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IS VELOCITY FLOW A LIMIT TO INCREASE CAPACITY? A STUDY CASE

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Abstract

There are several possibilities to guarantee reliable and safe liquid transport (mostly fuel) between two points. When the solution applicable is based on pipeline transport, two scenarios may be applicable: a green field new pipeline or capacity expansion of a brown filed pipeline.

Literatures show that pipeline velocities normally vary between 1.0 and 2.0 m/s. This range of line velocity generally yields the most economical solution corresponding to the lowest combined CAPEX and OPEX in Brazil. When considering using an existing pipeline with as build diameter and wall thicknesses based on the original design condition and flow capacity the modification and operation cost and operation limits at a different flow rate must be evaluated and compared against building a new pipeline.

Industrial standards and specifications normally do not restrict specify the suitable velocity limits to be used in pipeline design and operation. Researches and codes provide some recommendations on maximum allowable line velocity based on erosion and static electricity problems in pipeline transport of liquid. Some other considerations associated with higher line velocity in pipeline design and operation include, e.g. surge pressure created during transient conditions, and the conflicts between lower $NPSH_a$ and higher $NPSH_r$ at higher flow rates, etc. In addition to these technical issues that need to be taken into consideration, the focus should be on the increase of OPEX due to energy/fuel consumption increase and CAPEX increase for new pump stations or pump additions. This paper presents a case of capacity increase where the flow velocity will reach 3.6 m/s. Even considering the higher cost of higher energy consumption the project still remains economical.

1. Motivation

The Logum ethanol transportation system in the south-eastern and central-west regions of Brazil relies on the construction of pipeline corridors that integrate new and existing distribution systems. When there is the possibility of using an existing pipeline, it is necessary to evaluate the upgrades needed to provide the new project demands. This technical-economical-environmental solution must then be compared to new pipeline construction.

Following this theme, this paper's objective is to propose a procedure for selecting a solution that meets the delivery and supply needs, given the ramp-up volumes shown on Figure 1, where the following two options are compared:

- Solution A: increasing an existing pipeline capacity aimed at attending the maximum ramp-up volumes;
- Solution B: utilizing an existing pipeline with current capacity (blue value – Figure 1) and then designing and

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constructing a new pipeline for the movement of the excess volume (red value of Figure 1).

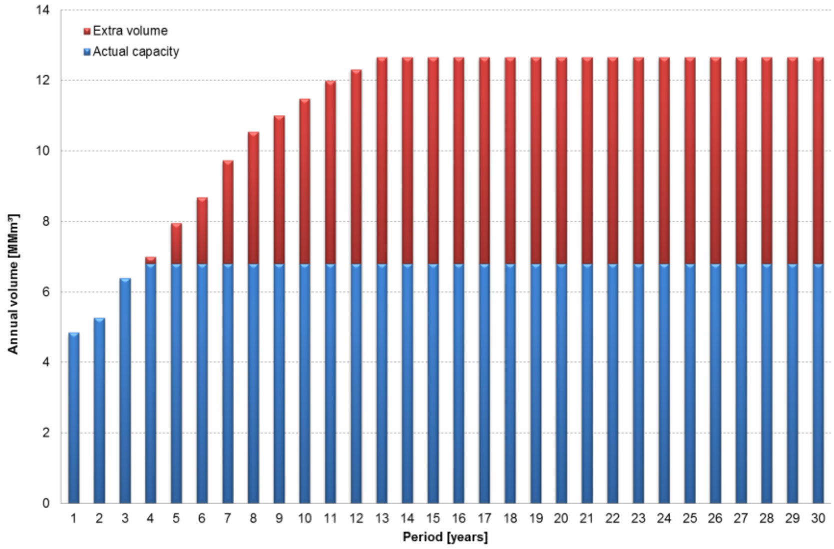

Figure 1, Annual ethanol volume projection

Thus, let's assume that there is already a customer requiring the demand of the current 18-in, 153 km, 0.375-in wall thickness, APS 5L X60 steel pipeline. The pipeline profile and MAOP (Maximum Allowable Operating Pressure) are shown on Figure 2. This pipeline currently transports ethanol (specific gravity 0.811 and viscosity of 1.2 cP at 20°C) at a flow rate of 1053 m³/h which is still below the pipeline's maximum flow capacity. However the planned ramp-up volume to be delivered to the receiving terminal will require the pipeline to flow at the maximum capacity in 3 years (Figure 1).

