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ECONOMIC AND OPERATIONAL EVALUATION OF THE USE OF DRAG REDUCING AGENTS IN A PIPELINE

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ABSTRACT

The use of drag reduction agents (DRA) can be a decisive factor in determining the technical and economic feasibility of new pipelines projects, meeting the demands not foreseen and seasonality accommodation without large investments in infrastructure. Knowing the friction reduction mechanism and its impact on the operating procedure of existing products is essential in order to have the guarantee of the benefit for your application.

Most of the works published report field experiences obtained from its application, seeking to determine the influence that internal and external factors have on the polymer. Knowing these effects is essential for better application performance. However, few authors have sought to identify the best way to operate an existing pipeline with DRA, with either an increase in capacity or an energy reduction.

Operationally, the use of drag reducing agents may decrease the currently used arrangement of pumps, or even the complete shutdown of a pumping station. In this context, the use of drag reducers may be a suitable solution for decreasing power consumption in fluid transport pipelines of petroleum and derivatives.

This paper presents a case study of the application of drag reducing agents in a Brazilian high-energy pipeline. It features five intermediate pumping stations and three withdrawal points along its nearly one thousand kilometer stretch. With the aid of a computer simulation software, it is proposed a methodology to evaluate the best application condition, minimizing pump costs, polymer volume and meeting the scheduled demand of the month.

This methodology first sought to validate the computational model of the pipeline. It was made a historical survey and inserted into the simulator, in order to reproduce faithfully a monthly operation. A sensitivity analysis is performed to determine which pump stations are most relevant. It was established an initial concentration of polymer to be injected in the sending refinery, aiming the reduction of arrangement or total shutdown of the subsequent station and keeping volume delivered on all points. The other bases remain working according to the operation of the month. This procedure is then repeated for the other bases, resulting in a combined and continuous injection, minimizing the operating costs.

An economic evaluation is finally performed to quantify the benefits of this application. A reduction in energy consumption of 49% was noticed, and considering the costs with DRA, the monthly movement had a 35% drop in the total costs of operation.

NOMENCLATURE

SPS	Synergi Pipeline Simulator
MAOP	Maximum Allowable Operational Pressure
DRA	Drag Reducing Agent

INTRODUCTION

Oil products are transported through pipelines from the input nodes, normally refineries or ports, to the output nodes where they are stored in tanks**.** The product is then extracted from the storage tanks to be delivered to the final consumers, normally by trucks. The products (Diesel oils, gasoline.) are injected in different batches, that is, at any time different products, separated by the corresponding interfaces are been transported. The energy needed for transportation is supplied by a set of electrically powered pumps.

It has been shown that the frictional pressure drops or drags, limiting the throughput of oil pipelines, can be significantly reduced by injecting long-chain polymers, the so called flow improvers or drag reducing agents (DRA) [1].

Turbulent drag reduction was first discovered in the mid 1940's by a British researcher named B.A. Toms**.** Despite the extensive search in the area of drag reduction over the past four decades, there is no universally accepted model that explains the mechanism of drag reduction. The Figure 1 shows a typical shape of a drag reduction curve.

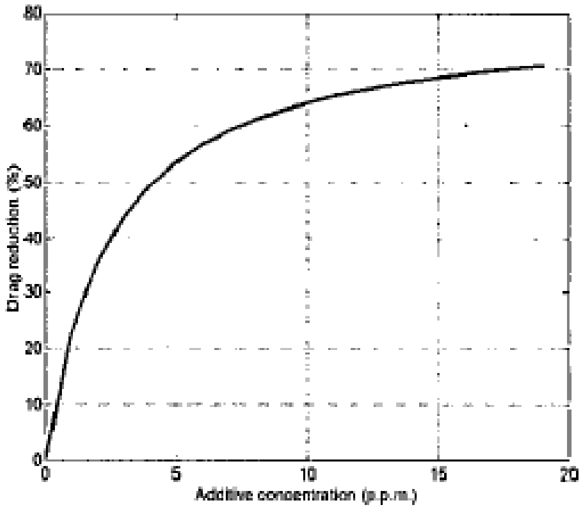

Figure 1. TYPICAL SHAPE OF A DRAG REDUCTION CONCENTRATION CURVE (6)

The drag reducing agents are additives that reduce turbulence in a flow within a pipe. Usually used in pipelines, they increase capacity by reducing turbulence, and thus allow fluid to flow more efficiently.

