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CHOICE OF OIL BLEND TO IMPROVE PIPELINE TRANSPORT

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Abstract

In Brazilian oil pipelines, the number of different oils transported is enormous and keeps on growing. The number of heavier crude oil is increasing worldwide, as well as in Brazil, and both the pipeline companies and the refineries are trying to adapt their system to this new reality. The standard procedure for oil pipelines is trying to transport the lightest possible oil blend, so as to increase flow and reduce operating costs. While this method works, it requires companies to buy lighter oil, what can be significantly more expensive. This paper intent to show that, depending on the pipeline and on the blend physical properties, using a heavier and more viscous blend can cause the flow to be higher or the specific energy needed to be equal or higher than a lighter blend. This phenomenon is explained using the Reynolds number and the different flow regimes. Using a hydraulic pipeline simulator, a theoretical pipeline and varying the blend transported within the pipeline, it will be shown that for higher viscosities there can be a higher flow then the original blend transported on the selected pipeline. A second theoretical pipeline will show a pipeline configuration where the desire effect does not happens. Afterward, the results can be used to change the standard procedure for oil pipeline transport that is used today.

1. Introduction

Selecting the optimal blend for oil transport through pipelines is usually about trying to transport the lightest and less viscous blend possible, while respecting the system logistics, refinery capacities and oil prices, among others. The lighter the oil, and less viscous, easier it is to transport it, and more expensive it cost. The logical thinking would be to reduce the blend's viscosity to insure a less costly transport and a richer oil to be refine. This is not necessarily true.

This paper will show, through the results of simulations and theoretical analysis, that working with some specific Reynolds numbers to change the flow type can result in interesting effects. The effects caused by the variation of the viscosity and density of a product in a system will be shown, separately. The velocity of the flow will also be influenced by these two physical properties.

$$\mathrm{Re} = \frac{\rho\left[\frac{kg}{m^3}\right] \times V\left[\frac{m}{s}\right] \times Dh[m]}{\mu[Pa]} \tag{1}$$

Equation 1 shows how the physical properties of a product directly influence on the Reynolds number of the flow, thus, on the flow regime. The Reynolds number is dimensionless, and is usually use to compare different dimensions or problems with similar design.

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Table 1. Product's Properties

Product	Density (kg/m³) @ 20°C	Viscosity (cP) @ 20°C
Albacora	882	25
Barracuda	903	80
Cherne	931	703
Marlim	930	500
Plataforma	833	23
Roncador	889	35

Table 1 illustrates the properties for different types of oil, showing that both viscosity and density varies significantly from one product to another. For the purpose of this study, a pipeline has been modeled to analyze the effect of different blends on the pipeline's flow. This hypothetical pipeline will be called VISC 30.

2. Simulation

2.1. Pipeline Description

VISC 30 is a 30 inch pipeline with a thickness range from 0.460 to 0.750. This pipeline contains: a supply station, another pumping station on kilometer 36 and a delivery station. Its elevation profile is shown on Figure 1.

