the oil under study. For crude oil exhibiting Newtonian flow, the general form of equation is as follows:

$$\log \mu = A - BT \quad (9)$$

Where A and B are constants.

Measured data has been used to develop an equation for Fula crude which is transported by Fula pipeline. The resulted equation is as follows:

$$\log \mu = 3.7776 - 0.023T \qquad (10)$$

The calculated density and viscosity are introduced to Darcy-Weisbatch formula to calculate friction loss within the pre-specified length interval.

Step 3

In this step, the operation scenario of the pipeline is selected and then the pressure transvers between pump stations is illustrated accordingly. There are five options of operation scenarios as shown in Figure 2. Clicking FULA PIPELINE tab will import Fula pipeline data (route profile and pump stations data). All results generated from step 1 and step 2 above is introduced to this step for calculation of hydraulic gradient and illustration of pressure transverse. The calculation follows the algorithm sown in Figure 3.

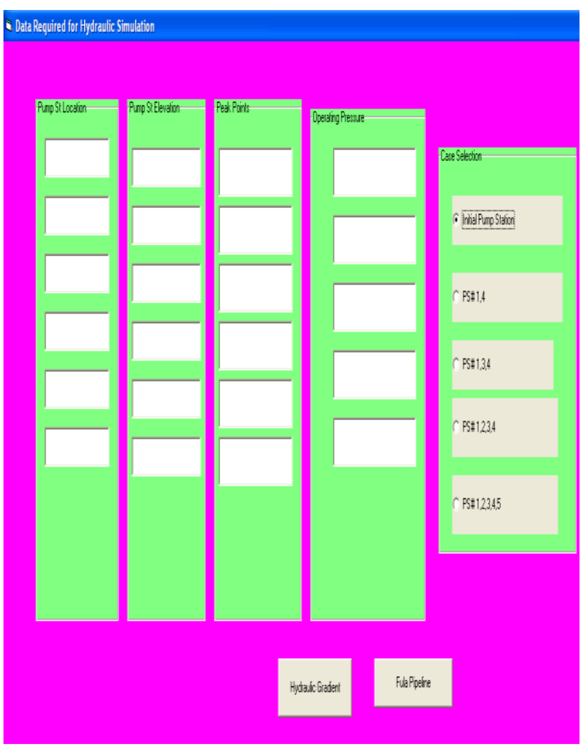

Figure 2: Input data form for hydraulics calculation and choices of operation scenarios