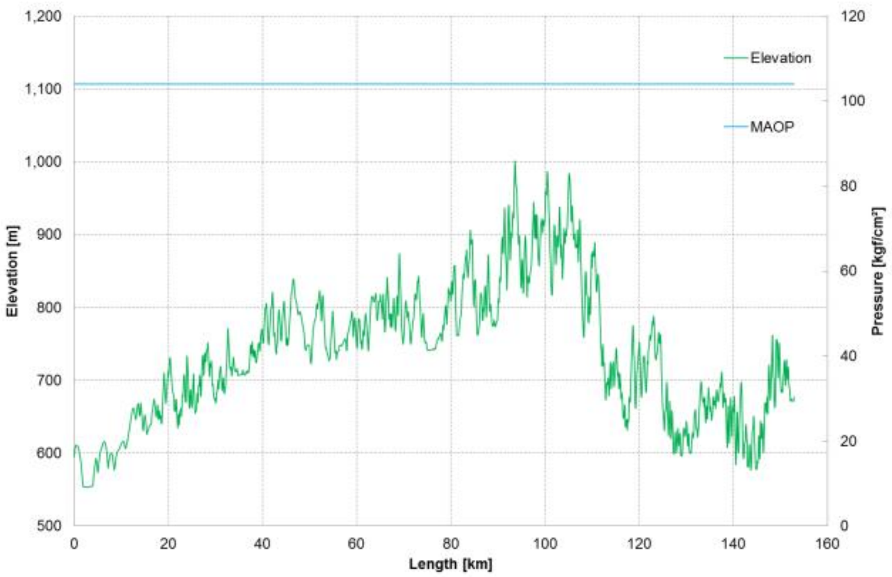

Figure 2, Pipeline profile and MAOP

2. Solutions

2.1. Solution A: Existing pipeline capacity increase

Solution A is aimed at meeting needed terminal delivery volumes by increasing the flow capacity of the existing pipeline. The pipeline capacity expansion considers to keep the pipeline MAOP, line size, and wall thickness unchanged. New pump stations will be added and existing pumps may be upgraded to achieve higher operation pressure and flow rates in different phases. The expansion project respects the installed pipeline limits and follows the ABNT NBR 15280-1 and ASME B31.4 design codes. In addition, the technical analysis considered the engineering and operational basis as follows:

- Products in the pipeline are incompressible liquids and there is no state change at normal operating conditions;
- The pipeline flow is assumed to be isothermal at 20C°;
- The minimum gauge pressure along the pipeline is 1 kgf/cm²;
- The pressure loss in the pipeline can be estimated using the Darcy-Weisbach equation;
- The Colebrook equation based on the effective pipeline roughness is used to assess the Darcy-Weisbach friction factor;
- Available pressure at the suction of the pipeline pump is 0 kgf/cm² gauge;
- The valve and station piping pressure losses are ignored;
- The overall efficiency of the electric Motor driven pump set is around 80%;
- Minimum required delivery pressure at the entrance to the terminal facilities is 6 kgf/cm².

Under the above design basis, the feasibility of capacity increase by adding new pump stations at proper locations is evaluated. Results show that the upgrade requirements can be satisfied by installing two new booster stations. Based on the analysis, the most economical is to increase capacity in three phases as follows:

- Phase 1: Keep the current pumping rate at 1053 m³/h which satisfies the delivery needs without additional investment until year 3 later. The operating conditions of this phase are shown on Figure 3;
- Phase 2: Increase the pumping rate to 1421 m³/h to meet the required ramp-up flow rate until year 6. This requires the installation of the first booster station and the change-out of the head station pumps. An investment of R$ 102 million is needed in year 3. The operating conditions of this phase are shown on Figure 4.
- Phase 3: Increase the flow rate to 1958 m³/h which satisfies the operation flow rate until the end of the ramp-up. This requires installation of a second booster station, and addition of one more pump in the head pump station in order to. An R$ 90 million investment is required in year 6. The operating conditions at this point are shown on Figure 5.