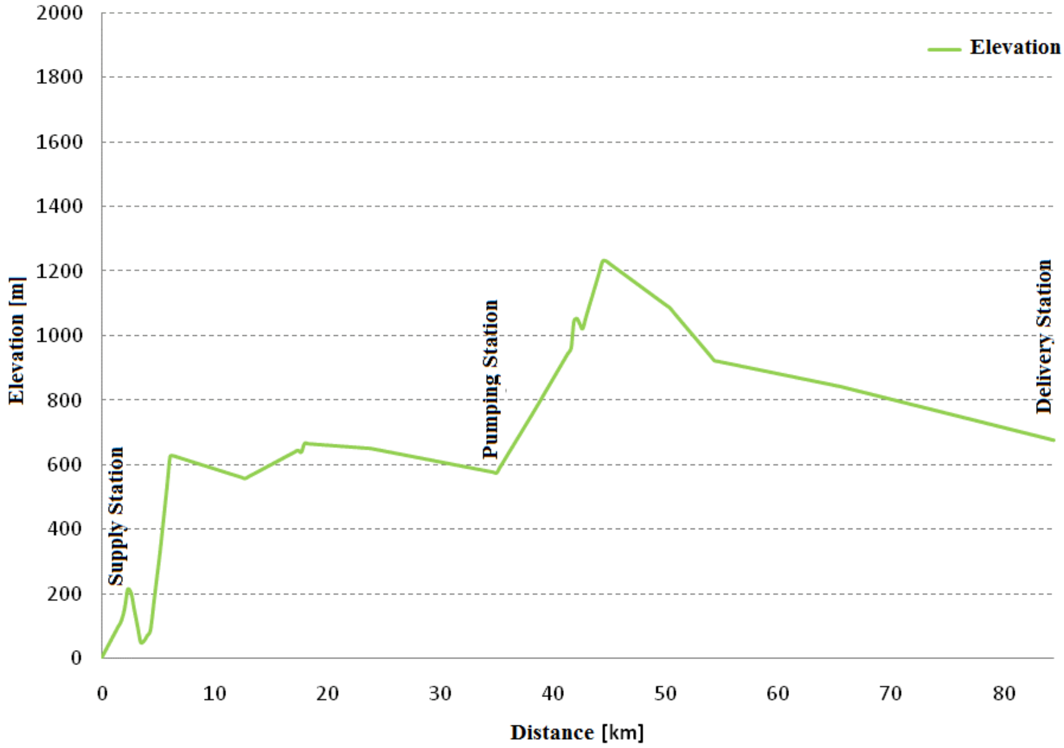

Figure 1. Elevation Profile for the VISC 30 Pipeline

2.2. Premises

To study the model above, some assumptions were made to limit the variables needed.

- Considering the values exposed in the Table 1, this study will consider a viscosity range from 10 to 700 cP;
- Three different densities were chosen to illustrate the effects of this parameter: 850, 900 and 950 kg/m³;
- The flow was considered to be isothermal, in the temperature of 20°C, with no thermal exchanges;

- The friction factor was determined through the Colebrook-White correlation (Fox and McDonald, 1998).

2.3. Methodology

Using the data presented on the item 2.1 and the assumptions of the item 2.2, a model has been developed for the pipeline VISC 30 for the software Stoner Pipeline Simulator (SPS). This model was used to simulate several steady flows for each one of these pipelines. It was modified to a 42’’ pipeline at the end of this work, to analyze a different condition. The software simulates the transient flow in pipelines, solving the mass continuity equation, conservation of linear momentum and energy equations using a one-dimensional approximation thru finite differential technic. The simulations were configured for a parametrical study, in order to create tables and charts that describe the influence of each parameter separately.

3. Results

Figure 2 illustrates a typical operational condition for the VISC 30 pipeline, with a product of 950kg/m³ and 50cP viscosity, what permitted a flow of 2382 m³/h. Each product’s transport will generate different hydraulic gradients, though.