The experimental studies performed with drag reducing agents were done mainly on pipes. In these experiments, variations in pressure differential and flow were observed, comparing flows with and without polymers within the solution.

One way of evaluating the behavior with drag reducing agents is given by the ratio ΔP / Q, where ΔP is the pressure variation and Q is the flow rate. A reduction in this ratio is observed with the use of polymers. Therefore, when ΔP is held constant, a higher flow rate is observed in the pipe, and in contrast, when Q is held constant, i.e.; maintaining the flow, a reduction in ΔP is observed.

The current work aims to present a case study of the use of drag reducing agents in an operational pipeline the researchers call OBA: Brazilian Pipeline. This study demonstrates a methodology that seeks to find simple and economical solutions for injecting drag reducing agents during a specific month of operation.

PIPELINE DESCRIPTION

The OBA is an oil pipeline of 785.6km that connects Refinery A to Terminal B and currently carries gasoline and diesel. In addition to the initial pumping station located at Refinery A, the pipeline has intermediate stations called 1, 2, 3, 4 and 5. Stations 2, 3 and 4, still receive product without an interruption in the pipeline flow to terminal B. The pipeline has the function of cyclically transporting batches of products from the Refinery A tanks and will be delivered to stations 2, 3, 4 and Terminal B, in addition to being distributed among surrounding cities. Figure 2 shows the schematic of the pipeline stations.

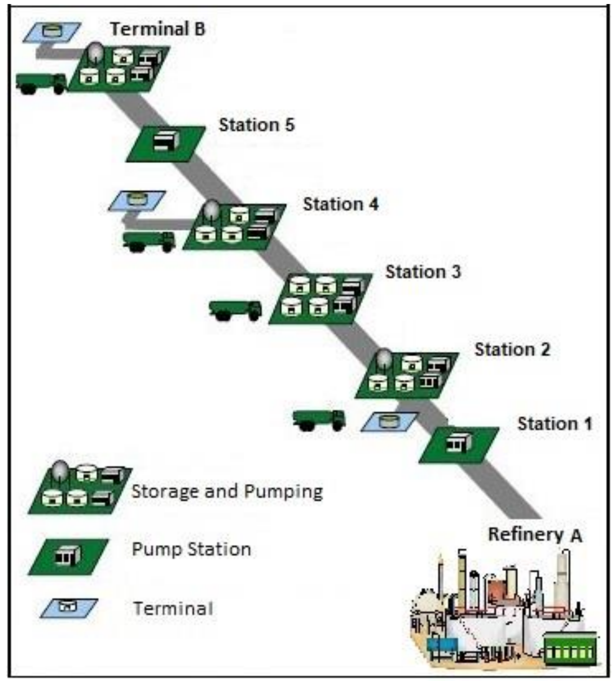

Figure 2. OBA PIPELINE

The OBA pumping system relies on pumps at all intermediate stations. Despite this availability of pumps, the operation does not use them in their entirety per station. Table 1 shows the number of pumps available per station and those used during the month of October 2014.

The number of pumps used per station is directly linked to the energy consumption of the pipeline. The higher the demand for pumps, the higher the operational cost.

Table 1. MAIN PUMPS PER STATION

STATION	DISPONIBLE PUMPS	PUMPS USED IN OCT/2014
Refinery A	3	2
Station 1	3	2 or 1 or 0
Station 2	4	2 or 1 or 0
Station 3	4	2 or 1 or 0
Station 4	3	1 or 0
Station 5	3	1 or 0

The products that are currently transported in the pipeline are diesel and gasoline. The main characteristics of there are presented in Table 2.

Table 2. FUELS PROPERTIES

Fluid	Gasoline	Diesel
Density (kg/m³)	713	863
Viscosity (cP)	0.20	3.00
Vapor Pressure (kgf/cm²)	0.40	0.08

METHODOLOGY

In this section the researchers discuss alternatives in monthly operations of the OBA pipeline with the use of DRA, approaching the optimal solution of the pipeline in regards to the use of energy.

The methodology begins with reproducing a monthly OBA operation in the SPS thermo-hydraulic simulator. It is necessary to use a computer model of the pipeline in which real operational data from the month of October was used and is referred to as the base case. October 2014 was chosen for analysis due to the high volume of flow and energy demand.

Once the base case is simulated and the model is validated, the drag reducing agents can then be used. At that time, adaptations are required in the computational model for the DRA injections.