In order to meet the demands and guarantee the safety of the Project, hydraulic simulations are carried out under the operation conditions using the Sinergy Pipeline Simulator 10.1. by DNV Both steady state and transient hydraulics simulations were conducted for normal operating and abnormal operating conditions.

The simulations at normal operating conditions include pipeline start ups, controlled shut-down, and batch operations for all of the phases of capacity increase. The transient simulations at abnormal operating conditions include situations such as unexpected block valve closure and pump station power failure. The system operational safety is guaranteed by the simulation of all the normal scenarios with pressures below the MAOP shown in Figure 2, and all the abnormal transient scenarios that have values less than the MAOP plus 10%.

As this is an existing pipeline, the following equipment and devices need validation, change-out or calibration:

- Instruments and valves (on-off and control);
- Interlocks for transient pressure pumps shut-down; PSV: change or validate suitability;
- Suction piping: $NPSH_a$ (Net Positive Suction Head – Available) and $NPSH_r$ (Net Positive Suction Head – Required) validation;
- Power supply: suitability of substations and new power line installation to the new booster stations;
- Tanks: modifications to accommodate new flows.

The maximum pipeline pressures are presented in Figure 6. When of the pipeline flow capacity raises 1958 m³/h the pipeline velocity is increased to 3.6 m/s. However, as noted in Figure 6, the maximum surge pressure is mitigated below the allowable surge pressure by proper setting of the receiver PSVs and controlled pump shutdown in case of overpressure.

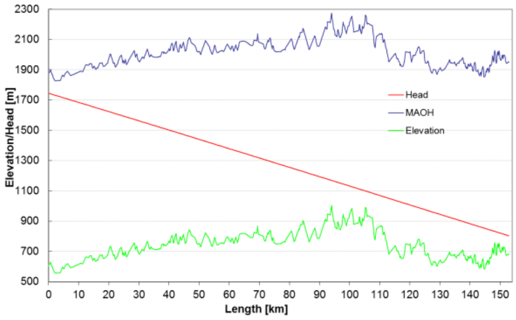

Figure 3, Phase 1

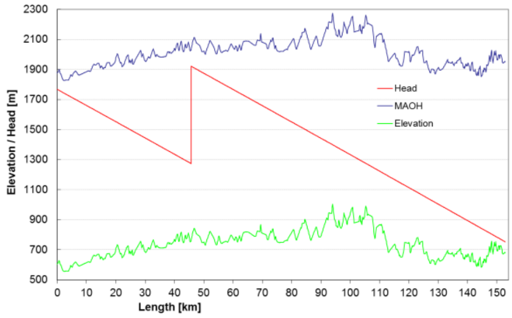

Figure 4, Phase 2

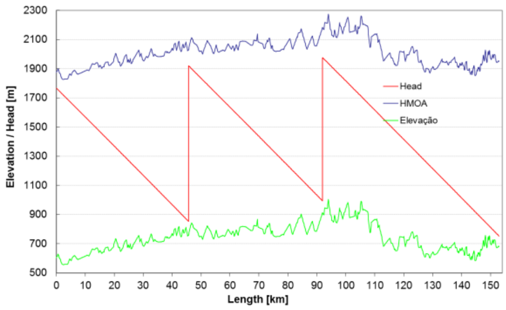

Figure 5, Phase 3

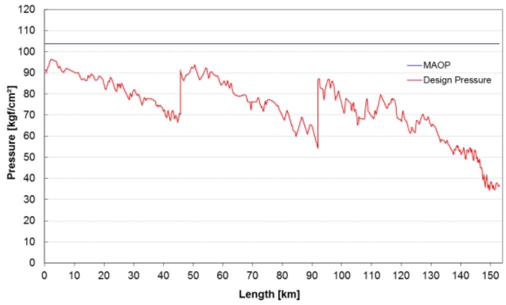

Figure 6, Design pressure

The CAPEX (Capital Expenditure) and OPEX (Operational Expenditure) brought to present value at a discount rate of 11.32% are presented in Table 1. These values assume the following:

- Fixed installations: the cost of land for new stations, substations, motorized and manual valves and pipe;
- Pumps and variable speed drives and their installation;
- Electrical supply, instrumentation, automation and communications;
- Construction and assembly;
- Environmental studies;
- Other costs.