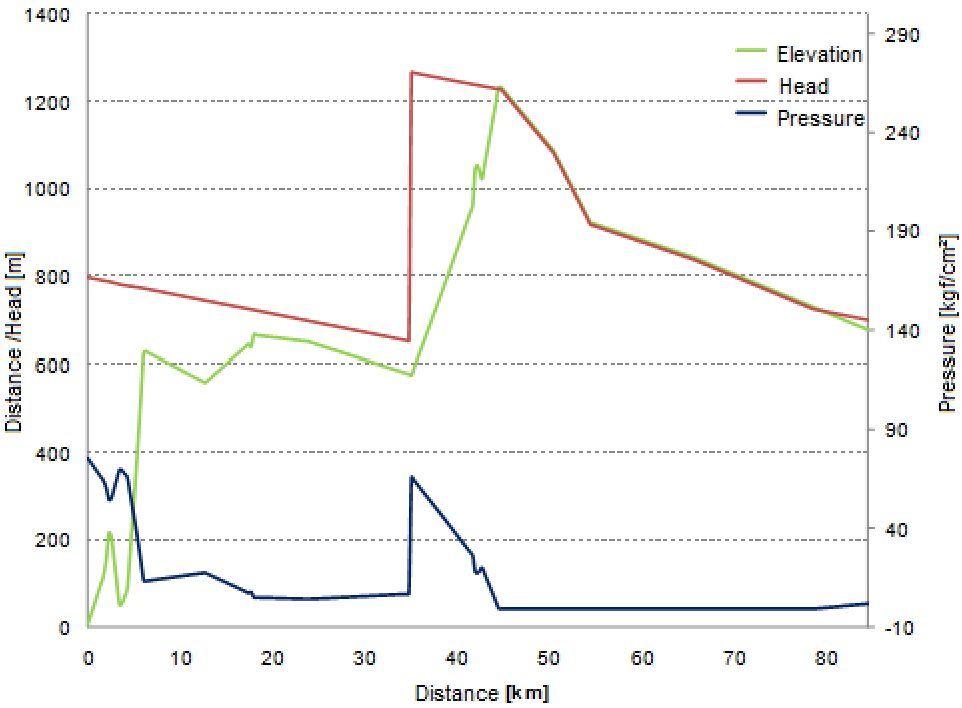

Figure 2. Typical Head, Pressure and Elevation Profile of the VISC 30 Pipeline

Flow rate results and the pump’s power usage were obtained through the simulations outputs, while the values for specific energy (kWh/m³) and cost (R$/m³) were calculated according to Equations 2 and 3. The value of 267 R$/MWh was used for the economic calculations. This value represents an average of São Paulo’s rates.

Equation 2 indicates how the specific energy was calculated. Equation 3 indicates how the specific cost was calculated.

$$Ee\left[\frac{kWh}{m^3}\right] = \frac{POTtotal\left[HP\right]\times 0.746}{Q\left[\frac{m^3}{h}\right]} \qquad (2)$$

$$Custo\left[\frac{R\$}{m^3}\right] = \frac{POTtotal[HP] \times 0.000746 \times cm\left[\frac{R\$}{MWh}\right]}{Q\left[\frac{m^3}{h}\right]} \quad (3)$$

The results for the simulations with different viscosities, for the density of 850kg/m³ can be found on Table 2, as an example of how the calculations were done.

Table 2. Results for Different Viscosities for a 850kg/m³ Product

Density (kg/m³)	Viscosity (cP)	Flow (m³/h)	Power Supply (HP)	Specific Energy (kWh/m³)	Average Cost (R$/m³)
850	10	2761.289	5047.61	1.364	0.37
850	20	2618.647	5010.53	1.427	0.38
850	50	2403.437	4999.455	1.552	0.42
850	100	2213.631	5018.838	1.691	0.45
850	150	2095.863	5076.545	1.807	0.48
850	200	2008.783	5122.296	1.902	0.51
850	250	1937.855	5147.749	1.982	0.53
850	300	2025.858	5357.609	1.973	0.53
850	350	2127.448	5550.881	1.946	0.52
850	400	2198.438	5706.007	1.936	0.52
850	450	2155.678	5747.538	1.989	0.53
850	500	1992.888	5667.645	2.122	0.57

Figure 3 shows how the flow rate varies with the viscosity, based on the data presented on Table 2 and for two other densities, shown on different colors. There are clearly three main zones on this chart: the first one between 0-300 cP, where the flow rate decreases with the viscosity; one in the middle, between 300-500cP where the flow rate increases with the viscosity and the last after 500 cP, where the pattern of decreasing the flow with the viscosity returns. This middle zone where the flow rate increases as you increase the viscosity can be explained through the Reynolds number of the flow and its regime. The first zone is the laminar flow zone, the middle is called transition zone, and the last is the turbulent flow zone.

A slight deformation can be seen when analyzing the different curves for different densities, but the most significant result for the variation of this parameter is the translation of the curve, to higher flow rates as the density gets lower.