The method for reproducing the chosen month of October was based on the previous data considered essential for the calibration of the model. The researchers evaluated the most relevant data and entered into the simulator as follows:

- Entry Data:
  - Density meter of delivery
  - Pump status
  - Receiving pressure
  - Flow of withdrawal at stations 2, 3 and 4

- Exit Data:
  - Pressure of delivery per station
  - Flow of delivery
  - Receiving flow at terminal B
  - Cumulative Volume

The density meter was used to reproduce the initial batch of product of the pipeline, in addition to stating which product is being delivered from Refinary A throughout the month.

All the entry data were interpolated every 30 minutes, so that the simulation would reproduce a time stamp exactly as it was happening from the first of October 2014 in the OBA [2].

VALIDATION

The simulation ran for a period of 720 hours after inserting the entry data into the computational model.

During the analysis period it was crucial to respect the operational limits of the pipeline, both for pressure and for maximum and minimum flows. In addition, the operation had to be kept with no slackline, i.e., no time at which the product could be vaporized due to the low pressures. The Figure 3 shows an instance of time extracted from the SPS.

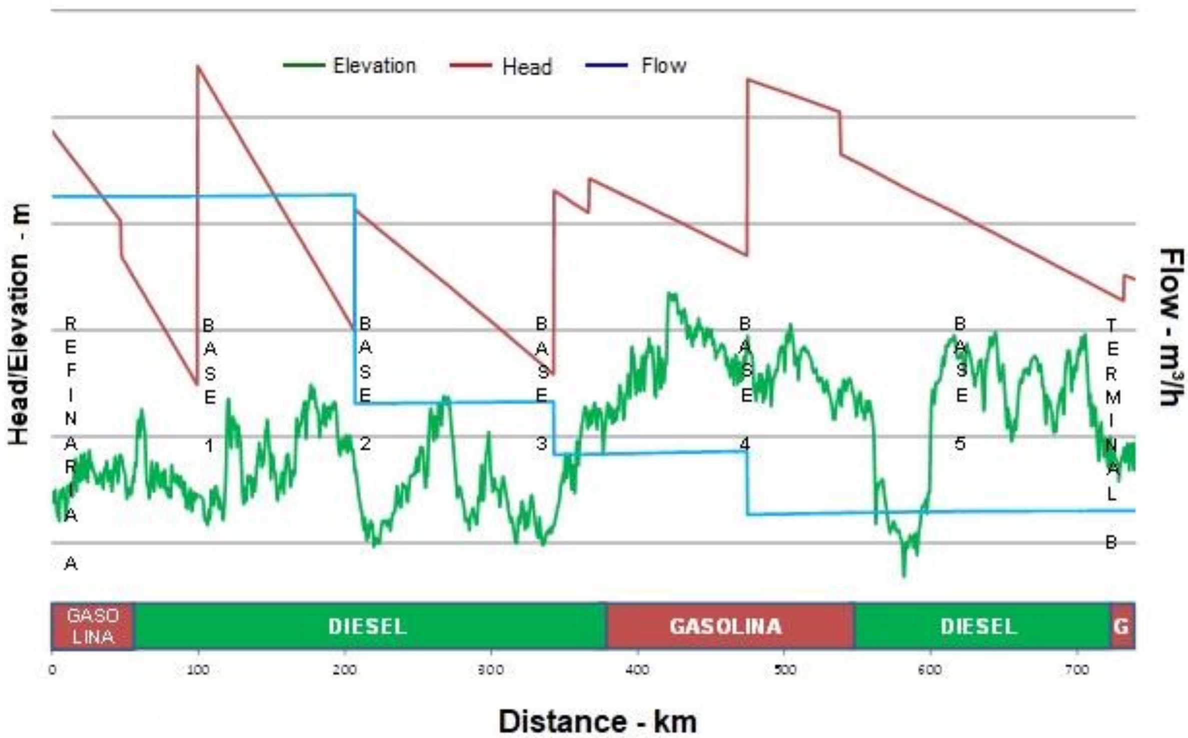

Figure 3. HEAD, ELEVATION, FLOW AND BATCHES POSITIONS WITHOUT DRA ON OCTOBER 1ST

The Figure 3 shows the configuration of OBA for an instant of time in October without DRA. The green line represents the elevation profile of OBA. The red line represents the head of the fluid where each vertical line indicates an operational pumping station. The blue line represents the flow where each vertical line indicates fluid being delivered at the station.

