Contamination between petroleum products through pipeline in Diwaniya depot and pump station

By
Rafid Kadhem Abbas
MSc. Petroleum Engineering
Al-Qadisiya university

Abstract

The present study deals with contamination at the interface between oil products. Data have been collected from the Iraqi oil Pipeline Company (Diwaniyia depot and pump station). Calculations of pressure drop through each product section are done by equations of newtonian fluid flow. Different equations have been used to determine friction factor (f) according to type of flow. Reducing flow rate extremely reduces pressure drop & consequently reduces contamination between oil products through pipeline. The study concludes that the reduction in flow rate is greater in gas oil section than in kerosene section in order to reach or to be close to the pressure drop in gasoline section and that leads to minimum contamination between oil products.

الخلاصة

الدراسة المقدمة تتناول التلوث عند السطح الفاصل بين المنتجات النفطية . البيانات تم جمعها من شركة خطوط الانابيب النفطية العراقية (مستودع و محطة ضخ الديوانية).

حسابات فرق الضغط خلال كل مقطع تمت باستعمال معادلات جريان المائع النيوتوني . معادلات مختلفة تم استعمالها لتحديد معامل الاحتكاك **(f)** وفقا" الى نوع الجريان .

تخفيض معدل الجريان**(q)** سوف يقلل فرق الضغط و بالتالي تقليل التلوث بين المنتجات النفطية .

التخفيض في معدل الجريان يكون أكبر في مقطع الـ **gas oil** مما هو في مقطع الـ **kerosene** لغرض الوصول الى أكبر تقارب مع فرق الضغط عند مقطع الـ **gasoline** مما يؤدي الى الوصول الى أدنى تلوث بين المنتجات النفطية .

Introduction

Identifying the interface between two successive refined products traveling through a pipeline is important to prevent cross contamination . Cross check detects refined product pipeline interfaces using electrical resistance measurements . Observing variations in resistance as a function of time monitors changes in composition of pipeline stream . Plotting the resistance of the fluid against time detects the interface , which occurs when resistivity changes significantly[(1)] **.**

Many people not realize that more than one product can be transported through a pipeline. In fact most pipelines carry a number of different products. They are introduced at carefully –planned intervals and methodically regulated by computer , where two products meet the interface .There is a management system using densitometers and colorimeters which enables a cutting system to prevent contamination [(2)].

Girard polyurathene spheres are used for separating various products such as gasoline , crude oil , jet oil and other petroleum products transported through a pipeline[(3)]**.**

Pipeline – plus is a new technology to prevent product change in pipelines .Oil transportation using long-range pipelines requires the identification of an interface between different products with different specific gravities (e.g. gasoline and gas oil) .If the interface is not effectively detected , product can be contaminated which can directly change the quality of the delivered product and consequently produce a bad brand image . By pipeline-plus , the interface can be effectively detected on a real-time basis[(4)].

Pipeline companies ship petroleum products of the same quality in sequence through a pipeline , with each product or “batch” distinct from the preceding or following .Batching is a method for dealing with the different products and specifications moving through the pipeline[(5)].

Theoretical background

Oil products considered as Newtonian fluids such as gasoline , gas oil , …, etc except tar , asphalt and heavy oils considered as non-Newtonian fluids . Fluid flow through pipes may be laminar or turbulent , where through laminar i.e.;(viscous flow)liquids moves in parallel or laminar layers , which is always parallel to flow direction , but in turbulent flow the irregularities and eddys imposes on the pattern of the main flow.

The design of piping and pumping systems for many industries requires knowledge of the pressure drop due to flow in straight pipe segments and through valves[(6)].