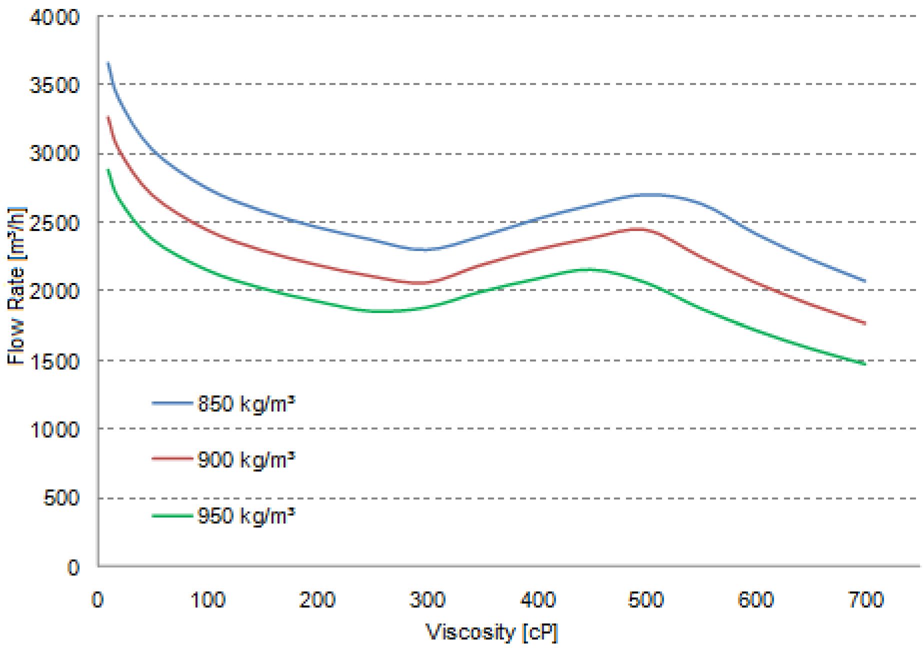

Figure 3. Flow Rate x Viscosity for the VISC 30 Pipeline

Table 3. Results for the Viscosity Study with a Product of 850kg/m³ for the VISC 30 Pipeline

Density (kg/m³)	Viscosity (cP)	Flow (m³/h)	Velocity (m/s)	Reynolds (HP)	Fluid Flow Type
850	10	3657	2.47	152068	Turbulent
850	20	3394	2.29	70566	Turbulent
850	50	3031	2.05	25207	Turbulent
850	100	2749	1.86	11431	Turbulent
850	150	2583	1.75	7160	Turbulent
850	200	2465	1.67	5125	Turbulent
850	250	2373	1.60	3947	Transition
850	300	2298	1.55	3185	Transition
850	350	2397	1.62	2847	Transition
850	400	2521	1.70	2620	Transition
850	450	2623	1.77	2423	Transition
850	500	2700	1.82	2245	Laminar
850	550	2636	1.78	1992	Laminar
850	600	2417	1.63	1675	Laminar
850	650	2231	1.51	1427	Laminar
850	700	2072	1.40	1230	Laminar

Reynolds experiment demonstrated two different, well defined types of flow: laminar and turbulent. For each one of these, friction factors could be determined as a function of the Reynolds number. In the transition zone, between these two types of flow, a friction factor couldn't be associated with a Reynolds number.

Figure 4 illustrates this phenomenon. The transition zone is approximately between 2300 and 4000 Reynolds.

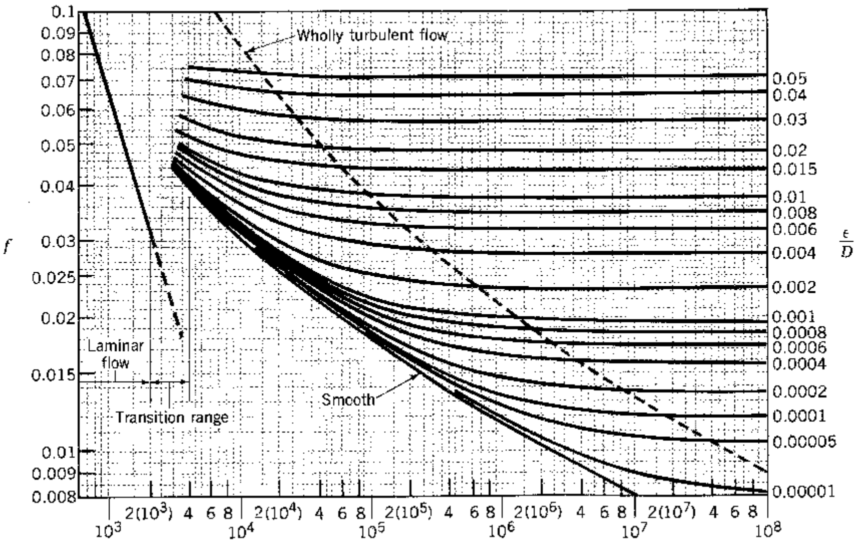

Figure 4. Moody’s Abacus

Despite the lack of knowledge about the analytical solution for the friction factor in the transition zone, some approximations had been made for numerical solutions through the years. Figure 5 illustrates one of these approximations, where the friction factor increases with the Reynolds number in the transition zone. The utilized software does an approximation similar to this one, using a polynomial function of the third degree.

