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Effects of temperature in an industrial bitumen mixing system approach

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Abstract

An industrial Bitumen Mixing System Philosophy was discovered to function abnormally, and an investigation was conducted to verify if the control philosophy performs as designed. Results obtained from the investigation show that the control philosophy was not working as required or designed. The result of the verification showed at the metering station that the control philosophy of expected blend ratio 88.45%:11.55% for the hard grade and soft grade respectively, now worked in a blend ratio of about 80%:20%. The result of temperature effect indicated that the present actual working temperature of the system is 160ºc, and its flow rate was about 6.63kg/sec which caused the high percentage of the soft grade during the blending process. This theoretical modelled temperature effect indicates the present viscosity of 0.039pa, velocity 0.037m/sec and pressure drop of the soft grade in the pipe. Therefore the verified result explains the reason for the irregular flow parameters of the system and the closing of the soft grade valve, during a loading operation. The investigation result reveals the reason and present set values of the flow parameters that resulted to the abnormal behaviour of the control system. Solution for this irregularity was achieved from the investigation result, which reveals on the model, the required temperature of 140ºcthat will give the desired blend ratio of flow rate 2.291kg/sec at a velocity of 0.037m/sec and viscosity of 0.11pa of soft grade. This had led to the recommendation of different solution process and measures to be taken to achieve the desired working control philosophy.

Keywords: Bitumen, temperature, pressure, velocity, viscosity and control philosophy

1. Introduction

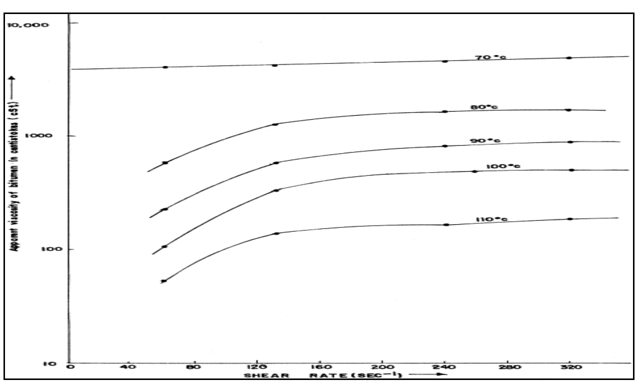
Bitumen characterised by its high viscosity, high density (low API gravity), high nitrogen, oxygen, sulphur and heavy metal concentration; has contributed immensely to the economic development and effective management of the world oil reserves. Bitumen is a residue product of the distillation of crude oil and is also surface mimed at about a depth of 250 feet through a Hot water process (Rap, 1994). In crude oil it is classified into paraffin base, bitumen base and bitumen-paraffin base and ranges to 25% to 40% crude oil composition (Sources and type, Bitumen type, 2008).

Bitumen rheological properties are essential for its uses in road and waterway projects. As a highly waterproof material, it acts as a sealant and resists acid, alkalis and water reaction. Bitumen is a very viscous liquid and the analysis of the fluid in motion is affected by factors such as velocity, viscosity temperature and pressure. These fluids are been modeled by coefficient of viscosity. Therefore Bitumen flow system is governed by the principle of laminar viscous flow incompressible flow in pipes.

The Concept of viscosity is a means of measuring the magnitude shear stress in a fluid when it is in motion [7]. Experiments has shown (NPTEL, 2007) [2] that velocity gradient and shear stress often has its largest value at the boundary to which the fluid stick and is a deciding factor in the determination of resistance to flow. Report of Ducan *et a*l, (197) described that when acceleration of the fluid caused by tangential stress is proportional to the viscosity but inversely proportional to the density, it is called Kinematic Viscosity and denoted as

$$\eta = \frac{\mu}{\rho} \quad (1)$$

Where η = kinematic viscosity
μ = viscosity
ρ = densit



Source**:** Okechukwu and Bayo, 1999.