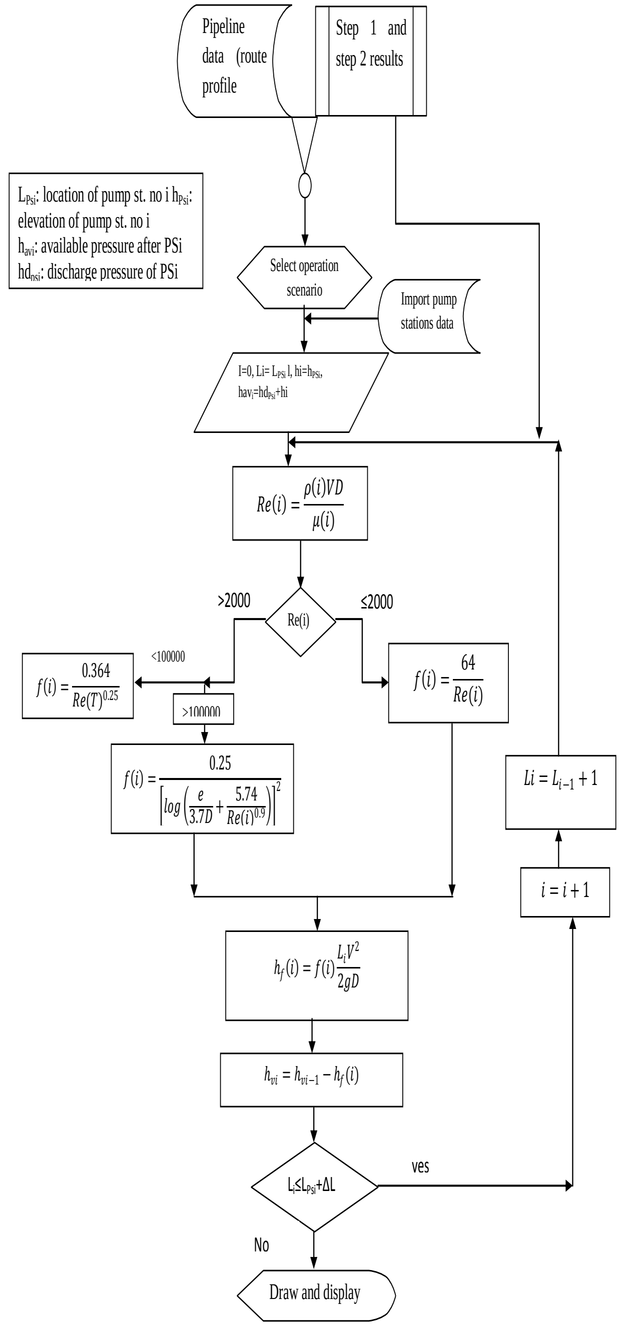

Figure 3: hydraulic calculation procedure

Results and Discussion

In this paper we will only discuss the results related to hydraulic conditions (or pressure transverse) between pump stations at different operation scenarios of Fula pipeline. Table 2 shows the input data used, which include the pipeline data and the operation scenarios' data. It is worth to mention that the actual pressure transverse during operation may looks significantly differ than the results contained hereafter. This is due to continuous changing of the rheological properties of the transported crude oil which is the main influential parameter on pressure losses due to friction.

Table 2: Input data

Parameter	Unit	Value
General parameters		
Internal diameter	mm	591
Outside diameter	mm	610
Crude oil density @ 20 °C	Kg/m^3	940
Inlet temperature	^{o}C	80
Surrounding temperature	^{o}C	29
Heat transfer coefficient	W/m^2.^{o}C	2.5
Heat capacity	j/kg.^{o}C	200
Operation scenario		
Scenario No.	Flow rate BOPD	Running pump stations (Discharge pressure kPa)
1	10000	PS01 (9200)
2	10000	PS01 (5500)
3	15000	PS01 (7000)
4	40000	PS01 (9200)
5	40000	PS01(7000), PS02(4500), PS03 (7000)
6	40000	PS01(8000), PS02(5500), PS03 (8000)

Scenario 1: one pump station, 10000 BOPD, Discharge Pressure of 9200 kPa

In this scenario it is assumed that the pipeline is operated by running only one pump station utilizing the maximum discharge pressure. The pressure transverse between PS01 and the terminal station is shown in Figure 4. The lowest line is the pipeline profile (potential pressure head) whereas the upper line is the total pressure head (potential pressure head plus the dynamic pressure head). At the pipeline inlet, the total pressure head is the sum of the elevation of the pump station plus the suction pressure of the initial pump station and pressure head exerted by the pump station. This pressure declines along the pipeline due to the effect of friction. In reality there is another pressure loss tem generated from oil passage of local piping components at pump stations and along the pipeline but this term is neglected because it is extremely low compare to the main (friction) losses. The pressure at the pipeline outlet is the pressure head remaining after the oil passes the whole pipeline. The figure shows very high remaining pressure (more than 450 m). This indicates that the discharge pressure head can be lowered less than 1200 m with still enough terminal pressure.

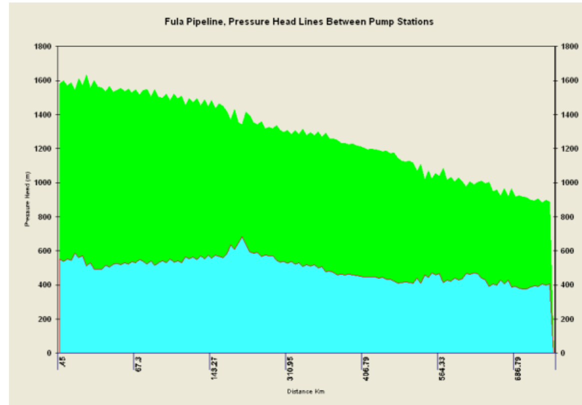

Fig 4: Fula pipeline profile and pressure transverse between initial and terminal pump stations (Discharge pressure=9200 kPa, throughput=10000 BOPD)

Scenario 2: one pump station, 10000 BOPD, Discharge Pressure of 5500 kPa

If we compare this scenario with scenario 1 we can notice that the pump station is operated with pressure highly lower than its maximum discharge pressure. The pressure head exerted by the pump station is capable of overcoming the main pressure loss with remaining pressure of more than 20 m. this scenario is recommended to achieve the pipeline flow rate of 10 kBOPD.