Pressure drop of fluid flow through pipes will be determined according to the type of flow. Using a dimensionless quantity named Reynold's number type of flow could be determined as following :

$$NR_e = \frac{\rho\, v\, d}{\mu} \qquad \text{..................................(1)}$$

and in field units :

$$NR_e = \frac{928\, \rho\, v\, d}{\mu} \qquad \text{..............................(2)}$$

where : 928 represents conversion factor , NR_e = Reynold number , d = pipe diameter (inch) , v = fluid velocity (ft/sec) ,
μ = fluid viscosity (centi poise (c.p)) , ρ = fluid density (lb/gal)
velocity could be calculated from the following equation :-

$$v = \frac{q}{2.45\ d^2} \qquad \text{.........................(3)}$$

where : q = flow rate , (gal/min)
$NR_e < 2000$ the flow is laminar.
$NR_e > 4000$ the flow is turbulent.
$2000 < NR_e < 4000$ the flow is transitional i.e ; (neither laminar or turbulent).
Now we need to get an equation for pressure drop calculation , from Fanning equation:

$$\frac{dp}{dl} = \frac{2\ f'\ \rho\ v^2}{g_c\ d}$$

where: dp/dl (pressure drop), g_c represents earth gravity, f = friction factor .
setting 4f′ = f

$$\frac{dp}{dl} = \frac{f\ \rho\ v^2}{2\ g_c\ d} \qquad \text{....................(4)}$$

By getting the benefit of Hagen –Poiseuille equation :

$$v = \frac{d^2\ g_c}{32\ \mu}\left(\frac{dp}{dl}\right), \left(\frac{dp}{dl}\right) = \frac{32\ \mu\ v}{g_c\ d^2} \qquad \text{..................(5)}$$

By using equality of equation (4) and (5) :

$$\frac{32\ \mu\ v}{g_c\ d^2} = \frac{f\ \rho\ v^2}{2\ g_c\ d}$$

$$f = \frac{64\ \mu}{\rho\ v\ d} = \frac{64}{NR_e} \qquad \text{.................(6)}$$ for laminar flow.

, while friction factor in turbulent flow could be calculated from different equations :

Smooth pipes

Friction factor for this case can be calculated by Nikuradse correlation , am empirical modification of the Von Karman equation[6] giving by :

$$\frac{1}{\sqrt{f}} = 4 \log \left(NR_e \sqrt{f} \right) - 0.4$$

An empirical equation that gives results similar to Nikuradse eqation was proposed by Drew , Koo and McAdams[6] as following :-

$$f = 0.0056 + 0.5\, NR_e^{-0.32} \qquad \text{...............(7)}$$

the above equation applied for $10^6 * 3 > NR_e > 3000$

Blasius also suggests an equation to compute friction factor for smooth pipes , but limited for 4000 < NR_e <100,000 as following[7] :

$$f = 0.316\, NR_e^{-0.25} \qquad \text{....................(8)}$$

Rough pipes

For this case friction factor related to the relative roughness (ε / d), many equations used for this case as follows :

$$\frac{1}{\sqrt{f}} = 1.74 - 2 \log \left(\frac{2\varepsilon}{d} + \frac{18.7}{NR_e + \sqrt{f}} \right) \qquad \text{...........(9)}$$

This equation was found by Colebrook and White [8] and it needs trial and error to determine the value of friction factor numerically.

Jain suggests the following equation to determine friction factor without trial and error[9] as follows :

$$\frac{1}{\sqrt{f}} = 1.14 - 2 \log \left(\frac{\varepsilon}{d} + \frac{21.25}{NR_e^{0.9}} \right) \qquad \text{.....................(10)}$$

Moody showed different values of roughness of materials for different values of pipe diameter and consequently relative roughness ε / d could be determined as shown in figure (1) , and Moody suggests the following equation to compute friction factor as follows[10] :

$$\frac{1}{\sqrt{f}} = 1.14 - 2 \log \left(\frac{\varepsilon}{d} + \frac{9.33}{NR_e \sqrt{f}} \right) \qquad \text{............(11)}$$

and now we return how to calculate pressure drop , Fanning equation i.e.; equ(4) used for this purpose [6]:

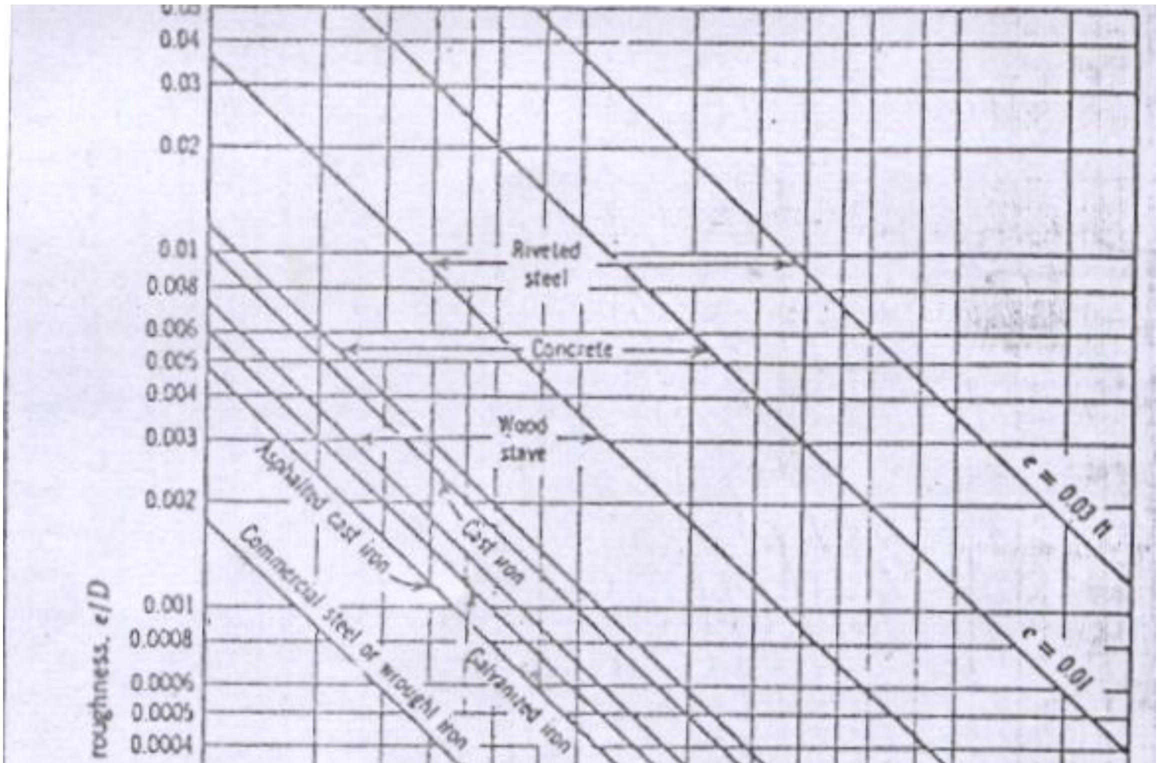
$$\Delta p = \frac{2 \rho v^2 L f}{d}$$

and in field units :

$$\Delta p = \frac{f \rho L v^2}{25.8\, d} \qquad \text{.................(12)}$$

where Δp = pressure drop (psi) , L = pipe length (ft).

Fig.(1) Values of relative roughness for pipes made of common engineering materials.



Collection of data

Data had been collected from Iraqi oil pipeline company (Diwaniyia depot and pump station). Data of viscosity was taken from the booklet of the Iraqi oil products properties .Table (1) illustrates the given data :

Table (1)

Property	Gasoline	Kerosene	Gas oil
Density	0.68 gm/c.c	0.765 gm/c.c	0.806 gm/c.c
Temperature	37˚ C	37˚ C	37˚ C
Specific gravity	0.9667 at 15.6˚C	0.7838 at 40˚C	0.8246 at 59˚C
Flash point	-----------	40	59

Flow rate = 200 m^3/hr , pipe diameter = 10 inch
Viscosity of gasoline = 0.97 centi stoke (c.st)at 10˚ C.
Viscosity of kerosene = 1.2 centi stoke (c.st)at 10˚C & less than 1 c.st at 50˚ C.
Viscosity of gas oil = 6 c.st at 37.8 ˚C and = 5 c.st at 50˚ C.

Results and discussion

The calculations have been done for each section of oil product individually and we will consider that gasoline section is the reference section , because that gasoline pumped first into the pipeline then kerosene and finally gas oil.
Calculations used equation (2), (3) and equations (7) to (12).
The data which had been obtained from the Iraqi oil pipeline company are not homogeneous to be used in the previous equations , so we must convert the given data to the units used in equations[11].