Fig 1: Viscosity as a function of shear rate at constant Temperature

The above graph exhibits the directly proportional effect of the shear stress on bitumen in a pipe with respect to its viscosity, research conducted by Okechukwu and Bayo (1999) [4] in Nigeria. At temperatures below 70 °C, the log of apparent viscosity varies linearly with shear rate. As shown at temperatures above 70 °C, no linear relationship exists between log of apparent viscosity and shear rate. The slopes of the straight lines decreased as the shear rates and temperatures increased, as expected.

Most viscous flows are lamina in nature, unless been altered by an increase in the speed of flow. Lamina flow is simply defined as flow in which the fluid moves in layers; one layer gliding over another adjacent layer with only one molecular interchange of momentum (Victor *et al.* 1985) [7]. Lamina flow has low Re value and vice versa for turbulent flows.

The study aim is to verify that industrial Bitumen mixing system control philosophy is performing as designed. The research will give a detail description of verification analysis, and the results found, which lead to the investigation for the reasons of its present working conditions. From the observation made, there is an inappropriate mixing of the two grades simultaneously (consistently), to give the wrong blend ratio at the metering station during a loading operation. An initial research of the bitumen system and state of the art description of the temperature- viscosity-pressure effect in the bitumen flow mixing system will be done. The state of the art work done on similar systems will give us a reasonable back up to the analysis done and provide reasonable fact for solution proposal.

2. Materials and Method

2.1 Methodology

In order to identify the area of concentration, I collected the relevant data and information concerning the system from the project manager. This includes the Bitumen system design diagram, design structure and materials, material and product specification, heating system and the specified area of concentration. This data was issued to me by the project manager of the company. From the observation, I then established a region of the system as the area where the problem exist and make necessary analysis. Results of the observation and information collect during staff discussion were also used as a guide.

2.2 Assumption made for the Bitumen laminar incompressible viscous flow

The following assumptions were made for the pipe parameters:

- The flow of the fluid is moving with an average velocity of the whole fluid body, in the tube.
- The change in pressure ΔP in the tube across the length, L is constant. That is $\Delta P/L$ = constant
- Volumetric flow rate and velocity of the fluid is same everywhere in the tube.
- Constant density of fluid

2.3 Modelling the Temperature-Viscosity-Mass flow rate Relationship in the bitumen flow system.

The process simulation was modelled on an excel spread sheet to show the effect of temperature on the viscosity, which in turn affected the flow rate of the fluid. The Poiseuille equation was applied to determine the volumetric flow rate and the average velocity of flow of the fluid, for the actual temperature and the designed temperatures of the flow system. The mass flow rate was in turn calculated from the volumetric flow and the density of the soft grade in concern. Calculations will be done and the results that will be obtained will serve as the means of comparing the system actual working condition to the design working conditions. According to (Glen, 2008) [1] the Hagen–poiseuille law states that for a laminar and non-pulsatile (no pulse) fluid flow through a uniform straight pipe, the flow rate (volume per unit time) Q is

- directly proportional to the pressure difference between the ends of the tube ΔP
- inversely proportional to the length of the tube, L
- inversely proportional to the viscosity of the fluid, ŋ and
- proportional to the fourth power of the radius of the tube, r^4

Equation is given as

$$\mathbf{Q} = \frac{\pi \Delta \mathbf{P} \mathbf{r}^4}{8\eta \mathbf{L}} \quad (2)$$

2.4 Pressure Analysis

Analysis of the system pressure will be done, to determine the pressure of the flow system at the various viscosity and flow rates respectively. The pressure is determined from the pressure viscosity relationship using Barus equation

$$\eta = \eta_{ref.} \exp(\beta(P - P_{ref})) \quad (3)$$

Where

η_{ref} = viscosity at reference pressure p_{ref}

β = piezoviscous coefficient

P =applied pressure

3. Results and Discussion

3.1 Results

The results of this research wor are presented in table 1-3 and figure 1 and 2 as shown below