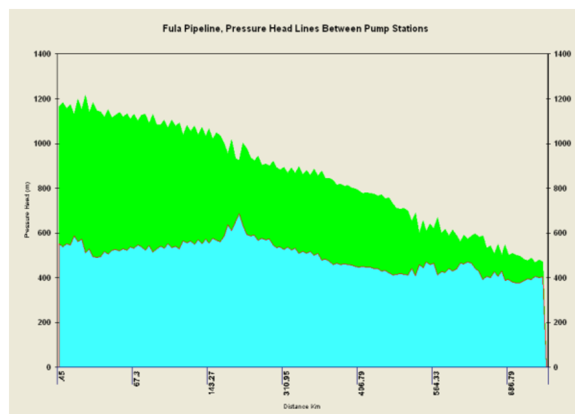

Fig 5: Fula pipeline profile and pressure transverse between initial and terminal pump stations (Discharge pressure=5500 kPa, throughput=10000 BOPD)

Scenario 3: one pump station, 15000 BOPD, Discharge Pressure of 7000 kPa

Increasing pipeline flow rate from 10000 BOPD to 15000 BOPD will increase the pressure losses due to viscous action (friction pressure loss), and hence, more discharge pressure should be available at the initial pump station. Figure 6 shows pressure transverse at discharge pressure of 7000 kPa. The pressure transverse curve indicates that with this discharge pressure the crude oil is capable of overcoming pressure losses and arrive the terminal station with remaining pressure of more than 200 m (equivalent to 1855 kPa). The initial pressure can, therefore, be reduced to 5500 kPa similar to transportation with 10000 BOPD.

This result is seemed to be illogical as it is well known that increasing flow rate will increase friction loss which turns in more initial pressure requirement. The explanation to these similar results is that increasing the flow rate will increase temperature along the pipeline which leads to lowering friction pressure. Both flow rates are fall within laminar flow regime where friction pressure is expected to be low. The increase of friction due to increase of flow rate may, therefore, be compensated with decrease of friction due to increase of temperature.

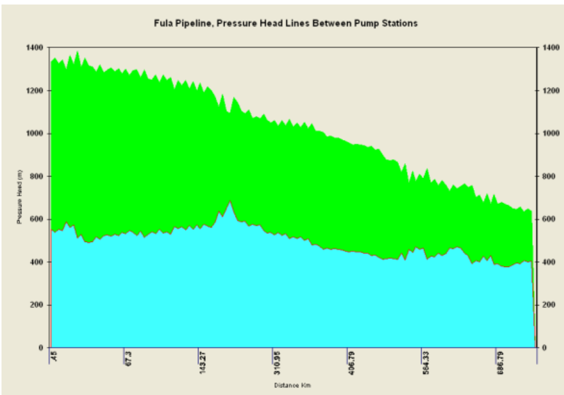

Fig 6: Fula pipeline profile and pressure transverse between initial and terminal pump stations (Discharge pressure=7000 kPa, throughput=15000 BOPD)

Scenario 4: one pump station, 40000 BOPD, Discharge Pressure of 9200 kPa

Figure 7 indicates that this scenario is unachievable. The maximum pressure from PS#01can delivers the oil to a distance less than 470 km. At least one more pump station is, therefore, required to operate.