The Figure 3 also shows the pump locations as follows: two pumps at Refinery A and Station 1, one pump at Station 2, two at Station 3 and one at Station 4. Withdrawals of fluid happen at Stations 2, 3 and 4. Specifically, batches of diesel are delivered to Stations 2 and 3, while gasoline is delivered to Station 4 and Terminal B.

The first evaluation conducted looks at pressure of the pipeline over time. Only the pump status was inserted in the simulator, therefore, the behavior of the delivering pressure will be a function of the pump curves inserted in the model and the situation of the system itself at that moment, i.e., the product being pumped, the flow and the pressure suction at that station The results of the pressure compared to the time-plotted error is shown in Figure 4.

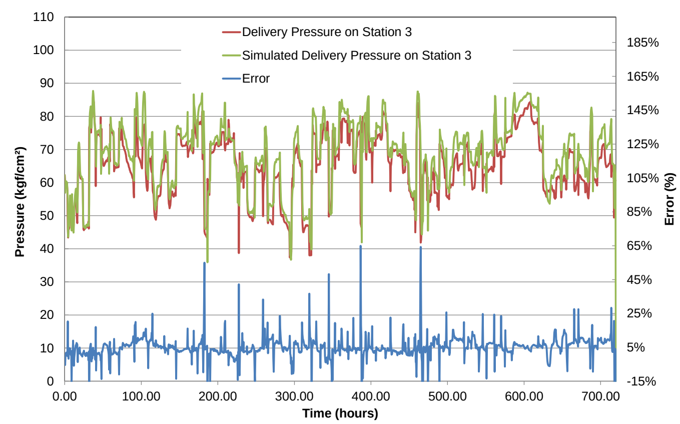

Figure 4. DELIVERY PRESSURE ON STATION 3

The receiving flow at terminal B was also analyzed as a function of time. The withdrawal flow in the intermediate stations 2, 3 and 4, are based off the entry data of the simulator, therefore, by mass conservation, validating the flow of the receipt ensures that the entire model is calibrated for this parameter. This comparison can be seen in Figure 5.

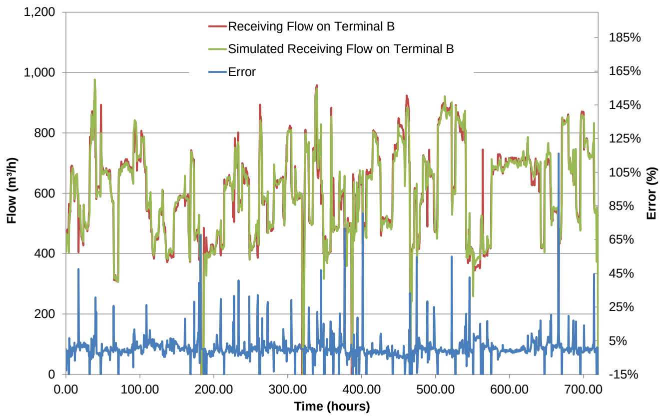

Figure 5. RECEIVING FLOW ON TERMINAL B

Once the validation from the simulator results for the pressures and flows have been exposed, it is possible to make a comparison between the average errors found per base, disregarding peaks due to operational transients. Table 3 presents some of these results.

Table 3. AVERAGE ERROR OF THE DELIVERY PRESSURE AND FLOW PER STATION

STATION	PRESSURE AVERAGE ERROR	FLOW AVERAGE ERROR
Refinery A	3%	2%
Station 1	3%	-
Station 2	2%	-
Station 3	3%	-
Terminal B	-	1%

The final cumulative volumes per base are absolute values, and therefore their analysis over time is not necessary. Table 4 shows the verified differences at the end of the simulation for the exit data.

Table 4. DIFFERENCES BETWEEN THE SIMULATED AND REAL DELIVERED VOLUME PER STATION

STATION	AVARAGE DIFFERENCE
Station 2	0.09%
Station 3	0.17%
Station 4	-0.04%
Terminal B	-0.21%

In addition to the hydraulic validation of the model, the energy consumed was also validated. It was necessary to acquire data of electric current by pump in the stations. Figure 6 presents the results of this validation in one of the pumps of station 2.