Table 1: Result of analysis for loading 1 at different time intervals

Time duration from t_0 (sec)	Actual mass of hard (kg)	Actual mass of soft (kg)	Actual blend ratio (%)	Designed mass of soft (kg)	Designed Blend ratio (%)	Actual soft mass flow rate (kg/sec)	Designed soft mass flow rate (kg/sec)
0, t_0	0.00	0.00	-	0.00	-	0.00	0.000
After 195, t_1	2870	746	79.37:20.63	374.82	88.45:11.55	2.00	1.922
After283, t_2	4166	1106	79.02:20.92	543.97	88.45:11.55	3.00	1.922
After 340,t_3	5741	1660	77.57:20.53	749.54	88.45:11.55	4.50	1.922
After 555,t_4	8170	2754	77.57:20.53	1066.8	88.45:11.55	2.45	1.922
After 700,t_5	10304	3169.32	76.48:23.52	1345.40	88.45:11.55	2.86	1.922
After 1647,t_f	24271	-	-	3169.32	88.45:11.55	-	1.922

Table 2: showing the Result of Analysis for loading 2 at different time intervals

Time duration from t_0(sec)	Actual or Design Mass of Hard (kg)	Actual Soft Mass (kg)	Actual Blend Ratio (%)	Proposed soft Mass(Kg)	Proposed Blend Ratio (%)	Actual Soft mass flow rate (Kg/sec)	Proposed Soft Mass flow rate (kg/sec)
0, t_0	0	0	-	0	-	0	0
After 154, t_1	1988	491	80.15:19.80	258.94	88.45:11.55	3.18	1.70
After 294, t_2	4023	938	81.33:18.96	525.30	88.45:11.55	3.35	1.78
After 364, t_3	6162	1403	81.45:18.55	804.65	88.45:11.55	2.40	2.21
After 484, t_4	8209	1853	81.58:18.42	1071.95	88.45:11.55	2.77	2.20
After 578, t_5	10526	2330	81.73:18.27	1374.50	88.45:11.55	3.23	2.30
After 1148,t_f	17691.57	-	-	2330.00	88.45:11.55	-	2.03_{avg}

Table 3: showing the model for a Bitumen soft grade (160-220) flow system parameters at different temperature.

T(°C)	μ(Pa.s)	Q(m³/sec)	ṁ(Kg/sec)	V_{avg}(m/sec)	P(bar)
130	0.200	0.001245	1.260143	0.069065	6.659
135	0.136	0.001831	1.853152	0.046964	6.496
140	0.110	0.002264	2.291169	0.037986	6.422
145	0.085	0.002930	2.965043	0.029353	6.319
150	0.065	0.003831	3.877364	0.022446	6.213
155	0.052	0.004789	4.846705	0.017957	6.125
160	0.038	0.006554	6.632333	0.013122	6.000
165	0.029	0.008588	8.690643	0.010014	5.893