Table 1, Solution A

CAPEX	OPEX	Total Cost
R$ 135,048,000	R$ 336,550,000	R$ 471,598,000

From the point of view of environmental considerations, these are one-off project expansions of an existing operation, as spelled out by Brazilian Conama n° 01/1986 e n° 237/1997. The environmental licensing process will be conducted in simplified form for low environmental impact interventions. Considering regulatory deadlines for environmental licenses review and issuance, environmental studies preparation time and construction; previous Logum process experience indicates a 2 year project timeline to operate, the details are presented in Figure 7. As shown in Figure 1, the capacity increase will occur only in the fourth year, thus the licensing process does not impact the overall schedule.

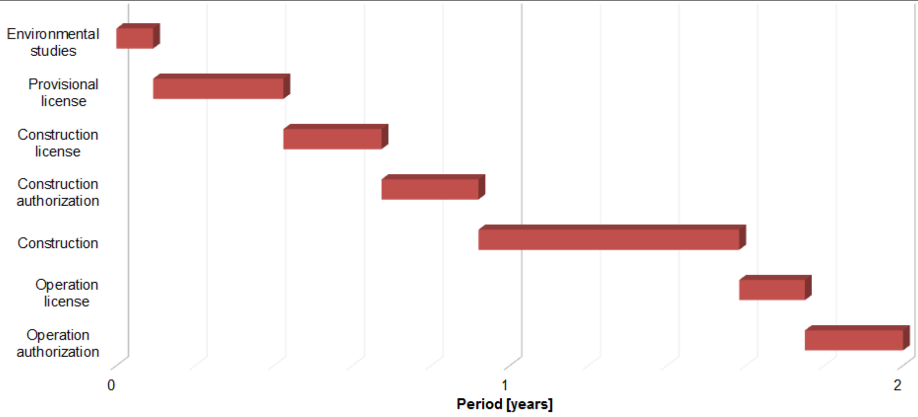

Figure 7, Solution A Environmental process timeline

2.2. Solution B: New Pipeline

As shown in item 1, solution B considers constructing a new pipeline to transport the excessive volume that the existing pipeline cannot handle (in red on Figure 1). As this is a new pipeline it is assumed that a right-of-way increase of 10 meters is necessary to the ROW used by the existing pipeline. This study considers the acquisition of this land and applicable environmental legislation.

In conformance with Brazilian Conama n° 01/1986 e n° 237/1997, pipeline transportation activity is considered to be of high environmental impact, thus necessitating the production of an Environmental Impact Analysis (EIA) and an Environmental Impact Report (RIMA). These documents assess the environmental impact inherent to the enterprise and are needed to obtain the environmental licenses (LP, LI and LO) from the governing environmental authority. In this case, considering the time necessary for regulators to analyze and issue environmental licenses, the time to prepare environmental studies and then construct the pipeline; based on Logum previous experience, the estimated time is 4 years to reach commercial operation. The detail is shown in Figure 8.