(1) Gasoline section calculations:

ρ = 0.68 gm/c.c * 8.33 lb/gal.c.c/gm = 5.6644 lb/gal .
q = 200 m^3/hr * 4.4 hr/m^3.gal/min = 880 gal/min.
μ (c.p) = μ (c.st) * ρ (gm/c.c) …………(13)
μ = 0.95 * 0.68 = 0.646 c.p , v = 880 / (2.45*$(10)^2$) = 3.592 ft/sec.
Now we compute NR_e in order to determine the type of flow :
NR_e = 928 * 5.6644 * 3.592 * 10 / 0.646 = 292284.4429
Hence , NR_e > 4000 , the type of flow is turbulent.
In this case we cannot use Blasius equation , i.e.; equ(8) , because NR_e exceeds 100,000 , so we need to use other equations for friction factor determinations .
- Using Drew et al equation i.e.; equ(7) , **f = 0.01451**.
We can consider the value of f above as an initial value of friction factor and considering that the pipe used in our case is made of commercial

steel & by using chart no.(1) for d = 10 inch , (ε / d) will equals to 0.00018 or ε for commercial steel = 0.00015 ft & hence
ε / d = 0.00015*12 / 10 = 0.00018 .

- Using Colebrook and White equation i.e.; equ(9) , and numerically we found that **f = 0.01626** and as mentioned before we used the value of f obtained from Drew equation as an initial value for all equations needs trial and error (numeric work).
- Using Moody equation i.e. ; equ(11) , and numerically **f = 0.01625**.
- Using Jain equation i.e. ; equ(10) that doesn't need trial and error obtained **f = 0.01618** . And in general we will use **f = 0.0162** as an average value for f in this section.

And finally for this section we used equ(12) for determining pressure drop and considering pipe length L is unknown :
Δp = 0.00459 L (psi) .

2-Kerosene section calculations:

The same steps of calculations had been done for this section , we tabulate the results in table (2) below :

Table (2)
Results of calculations for kerosene section

Density of kerosene ρ (lb/gal)	Viscosity μ (c.p)	Reynold no.(NR_e)
6.37245	**0.8797**	**241466.09 (turbulent flow)**
Friction factor by Blasius equation : not appliciable because NR_e > 100,000		
Friction factor by Drew et al equation : f = 0.01507 (initial value of f).		
Friction factor by Colebrook & White equation : f = 0.016658		
Friction factor by Moody equation : f = 0.01664		
Friction factor by Jain equation : f = 0.01656		
Average friction factor for this section : f= 0.0166		
Δp = 0.00529 L (psi).		

3- Gas oil section calculations:

Table (3) showed the results of calculations as shown below :

Table (3)
Results of calculations for Gas oil section

Density of gas oil ρ (lb/gal)	Viscosity μ (c.p)	Reynold no.(NR_e)
6.71398	**4.6748**	**47874.176 (turbulent flow)**
Friction factor by Blasius equation : f = 0.02136 (initial value of f).		
Friction factor by Drew et al equation : f = 0.02149 (initial value of f).		
Average initial value of friction factor : f = 0.02142		
Friction factor by Colebrook & White equation : f = 0.02177		
Friction factor by Moody equation : f = 0.02174		
Friction factor by Jain equation : f = 0.02164		
Average friction factor for this section : f= 0.0217		
Δp = 0.00728 L (psi).		

We realize that the differences in pressure drop (Δp) between the sections will produce contamination between the oil products .

Reducing flow rate:

Considering that gasoline is a reference section and other calculations related to it as following :

1. Kerosene section :

- Reducing flow rate from 880 gal/min to 800 gal/min leads to the following :

$v = 800 / (2.45*(10)^2) = 3.2653$ ft/sec , table(4) illustrates the rest calculations :

Table (4)
Effect of reducing flow rate to 800 gal/min on results of calculations for Kerosene section