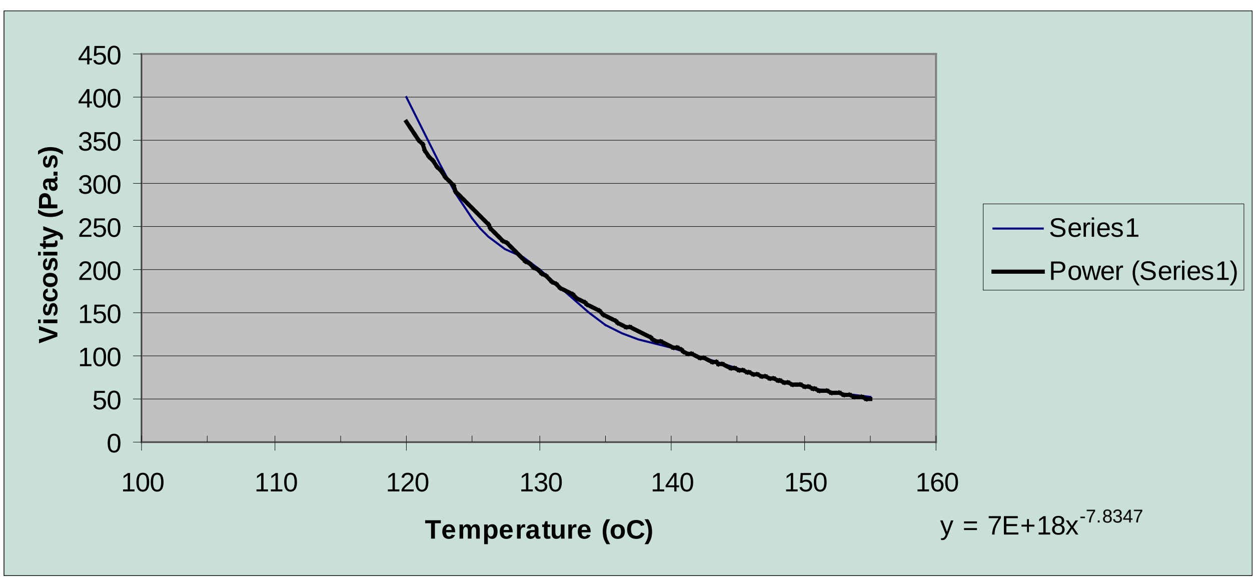


Fig 2: Graph of Viscosity vs. Temperature

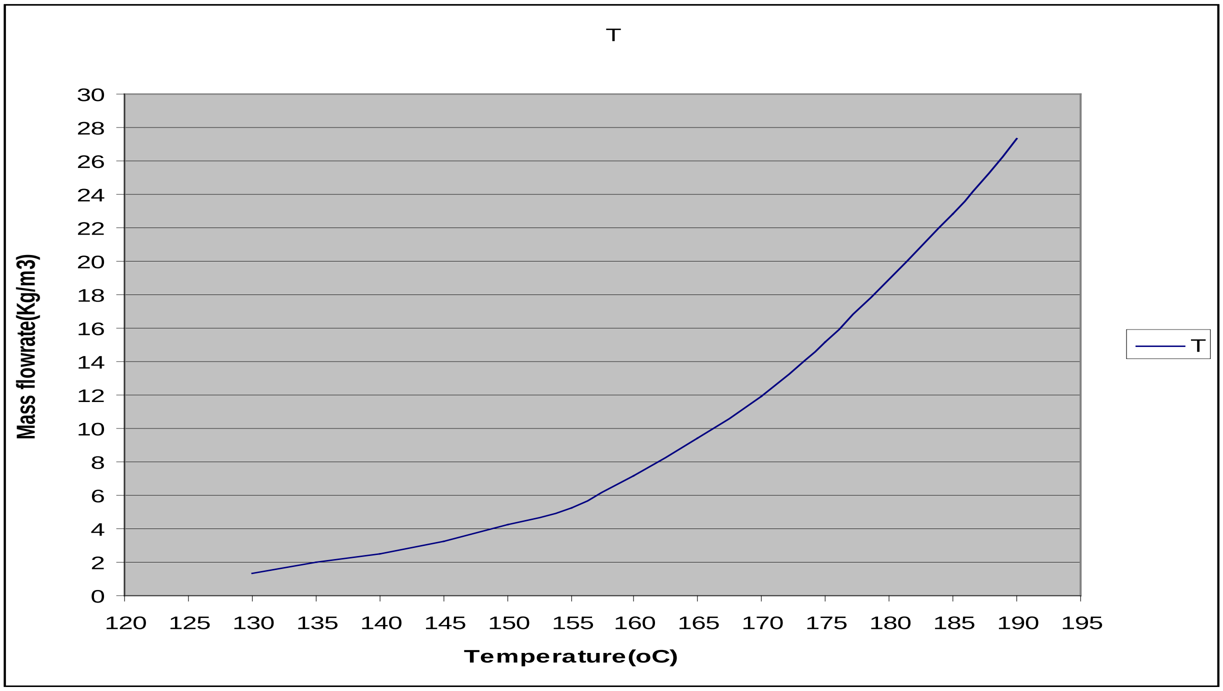


Fig 2: Graph of Mass flow rate vs. Temperature

3.2 Discussion of Results

Table 1 show that the irregular tripping off of the valve indicates that the flow rate is high. This causes the valve to close because the flow rates are above the required ratio. It shows that the valve is a ratio control valve and is not sensitive to temperature. It was also noticed that the high flow rate is experienced in the soft grade, which is at the same temperature with the hard grade. Loading one and loading two showed the Actual flow rate of the soft grade and compared it with the designed soft grade flow rate. Note that the actual hard grade is assumed equal to the designed hard grade, and is used as the basis to determine the designed soft grade flow rate. That shows that the heating medium for the two pipes are at the same temperature and from the same source, as observed in the design diagram. Further description of the system and diagrams of this are on the appendix: background.

The tripping off of the high level alarm in the tanker during some loading operations (Table 2). This can be explained due to layer loading of the bitumen system of two different grades. Knowing that the soft grade flows faster than required, it then result to an initial loading of the soft grade in the tanker which is then accompanied by the hard grade. This flow and loading of the hard grade on the already loaded soft grade, causes a rise in the density of the product in the tanker and thereby an increase in the height in the tanker which trips the alarm. Therefore, despite having the required quantity of mass in the tanker, the density is not the same due to layer loading and thereby tripping off of the alarm in use.

Result also shows that it has a design default which was not originally meant for bitumen mixing and loading. It also revealed that there are changes in the variation of the bitumen specification. This variation especially in density affects the control system settings on the flow rate. This makes the valve to have in consistent flow rate reading.