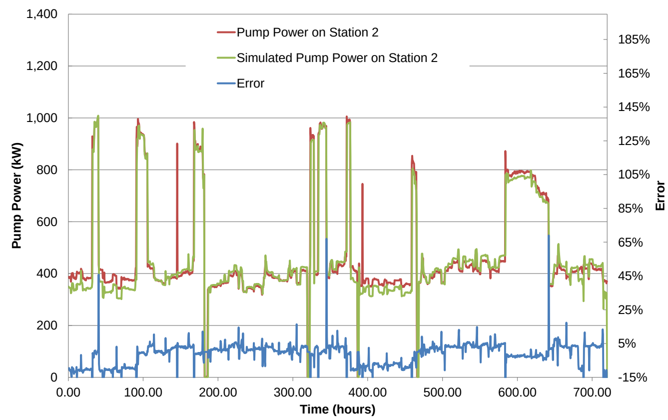

Figure 6. PUMP POWER ON STATION 2

The model calibration presented strong significant results with general errors less than 5% for pressure, flow and power. The cumulative volume as a consequence of this calibration, also obtained values similar to the reality of the operation. From now on, the DRA will be injected seeking for alternative operations.

SCENARIOS WITH DRA

Once the computational model has been validated, the process is summarized to perform injections of DRA in different stations, in order to seek the best pump arrangement for that operation. The study was based on "trial and error", making several combinations of injections, selecting the operational month of October due to high volume.

To perform the study with the DRA, it was first necessary to adapt the computational model with the skids of polymer downstream of each pump station. It was also necessary to insert the manufacturer curve of drag reduction for each product. The curves shown in Figure 7 were computed into tables and then added to the simulator.

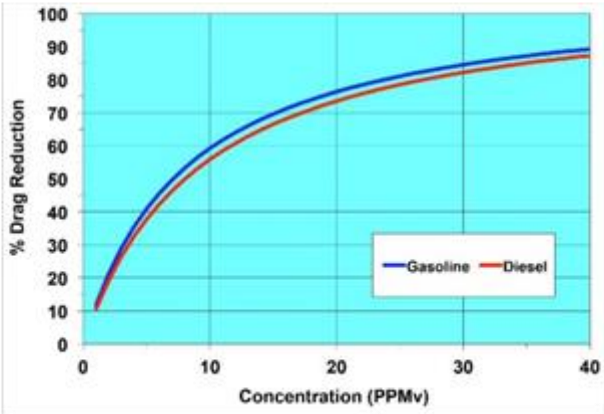

Figure 7. DRA EFFICIENCY CURVES FOR GASOLINE AND DIESEL

For these new scenarios, the researches kept the following entry data:

- Entry Data with DRA:
  - Density meter of delivery
  - Fixed receiving pressure
  - Pump status
  - Flow of withdrawal at stations 2, 3 and 4

To evaluate this new scenario, the exit data are the following:

- Exit Data with DRA:
  - Cumulative volume per station
  - Pump power
  - Highests and lowests pressures

The scenarios with DRA were progressively evaluated. New monthly simulations were carried out with DRA injections in each of the stations from Refinery A all the way to Terminal B.

Since pump arrangements using DRA are different from those observed during the month of October, it is not appropriate to make new comparisons between pressures. Therefore, new premises must be followed and are detailed in the following section.

BY-PASSING OR REDUCE NUMBER OF PUMPS

The new premises were based on the search for the largest possible number of bypasses of intermediate stations, generating less energy costs to the transporter. If it is not possible to completely disconnect the base, at least the reduction of the pump arrangement was considered.

The new premises established were:

- Operate under the same conditions proposed for the base case, in order to reproduce the batches that will be sent from Refinery A, the withdrawals in the stations and the receiving pressure in Terminal B
- Fill in the products and concentration of DRA studied on October 1st
- Always operate within the operational limits of the pipeline
- Respect the volumes delivered at each of the stations
- Do not exceed the total limit of 20 ppm of DRA in the pipeline

The application of the method started with the injection of 5 ppm in the first pumping station, Refinery A. The DRA was introduced on October 1st and the simulation lasted for one month. After the conclusion of the simulations, it was verified the attendance or not of the established premises. In this first evaluation, the by-pass of Station 1 was possible with the injection and reaches a final volume above that required at Terminal B. The method did not seek to change the initial configuration in the Refinery A, based off the operation.