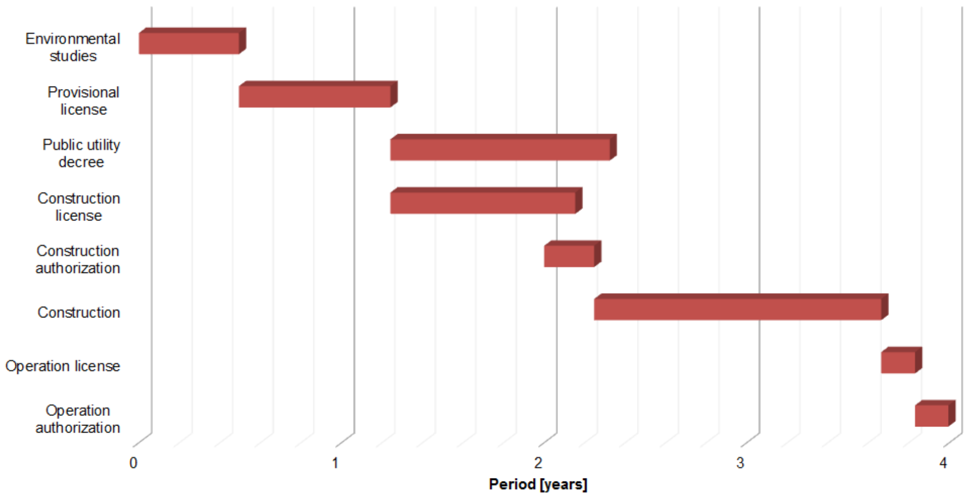

Figure 8, Solution B Environmental process timeline

As shown the new pipeline solution requires minimum 4 years to be ready for commercial operation. Thus in the fourth year the required pipeline capacity cannot be met which means a revenue loss. The new pipeline project basis considers metrics and values used by Logum for the design and construction of their system. Simulations made consider CAPEX investment with OPEX brought to present value at 11.32% per annum. The solution that produces the lowest total CAPEX and OPEX is the best alternative. The value of the OPEX considers staggered energy consumption due to ramp-up.

This study considers 12 cases with pipeline diameters of 14, 16, 18, 20, 22 and 24 inches with or without intermediate booster stations. The engineering and operational assumptions are the same as used for the expansion of the existing pipeline. The parameters considered in this study are:

- Fixed Installations: cost of new stations (if necessary) including land, substations, motorized and manual valves;

- Pumps and variable frequency drives and their installation;
- Electrical supply, instrumentation, automation and communications;
- Pipeline construction;
- Pipeline steel pipes;
- Pipeline ballast;
- ROW widening;
- New ROW land aquistition;
- Environmental studies;
- Other costs.

The solutions cost (CAPEX plus OPEX) in present value terms for the 12 cases is presented in Figure 9. Based on the results the lowest cost solution selected is an 18 inch diameter pipeline, with a design flow of 905 m³/h and without any booster stations. The hydraulic gradient of this solution is shown on Figure 10. The CAPEX for this solution is estimated at R$ 815 million and is distributed over the 4 year construction period. The CAPEX annual distribution considered 6.13% on the first year, 27.89% on the second year, 41.34% on the third year and 24.64% on the fourth year. Table 2 presents in present value the solution B cost.