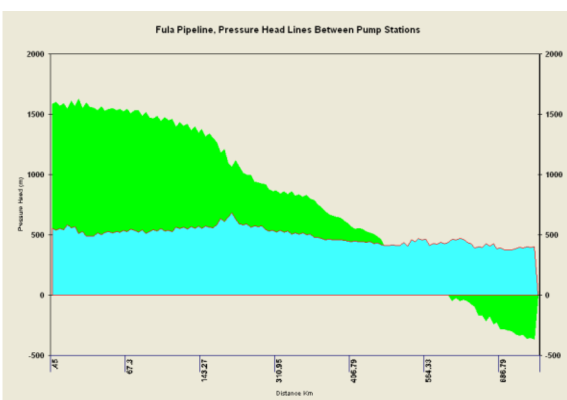

Fig 7: Fula pipeline profile and pressure transverse between initial and terminal pump stations (Discharge pressure=9200 kPa, throughput=40000 BOPD)

Scenario 5: three pump stations, 40000 BOPD

Operating three pump stations, flow rate of 40000 BOPD is achievable. At this scenario, PS#01, PS#03, and PS#04 are running whereas PS#02 and PS#05 are shutdown. The discharge pressures from PS#01, PS#03, and PS#4 are 7000, 4500, and 8000 kPa, respectively. From the curve, the suction pressures at PS#03 and PS#04 indicates that the discharge pressures can be slightly lowered. Attention, however, should be taken to guarantee that the suction pressures will not fall below the net positive section head of the pumps.

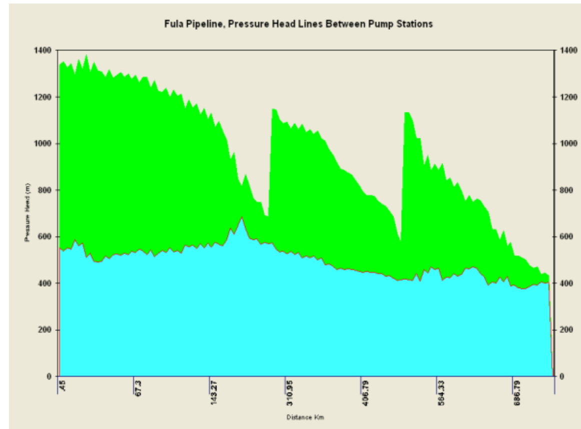

Fig 8: Fula pipeline profile and pressure transverse between pump stations (3 PS, throughput=40000 BOPD)

Scenario 6: three pump stations, 40000 BOPD

Operating three pump stations, flow rate of 40000 BOPD is achievable. At this scenario, PS#01, PS#03, and PS#04 are running whereas PS#02 and PS#05 are shutdown. The discharge pressures from PS#01, PS#03, and PS#4 are 8000, 5500, and 8000 kPa, respectively. From the curve, very high section pressure in PS#03 and PS#04 and very high terminal pressure in PS#06 is observed. The discharge pressure from pump station can, therefore, be lowered with significant amount.

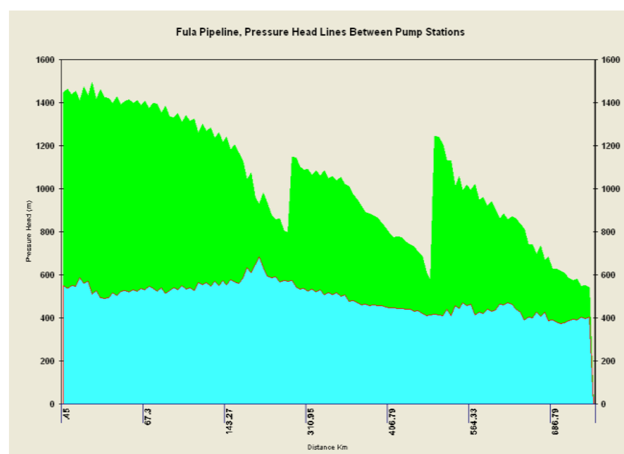

Fig 8: Fula pipeline profile and pressure transverse between pump stations (3 PS, throughput=40000 BOPD)

Conclusion

Pressure transverse between pump stations of Fula pipeline has been simulated and analyzed at different operation scenarios. The simulation results indicate that the operating only initial pump station with maximum discharge pressure can generates flow rate up to 15000 BOPD. For safe transportation of 40000 BOPD at least three pump stations are required. The 40000 BOPD can also be transported with two pump stations providing that the initial pump station is operated with its maximum discharge pressure and another pump station should be located no far than 470 km from the initial pump station. The results in this paper are valid for the rheological properties used for the calculations. Updated operational rheological properties may generate different results.

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