The next procedure sought to inject the same concentration into the first station, maintaining the usual operation of the first one and looking for the by-pass of station 2. In this situation, the injection of 5 ppm was not enough, observing a volume lower than the required amount at Terminal B. An injection of 10 ppm was then proposed and tested, which proved to be effective.

Injections of 5ppm and, if necessary, 10 ppm were made in all bases independently in order to reduce the pump arrangement. Doing so, resulted in higher sensitivity, making it possible to observe the most significant compared to the least significant stations for the operation. Shown in Figure 8 is a flowchart of the method for the first three pump stations.

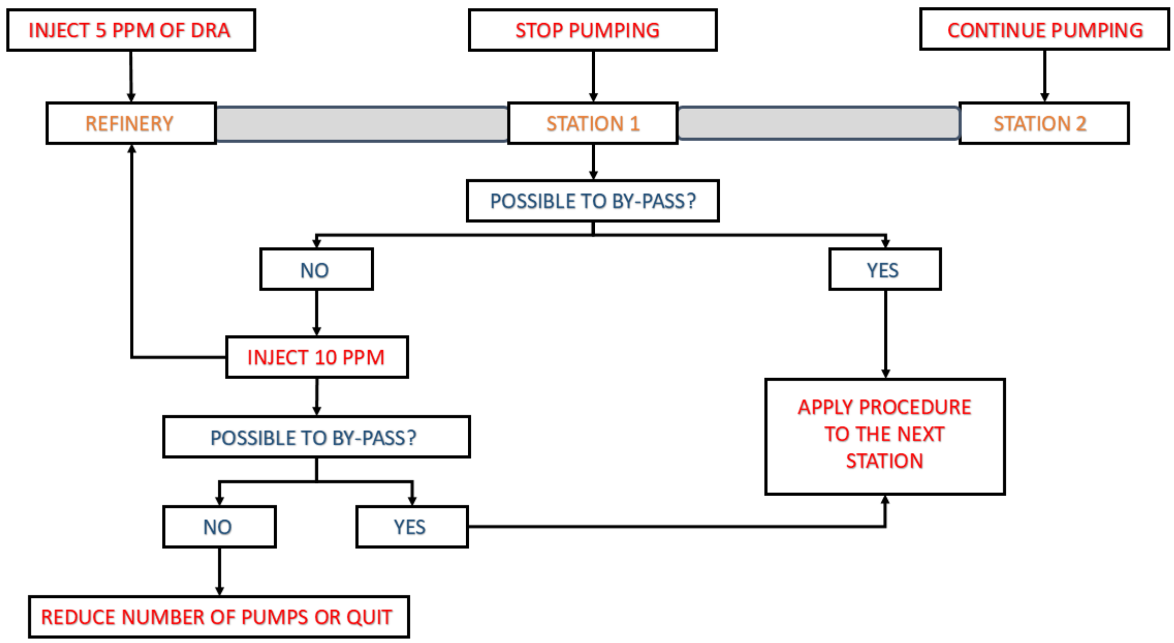

Figure 8. FLUXOGRAM OF THE METHODOLOGY

Utilizing this method gave the following results:

- The by-pass of Station 1 is possible with the injection of 5 ppm in Refinery A
- The by-pass of Station 2 is only possible with the injection of 10 ppm in Station 1
- It is not possible to by-pass station 3 with the concentrations used, only the reduction of the arrangement to always operate with one pump
- The by-pass of Station 4 is possible with the injection of 5 ppm in Station 3
- The by-pass of Station 5 is possible with the injection of 5 ppm in Station 4

Based on observation of these conditions, the by-pass of two consecutive stations is sought. As Stations 1, 4 and 5 could be by-passed with only 5 ppm, the simulation was redone with the injection of DRA in the bases previous to these, to do this verification. As a result, it was observed that:

- The by-pass of stations 1 and 2 is possible with injection of 10 ppm on Refinery A
- The by-pass of stations 4 and 5 is possible with only 5 ppm on station 3

This conditions respects all the premises established, but in an independent way. The simultaneous injection on Refinery A and station 3 is now proposed.

SIMULTANEOUS INJECTION

The proportions of 10 ppm in Refinery A and 5 ppm in Station 3 are sufficient for the entire operation to occur respecting established premises, but independently. To evaluate the operation simultaneously it was necessary to run the simulation again for this new condition. The results show that:

- The sufficient concentration for this operation to occur is 13 ppm in Refinery A and 6 ppm in Station 3.