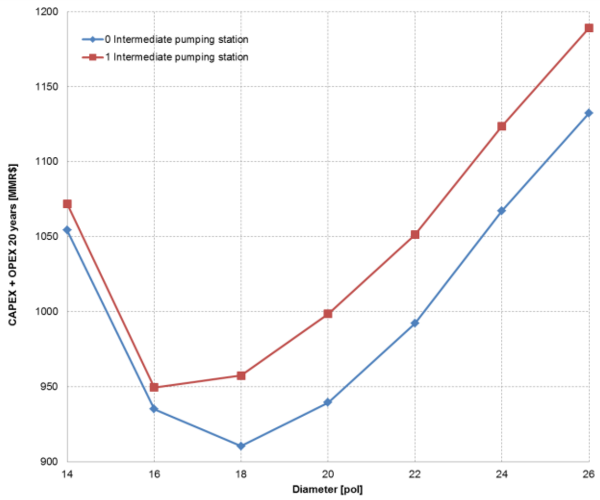

Figure 9, Solution B – Results

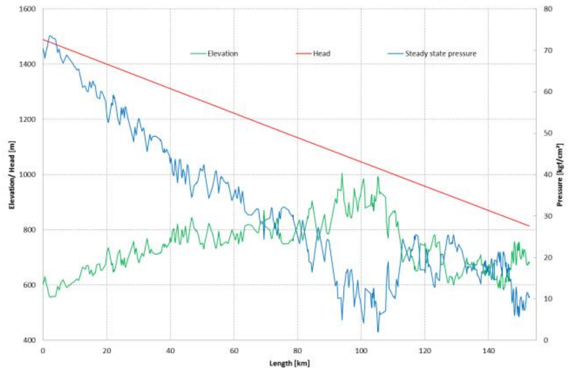

Figure 10, Solution B

Table 2, Solution B

	CAPEX	OPEX	Total Cost
New Pipeline	R$ 699,153,000	R$ 59,230,000	R$ 758,384,000
Existing Pipeline	R$ 0.00	R$ 119,066,000	R$ 119,066,000
Total [R$]			R$ 877,450,000

2.3. Results comparison

In order to analyze the best solution, the highest NPV (Net Present Value) for expansion capacity is sought. Simplified, a tariff revenue estimate using R$ 45.00/m³ of pipeline freight is used. In the case of Solution A, there is no revenue loss, since the ramp-up schedule is not impacted by the physical plant expansion. In the case of Solution B, due to the time required for the licensing and construction steps one year of revenue is lost.

In this way for Solution A, the constructed cash flow considered the product tariff revenue times the volume pumped subtracting the energy consumed and the CAPEX in each year of investment. Solution B cash flow was constructed considering the product tariff times the volume pumped (by both the new and existing pipelines also considering the year of lost revenue) subtracting the energy consumed in the two pipelines and the CAPEX in the year of the investment. The new pipeline construction CAPEX is divided in equal parts along the 4 years of the project licensing and construction. Figure 11shows the resulting cash flows for the two solutions.

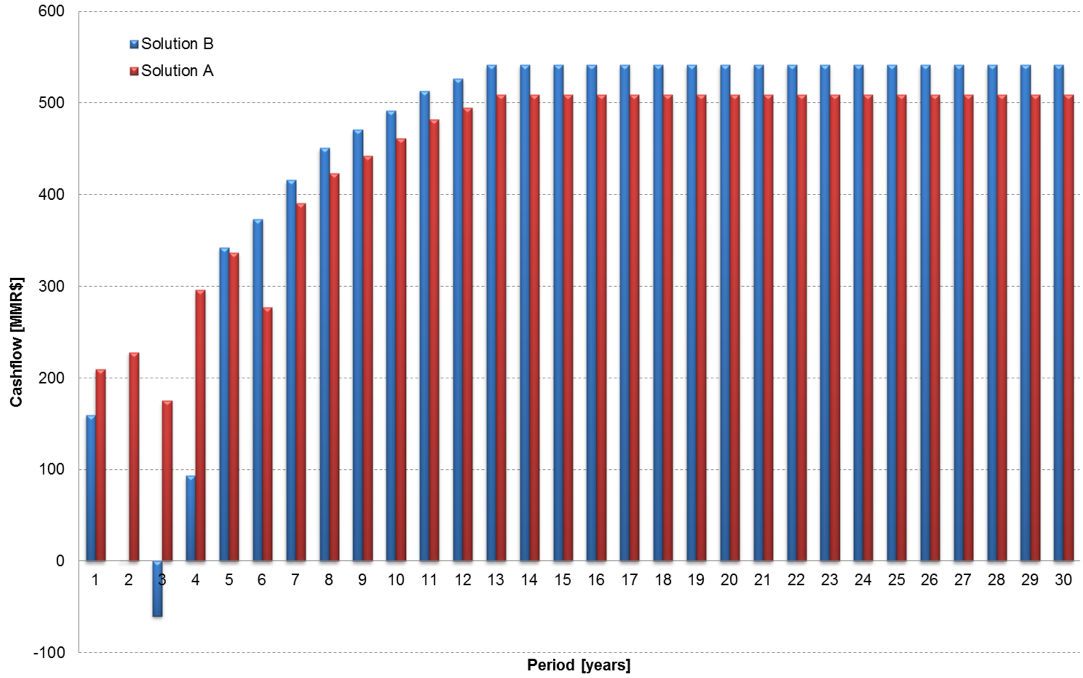

Figure 11, Cash flow for the solutions

These cash flows when brought to present value brings results as follows:

- Solution A NPV: R$ 3.3 billion
- Solution B NPV: R$ 3.1 billion

In qualitative terms, Table 3 represents the Solution A pros and cons, and Table 4 the Solution B pros and cons.