Table 3 shows the achievement of the first aim of the Analysis: verifying that the control system is working as per the design control philosophy. The mass and the mass flow rates of the hard grade and the soft grade during loading is been taken note at every time the valve closes at the respective time and the result of the verification process analysis done, show that the control system is not working as design to be. The designed philosophy for the loading of 40-60 product blend is 88.45%:11.55% blend ratio of the flow rate at the valves and the mass of the two grades in the tanker. But in contrast, it gives a blend ratio of approximately 80%:20% in average for the Actual loading operation presently.

The effect of this present blend ratio observed on the system presently is the continuous closing of the soft grade valve during loading operation. It therefore leads to inconsistent loading of the product during operation.

Also, the analysis shows the irregular, high mass flow rate of the soft grade for the Actual conditions in column seven, and that of the steady, low mass flow rate of the designed conditions in column eight. This explains the high level alarm that trips off in the tanker during loading operation due to layer loading.

Layer loading is experienced during loading operation due to the fact that the soft grade flow faster and therefore loads initially, while the hard grade then load on it afterwards. This causes the tank alarm to trip off due to expansion of the product volume due to layer loading of more dense material on top of a less dense material.

3.2.1 System Model Discussion

The model table show the working conditions and parameters during a loading operation of 40-60 blend ratio of the product. Figure 1 shows the graph of the temperature-viscosity relationship. The graph show that as the temperature of the soft grade increases, the viscosity decreases. Therefore, the flow temperature of the lesser viscous soft grade is meant to be lower than that of the hard grade, so as to obtain the desired flow rate for the designed blend ratio. This viscosity relationship is a key factor in calculating the volumetric flow rate which in turn produced the mass flow rate of the soft grade respectively.

Figure 2. 1 shows the temperature-mass flow rate relationship. The table shows the mass flow rate and temperature at which the Actual mass flow rate of the soft grade is flowing presently, that is 6m/sec and 160ºC/170ºC respectively. While the soft grade Designed mass flow rate of 2m/sec, according to the calculated value in appendix: calculation, is at about and 140ºC of Temperature.