The differences between the volumes moved in real situations (without DRA) and simulated (with DRA) are shown in Table 5.

Table 5. DIFFERENCES BETWEEN THE DELIVERED VOLUME WITH AND WITHOUT DRA

STATION	DIFFERENCE
Refinery A	-0.25%
Station 2	-0.01%
Station 3	0.00%
Station 4	0.02%
Terminal B	-0.42%

Figure 9 shows the same instant of time as Figure 3, on October 1st, but with a reduced pump arrangement due to the presence of the DRA.

Figure 9. HEAD, ELEVATION, FLOW AND BATCHES POSITIONS WITH DRA ON OCTOBER 1ST

The composition of the products in the pipeline and the withdrawals flows again are repeated in stations 2, 3 and 4. However, due to the presence of the DRA in the established concentrations, for that instant, the pump arrangement was reduced as follows:

- Station 1: two pumps to zero
- Station 2: one pump to zero
- Station 3: two pumps to one
- Station 4: one pump to zero

This arrangement reduction was established for the entire month and the results in terms of energy and cost are presented in the following section.

LEAK DETECTION AND MEASUREMENT

It is important to analyze the effect of this injection on the operation. The first impact is on the leak detection system. This pipeline operates using RTTM system and has parameters for input of the characteristics of the DRA and reads the polymer injection flow, i.e., the pipeline maintains the same sensibility and reliability of detection [3].

The measurement had no significant change since the injected polymer flow is insignificant in relation to the pipeline flow, in addition the operating flow threshold remained the usual.

RESULTS

After completing the DRA injection methodology, the concentrations by base that obtained the best results in energy savings during the month of October are presented below:

- 13 PPM in Refinery A
- 6 PPM in station 3

The values exposed are independent of the product being moved. The reduction in the friction factor for each product, corresponding to the manufacturer curve, is presented in Table 6.

Table 6. DRAG REDUCTICON

PRODUCT	REDUCTION FOR 13 PPM	REDUCTION FOR 6 PPM
GASOLINE	70%	59%
DIESEL	61%	51%

The table above reflects the reduction in friction as a function of the concentration used, referring to the manufacturer's curve. Once this reduction in the friction factor is obtained, it is possible to find the results presented in this article.

The final injection reduced as many pumps as possible throughout the month of October. Pump arrangements before and after injection are shown in Table 7.

Table 7. COMPARISON OF PUMP ARRANGEMENT

STATION	REAL ARRANGEMENT	ARRANGEMENT WITH DRA
Refinery A	2	2
Station 1	2 or 1 or 0	0
Station 2	2 or 1 or 0	0
Station 3	2 or 1 or 0	1 or 0
Station 4	1 or 0	0
Station 5	1 or 0	0

The results shows that a monthly operation, which normally performs arrangements of 2 pumps per station, can now be operated only with Refinery A and Station 3, the refinery configuration being maintained and the arrangement in Station 3 reduced to only one pump.

Operating the pipeline in this new way, brings benefits to the operational routine itself, facilitating the control of the operators of the console, as well as the monthly cost of electric power per base that will be discussed further in the following section.

REDUCTION OF THE ENERGY COSTS

The final objective of the article is to study the reduction ~~of~~ in the operational energy cost during the month of October. In this context, it is firstly important to identify the energy consumption practiced in each station of OBA pipeline.

The cost reduction was obtained from the power output values of the simulator. The data were captured during 720 hours of simulation with a time step of 30 minutes. By integrating power over time, it is possible to compare the simulated energy consumed before and after the DRA injection. These data are shown in Table 8.

Table 8. SIMULATED ENERGY CONSUMPTION

STATION	SIMULATED ENERGY WITHOUT DRA (MWh)	SIMULATED ENERGY WITH DRA (MWh)
Refinery A	1458	1471
Station 1	817	0
Station 2	510	0
Station 3	897	575
Station 4	280	0
Station 5	22	0

Each station has a different energy cost, varying according to its geographic position, the taxes collected in the state and if there is cogeneration in place. In addition, all of them have a seasonal daily period, where the cost of energy increases. This time usually corresponds to 3 hours of a business day. From the data collected with TRANSPETRO, it was possible to calculate the final energy cost of each station at the end of the month studied and to compare it with the simulated period with DRA.

Figure 10 and Figure 11 represent a comparison between the costs before and after DRA injection.