Table 3, Solution A pros and cons

Pros	Cons
Highest Project NPV	
In case the transport volumes do not materialize it will be possible to stop the expansion and avoid unnecessary expense	The system is taken to its limit making further expansion practically unviable
Shorter implementation schedule	
Lower maintenance costs due to fewer assets	System has no back-up capacity
No loss of receipts due less time for licensing and construction	Risk based on the energy cost increase
Low environmental impact resulting from the project implementation	

Table 4, Solution B pros and cons

Pros	Cons
Capacity for future expansion	Lower project NPV
In the case where the existing pipeline is stopped for maintenance, operation can continue with restrictions	In the case where the ramp-up volumes do not firm up, the investment has already been made – pipeline has idle capacity Higher maintenance costs due to a larger quantity of assets Larger insurance costs due to larger asset value Higher environmental impact due to project implementation

2.4. Flow velocity analysis

For a new liquid pipeline, the flow velocity is critical in the selection of economical pipeline diameter. Simply put, the economics are a trade-off between the capital cost (CAPEX) and the operation costs (OPEX), the OPEX being mostly the energy consumed in pumping.

The principle codes and standards for transportation of petroleum liquids are generally silent on the subject of operating velocity. Mo Mohitpour et al. present recommendations where there is the possibility of erosion or static electricity generation, applicable to pipelines carrying liquids with the following characteristics:

- Liquids of low vapor pressure possibly containing suspended solids – sand – in the erosive case;
- Liquids of low or high vapor pressure in the case of static electricity.

A product with vapor pressure below 110 kPa at 38°C is considered a low vapor pressure product. Ethanol is a low vapor pressure product with a vapor pressure of approximately 40 kPa at 38 °C. In both cases, the recommended velocity limit is 5 m/s; a value above the maximum velocity of the pipeline expansion project. Considering that solid particles are very rare to be formed in ethanol pipeline, the maximum velocity due to erosion will be much higher than 5 m/s. DNV RP O501 says: "Erosion may occur in the parts of the system containing sand particles or other solid particles. For systems not containing solid particles, no velocity limitations with respect to erosive wear will apply...".

API RP 14E presents a practical recommendation for preliminary sizing of offshore production piping which indicates the maximum flow velocity limit to be 15 ft/s (4.6 m/s). This value is obtained by the empirical expression presented in API RP 14E for two-phase flow based on a gas/liquid ratio being zero. ABNT NBR 17505-5 presents the requirement that flow velocity entering storage tanks, in order to prevent formation of static electricity charge:

- Cannot be greater than 1 m/s until the filling pipe is submerged by two times the diameter of the pipe, or 0.6 m whichever is less;
- Can reach up to 7 m/s, when the filling pipe is submerged.

It is obvious that the line velocities for the two options presented in this paper are within the acceptable range based on the limited known restrictions in the design code and recommended practices.

3. Conclusions

In view of the above, the two proposed solutions meet the ethanol supply demands. Technically both systems are able to operate safely and reliably. Analyzing from the economical point of view, Solution A represents the highest return on investment and because it is be staged, the business risks are reduced should the needed volumes not materialize. On the other hand, Solution B presents an opportunity to expand the system should higher than planned volumes materialize.

As shown in this paper, the flow velocity of 3.6 m/s is in no way an impediment to Solution A, and even with higher power consumption the solution is economically viable.

Due to the longer project duration, Solution B is economically impacted by one year's revenue loss. It is important to point out that if the growth rate of the ramp-up curve is faster, the revenue loss is even greater.

Finally, it should be emphasized that the current projects and especially those operating at the highest velocities must be modeled thermo-hydraulically with reliable and trusted simulators to assure safe operations.

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