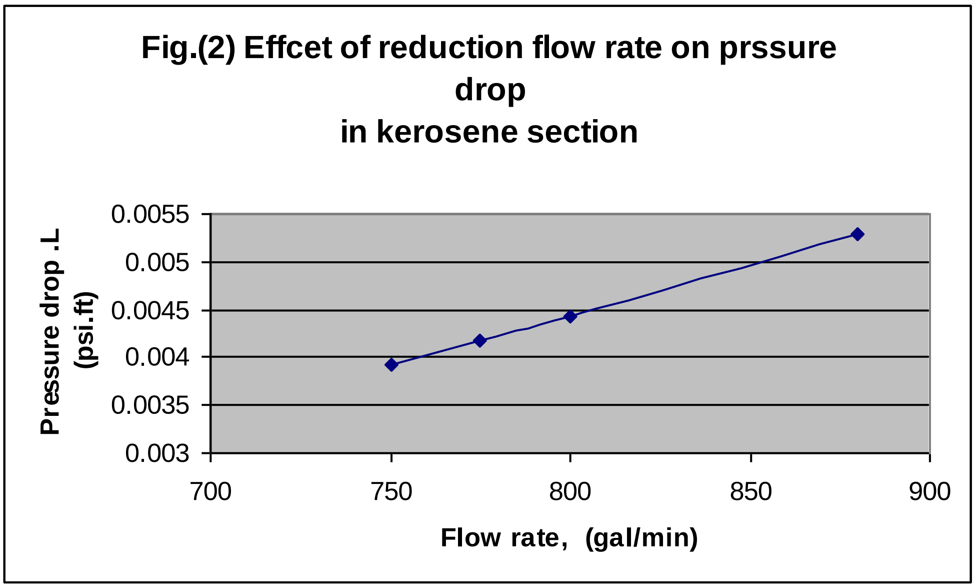
Density of kerosene ρ (lb/gal)	Viscosity μ (c.p)	Reynold no.(NR_e)
6.37245	**0.8797**	**219504.237 (turbulent flow)**
Friction factor by Blasius equation : not appliciable because NR_e > 100,000		
Friction factor by Drew et al equation : f = 0.01536 (initial value of f).		
Friction factor by Colebrook & White equation : f = 0.01686		
Friction factor by Moody equation : f = 0.01685		
Friction factor by Jain equation : f = 0.01676		
Average friction factor for this section : f= 0.01682		
Δp = 0.004429 L (psi).		

- Reducing flow rate from 880 gal/min to 775 gal/min leads to the following :
$v = 775 / (2.45*(10)^2) = 3.1632$ ft/sec , table(5) illustrates the rest calculations :

Table (5)
Effect of reducing flow rate to 775 gal/min on results of calculations for Kerosene section

Density of kerosene ρ (lb/gal)	Viscosity μ (c.p)	Reynold no.(NR_e)
6.37245	**0.8797**	**212640.738 (turbulent flow)**
Friction factor by Blasius equation : not appliciable because $NR_e > 100,000$		
Friction factor by Drew et al equation : f = 0.01546 (initial value of f).		
Friction factor by Colebrook & White equation : f = 0.016939		
Friction factor by Moody equation : f = 0.016924		
Friction factor by Jain equation : f = 0.016836		
Average friction factor for this section : f= 0.0169		
Δp = 0.004176 L (psi).		

Using the same procedure of reduction flow rate we will obtain the following: when reducing (q) to 750 gal/min the pressure drop Δp equals to 0.003934 L (psi).
We notice that reducing flow rate (q) slightly i.e ; little bit more than 800 gal/min makes the pressure drop in this section close to the pressure drop in the reference section (gasoline section) and consequently reduces contamination between gasoline and kerosene. Figure (2) shows the reduction of flow rate and it's effect on pressure drop :



2.Gas oil section :

- Reducing flow rate from 880 gal/min to 750 gal/min leads to the following results :

$v = 750 / (2.45*(10)^2) = 3.0612$ ft/sec , table(6) illustrates the rest calculations :

Table (6)
Effect of reducing flow rate to 750 gal/min on results of calculations for gas oil section

Density of gas oil ρ (lb/gal)	Viscosity μ (c.p)	Reynold no.(NR_e)
6.71398	4.6748	40799.673 (turbulent flow)
Friction factor by Blasius equation : f = 0.02223 (initial value of f).		
Friction factor by Drew et al equation : f = 0.02233 (initial value of f).		
Average initial value of friction factor : f = 0.0222		
Friction factor by Colebrook & White equation : f = 0.02249		
Friction factor by Moody equation : f = 0.02246		
Friction factor by Jain equation : f = 0.02236		
Average friction factor for this section : f= 0.02243		
Δp = 0.00546 L (psi).		