Therefore the model explained the effect of the temperature on the mass flow rate of the soft grade and how this in turns causes the closure of the valve. The high temperature at which the mass flow rate is flowing at presently does not give the desired blend ratio of the two grades at the valves. The actual soft grade flow rate is about 6m/sec, while it is designed to flow at about 2m/sec, to give the desired blend ratio at the valve.

The temperature-mass flow rate graph in figure 2.2, shows an increase in the temperature of the soft grade which resulted to an increase of its mass flow rate.

The discussion of the entire system observation and data collected, control system verification and temperature effect on the mass flow rate for the soft grade will provide an understanding of the system and a foundation on which solutions will be recommended.

4. Conclusion

The control system is not functioning as designed and this lead to an investigation of the causes for the abnormal control system presently. The modelled results of the investigation and analysis show the set temperature effect on the flow rate of the system. It also showed the actual present working parameters of the system and the proposed designed temperature that will yield the desired flow rate for the required blending ratio for a consistent and regular working principle of the control valve. The observations also showed that most irregular readings during operation were located at the soft grade.

5. Recommendations

The solution recommended below is a as a result of the adequate observation of the system, efficient analysis plus the state of the art literature review and research of bitumen mixing system and properties. It also give insight of further work and research to be done on the system. Therefore the following are recommended solutions for the industrial Vopak Bitumen Road loading Mixing System:

- **The Temperature for the soft grade flow system should be reduced:** In order to achieve the desired blend ratio at the control valve, so as to stop the closure of the valve, the soft grade temperature should be reduced. This reduced temperature will in turn reduce the flow rate to the desired value required to achieve the blend ratio in the valve.

  Two ways of achieving this temperature reduction is reducing the heating medium flow rate on the soft grade and by reducing the temperature originally from the storage tanks.

Heating system Automation.

This is necessary because, it will maintain the bitumen system in the right temperature, by regulating the set temperature depending on weather, and adjusting the flow rate of the oil to maintain a steady state heat transfer of the system, depending on the type of loading being ordered**.** The heating system temperature should be regulated in such a way that the temperature of the hard and soft grade lines respectively will be set at different point depending on the flow rate of the each respective grades to give blend ratio ordered.

- **The control system should be linked to the pump system:** The pump is the heart of the system. Therefore control measures should be put in place to regulate the flow rate, temperature and pressure from the pumping system.

  Installation of pump control system and regulator will create different means of controlling and regulating the system parameters and working conditions from the origin and will yield higher efficiency.
- **The control system should be sensitive to temperature in order to detect effect of temperature on the flow rate reading:** The flow rate of the viscous bitumen material is directly proportional to the flow rate as shown in the result of the analysis in figure---, therefore implying that the control system should respond to changes in temperature.

  This will give the required flow rate for any ordered blend at the respective temperature
- **A pump specified for high viscous material such as bitumen be used:** Proper investigation and analysis of the require pump specification to be used for the system to give the required parameters of different blend and highest efficiency.
- **Adjustment of Pump speed and rate of discharge:** This is a means maintaining and regulating the flow rate of the system. It requires the adjustment of the speed of the pump gear system to maintain flow rate of system for maximum efficiency.
- **Regular and adequate pump inspection and maintenance should be conducted:** Pump seals, suction/discharge head and pressure, and working conditions should be maintained to increase efficiency of the Bitumen system.
- **Proper sample test on Bitumen from suppliers should be done:** Bitumen tests on the supplied bitumen should be conducted to before delivery to the mixing system, to determine the properties, and verify if it is of standard specification of the material for the system.
- **Floating high level alarm equipment should be used in the tanker:** Floating high level signal instrument

should be used on the tanker, to indicate the level of the product loaded.

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