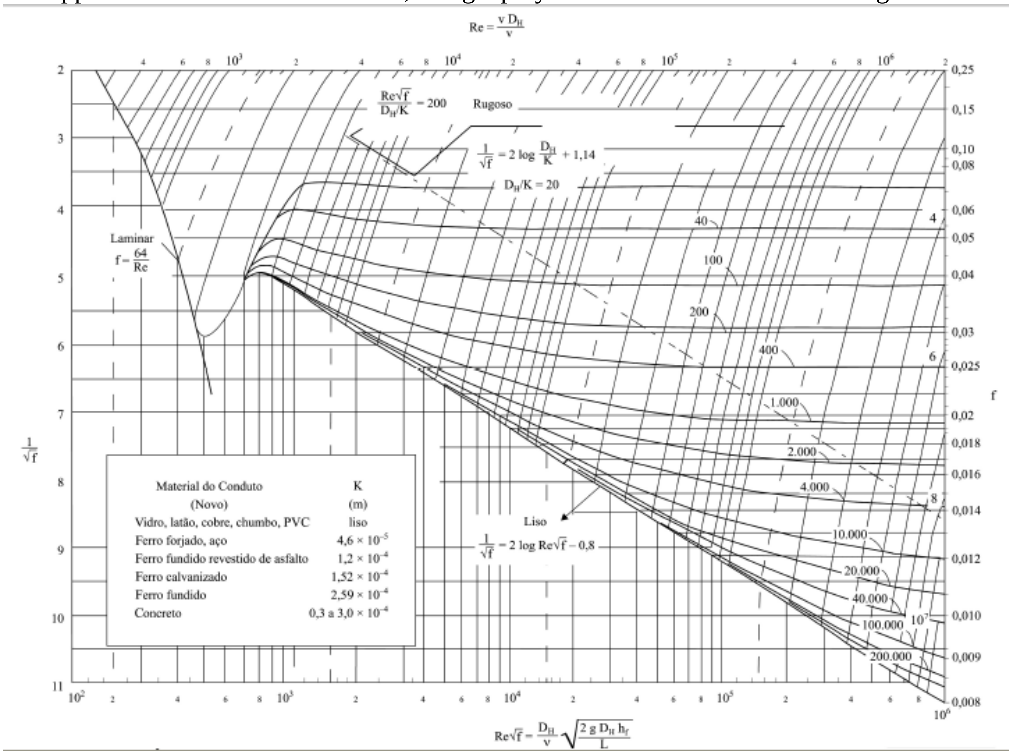

Figure 5. Moody’s Abacus with an approximation for the transition zone

Figure 6 shows the behavior of the specific energy as a function of the viscosity for three different densities, and Figure 7 shows the specific cost.