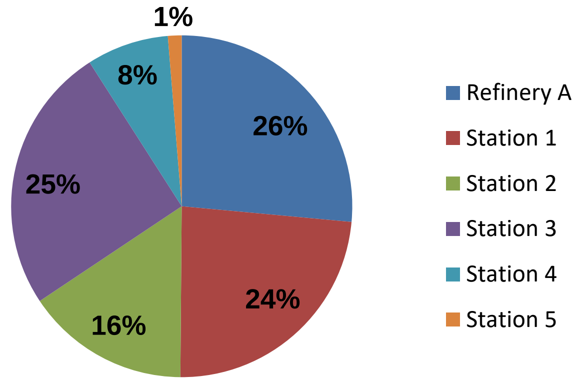

Figure 10. PERCENTAGE OF COST PER STATION

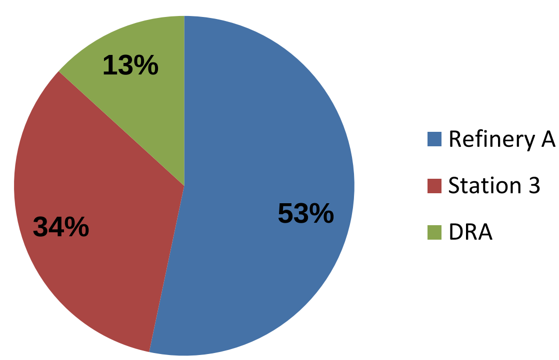

Figure 11. PERCENTAGE OF COST PER STATION AFTER DRA INJECTION

The energy consumed that was previously distributed by all bases, is now restricted only to Refinery A and station 3. The new condition brings a reduction in the overall energy cost by 49%.

In the context of energy reduction, it is also important to reinforce that the cost of the polymer becomes a concern of TRANSPETRO, and will soon have to include it in its operating cost (OPEX). The cost of the polymer was calculated based on the price per liter multiplied by the total volume used in the month, as the basis of the selected movement and concentrations.

In order to perform the operational cost calculations, it is necessary to know both the electric energy and the DRA costs. Table 9 represents the energy saving values obtained, and the resulting reduction in the operating cost, discounting the cost with DRA.

Table 9. FINAL RESULTS

ENERGY ECONOMY	OPEX REDUCTION
49%	35%

CONCLUSION

The results obtained from this methodology indicate the injection of DRA at Refinery A and Station 3 at respective concentrations of 13 and 6 ppm.

The total injection of DRA in the pipeline is limited to 20 ppm by TRANSPETRO, so it is still possible to increase the concentration in one of the stations by 1 ppm in order to reproduce the expected reduction of friction.

This application reveals that these two stations can be operational together, without the need of support from the others stations throughout the month, facilitating the operational routine.

A reduction of 49% in the cost of energy and 35% of OPEX. In this calculation, maintenance costs and personnel expenses are not being considered, which will be reduced due to the new operating arrangement.

The operational cost could have been reduced even more if the pump arrangements had been reduced during peak hours in combination with the use of the DRA.

The study is limited to one month of operation and it is not possible to say whether these conditions could be maintained during other dates. The OBA is a pipeline with high seasonality, with periods of low and high demand. In addition, the volatility of the DRA price is a decisive factor in its application.

Another important point is the issue of electric energy in Brazil. The cost of energy varies according to the season and the level of the water reservoirs, since the hydroelectric plant is the main energy source of the territory. The use of energy from thermoelectric plants makes the operation more expensive. Depending on the base energy being used, the cost benefit of polymer application should be evaluated.

It is necessary to extend the study to other operating conditions and this is the first step for future decision making with regard to the use of the DRA.

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REFERENCES

[1] TOMS, B.A. (1949). Some Observations On The Flow Of Linear Polymer Solutions Through. Straight Tubes At Large Reynolds numbers. Pages II135{41 of: Proc. 1st Intern. Congr. Rheol. North Holland

[2] AMORIM, B (2015). Avaliação Econômica E Operacional Do Uso De Redutor De Atrito Em Um Poliduto. Monografia – Departamento de Engenharia Mecânica, Pontifícia Universidade Católica do Rio de Janeiro.

[3] LIMEIRA, F., Sampaio, D., Lavoura, J., Krause, P. (2011). OPASC Pipeline Optimization Using DRA. Rio Pipeline Conference, Rio de Janeiro, Brazil : Brazilian Petroleum, Gas and Biofuels Institute – IBP.