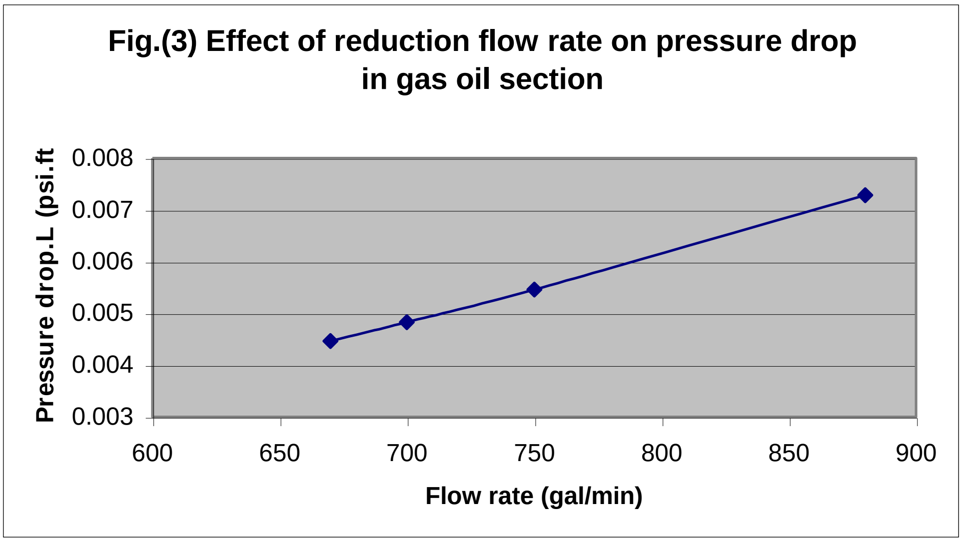
- Reducing flow rate from 880 gal/min to 700 gal/min leads to the following results :

$v = 700 / (2.45*(10)^2) = 2.8571$ ft/sec , table(7) illustrates the rest calculations :

Table (7)
Effect of reducing flow rate to 700 gal/min on results of calculations for gas oil section

Density of gas oil ρ (lb/gal)	Viscosity μ (c.p)	Reynold no.(NR_e)
6.71398	4.6748	38079.428 (turbulent flow)
Friction factor by Blasius equation : f = 0.02262 (initial value of f).		
Friction factor by Drew et al equation : f = 0.022706 (initial value of f).		
Average initial value of friction factor : f = 0.02266		
Friction factor by Colebrook & White equation : f = 0.022804		
Friction factor by Moody equation : f = 0.022778		
Friction factor by Jain equation : f = 0.0226944		
Average friction factor for this section : f= 0.02275		
Δp = 0.00483 L (psi).		

Also using the same procedure of reduction flow rate we will obtain the following: when reducing (q) to 670 gal/min the pressure drop Δp equals to 0.00446 L (psi).
We realize that reducing flow rate from 880 gal/min to about little bit more than 670 gal/min will make the pressure drop in this section close to the pressure drop in the reference section (gasoline section) and consequently reduces contamination within the oil products.
Also we realize that the reduction in flow rate in this section is greater than the reduction happened in kerosene section in order to reach the pressure drop in gasoline section .Fig.(3) shows the reduction of flow rate and it's effect on pressure drop.



Conclusions :

1- Fluid flow is turbulent for the three different products that pass through the pipe .
2- The interface section between petroleum products can be determined by the change in pressure in order to avoid contamination.
3- Calculations of flow rate reduction took under account that gasoline section is considered the reference section , because it is pumped firstly , then kerosene and finally gas oil .
4- Friction factor (f) which computed by Drew at al & Blasius equations was considered an initial value of (f) , because it doesn't took into account pipe roughness.
5- Reducing flow rate will reduce pressure drop and consequently reduces the contamination between oil products .
6- Reduction of flow rate in gas oil section is greater than what happened in kerosene section in order to reach or to be close to the pressure drop in gasoline section .

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