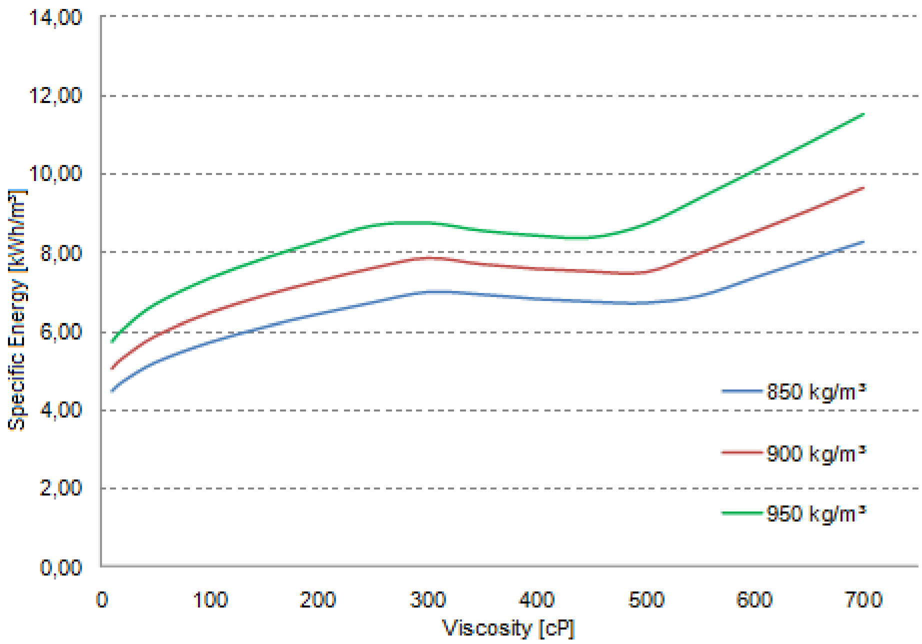

Figure 6. Specific Energy x Viscosity for the VISC 30 Pipeline

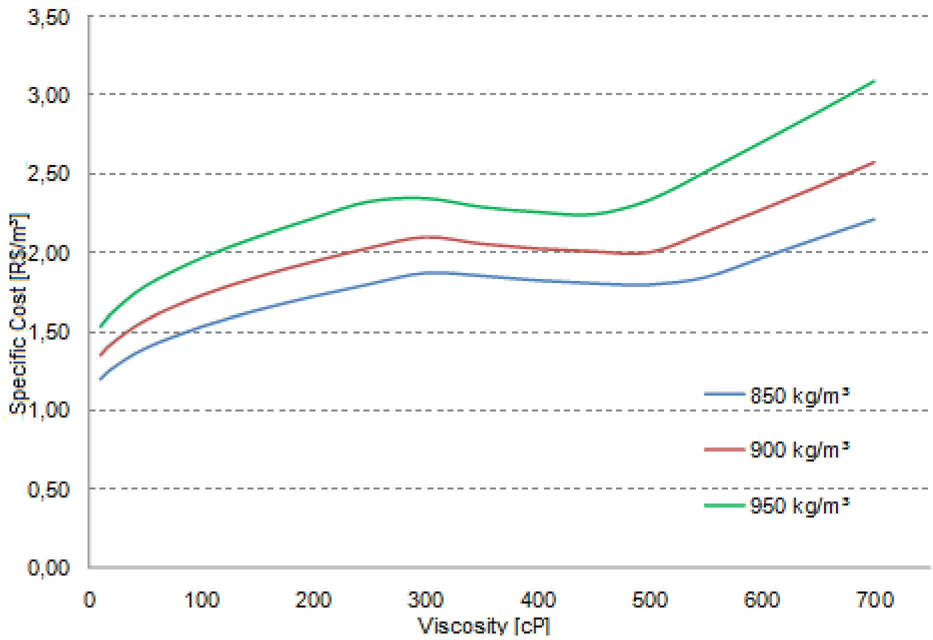

Figure 7. Specific Cost x Viscosity for the VISC 30 Pipeline

Between approximately 300 and 500 cP, the software estimates that the specific cost decreases with the viscosity, contrary to what happens for the laminar or turbulent flow. This result occurs due to the approximation of the friction factor for the transition zone, as presented at Silva (2010).

However, for this phenomenon to occur, it is necessary that the system's average Reynolds number is close to the Transition zone. Otherwise, when the transition zone can't be achieved by the system, this phenomenon can't be explored. If you consider the pipe with a higher diameter, and the same profile, for instance, the pipeline cannot reach the transition zone, and said blend operation loses financial and technical interest. Figure 8 and Figure 9 show the behavior of the Flow Rate and Specific Cost as a function of the viscosity for a 42 inches diameter pipeline.

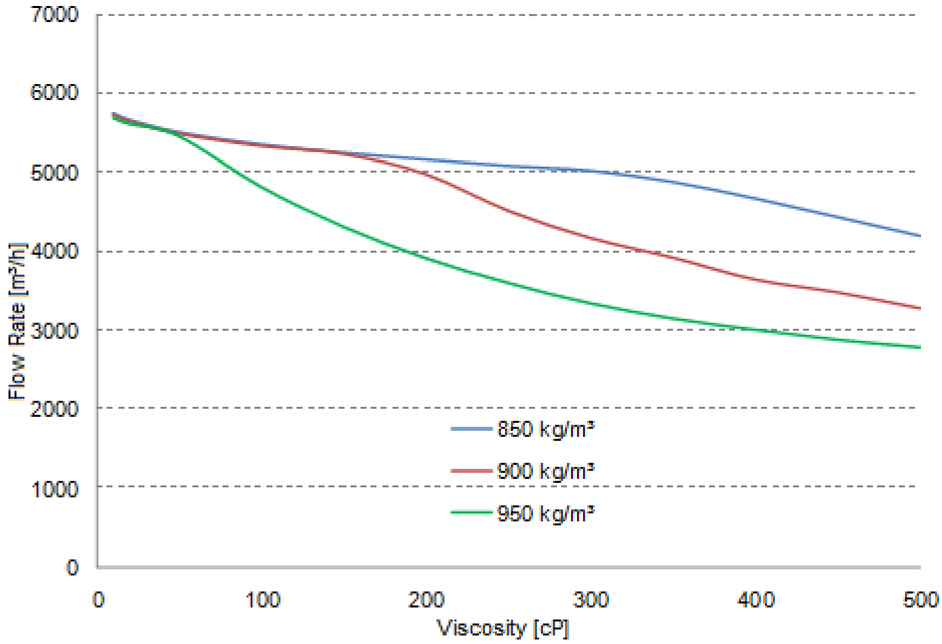

Figure 8. Flow Rate x Viscosity for the VISC 42 Pipeline

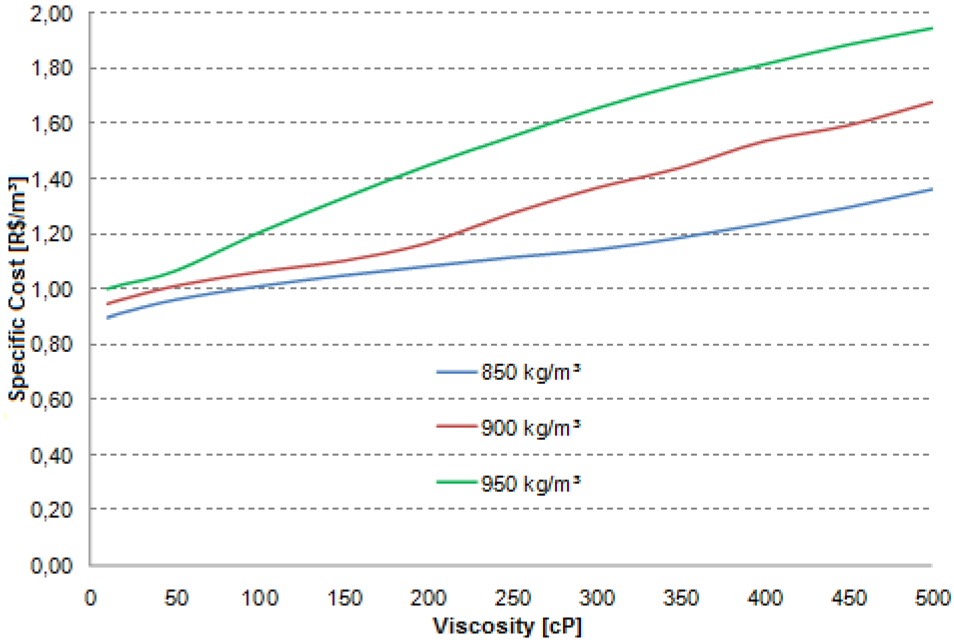

Figure 9. Specific Cost x Viscosity for the VISC 42 Pipeline

6. Conclusions

When choosing the blends for the transport of different products through a Pipeline, one must observe the average Reynolds number of the flow. If it’s close to the transition zone, there may be some blends that are actually more viscous, but still cheaper to transport, as shown on the results of the VISC 30 Pipeline simulation.

This method can be applied in all systems that have blending tanks or mixers available. Considering the products in the supply station and the logistics of the operation, an optimal blend can be obtained through the use of simulations. However, logistics must always have the final say in the blend decision, as of the Refinery capacity for high viscosity crude oils, to insure that the whole system benefits from the choice.

7. References

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