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STUDY OF CRITERIA AND PROCEDURES TO OBTAIN THE MAXIMUM OPERACIONAL PRESSURE PROFILE IN PIPELINES

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Abstract

The maximum pressure profile of a pipeline must obey certain criteria and procedures to ensure the operational safety, obeying the standard ASME B31.4.

To obtain the maximum pressure curve, a computer model of the pipeline is created and the pressure along its length is simulated. The simulation calculates the steady state of each product transported by the pipe, the transient state of a product dislocating another and the transient of possible operational failures.

The pressure control valve (PCV), installed at the downstream of pumps or at the upstream of the receiving terminal can alter the maximum pressure results if they are active during the transient state. The controller's PID of a PCV can also affect the results. If the PCV fails, the fail safe mode (open, close or remain at the same position) also have to be considered. There is an adequate fail safe mode for the PCV depending on its operational function at the pipeline.

The interlocks also change the maximum pressure results when considered. The interlocks can be local (linked directly to a pressure gauge near a pump, for example) or remote (for instance, a satellite connection that stops the pump when the receiving end block valve closes). The remote interlock should only be consider if the communication of the remote system if reliable.

This study analyses the most reliable criteria and procedures used for thermal-hydraulic simulations to acquire the maximum pipeline pressure and the influence of different configurations on the pipeline project.

1. Introduction

The increasing rise of production, refine products and as consequence the transport of oil products using pipelines brings a necessity to create new pipes or enhance the existing ones. In the selected process, regularizations and standards must be followed regarding pipe and equipment projects.

To ensure a safe pipeline construction and operation, the American Society of Mechanical Engineers (ASME) created the standard ASME B31.4 (Pipeline Transportation Systems for Liquid Hidrocarbons and Other Liquids) that presents the requirement for pipeline projects.

This paper presents the requirements to obtain the Maximum Allowed Operating Pressure (MAOP) and studies the criteria and procedures to obtain the Maximum Operating Pressure (MOP) and the Maximum Transient Pressure (MTP).

2. Requirements of PMOA

The MAOP of each point of the pipeline is defined by the smallest value between the hydrostatic test divided by 1.25 and the project's pressure, calculated using equation (1).

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$$Pi = \frac{2\,S\,t}{D} \tag{1}$$

Where,

Pi = internal design gage pressure [psig]
S = applicable allowable stress value [psi]
t = nominal wall thickness [in]
D = outside diameter [in]

According to ASME B31.4, the MAOP should not be crossed during normal operation, such as steady flow, the starting and stopping of pumps, and the hydrostatic condition of the pipeline while stopped, for all transported products. Therefore, the MOP should not cross the MAOP.

In the transient cases, the MTP cannot cross the MAOP added 10% of its value (MAOP+10%).

3. How to obtain MOP and MTP?

The solution for pipeline flow involves the determination of the fluids properties according to the position in space and time. For such, the laws of classical mechanics and thermodynamics.

To obtain the flow and pressure along the pipeline in steady state is simple. However, when there is a need to know the maximum pressure along the pipeline due to an event that varies with time, the solution for the equation requires complex numeric solution, implemented in known computer simulation programs. To allow the program to calculate the problem at hand, a model of the pipeline must be created. This model usually is built using the programs own computer language and must be created with caution. A mistake in the model or the interpretation in how to transport the reality of the pipeline to the model accordingly to the programs limitation can lead to results that do not represent the phenomenon studied.

But it isn't just the correct modeling of the pipeline that guarantees good results. It's necessary to pay attention to a number of criteria's and procedures used during the transient simulation.

4. Criteria's and Procedures during the Transients Simulations

The criteria and procedures used during a transient state of a pipeline simulation influence heavily on the outcome result of the MTP.

4.1. Scenarios and Steady State

The first step on a transient state pipeline simulation is deciding which scenarios will actually be simulated. The transient occurring normally during the operation of the pipeline, such as starting and stopping the operation of the pipeline, set-point changes, changing the numbers of operating pumps must be separated from the unusual transient, such as irregular or unscheduled block valve closing, pumps stopping due to lack of power.

The MOP will be composed by the steady state with each product transported by the pipeline, the transient of starting and stopping the operation and the batch operation with the less viscous product pushing the most viscous product.

The MTP will be composed by all unusual transients that the pipeline can be imposed. Generally speaking, it's recommended to simulate the irregular closing of motorized valves and receiving ends valves (i.e. on scrapers).

4.2. Products

The next step is to check the products transported by the pipeline, which results on the maximum pressure and flow during the steady state. Those will probably be the ones generating the highest pressure during the studied transient state. Nevertheless, it's recommended to simulate the transient state with all products transported on the pipeline.

Besides the products themselves, the transportation of more than one product on the pipeline can causes higher pressures then an individual one. If a low viscosity product "pushes" a medium or high viscosity product, it will probably create a higher MTP then either product alone, depending on the difference of the viscosity, the elevation profile, flow, and the densities.

The Figure 1 show the pressures of steady state of a example pipeline with two products e the batch between them.

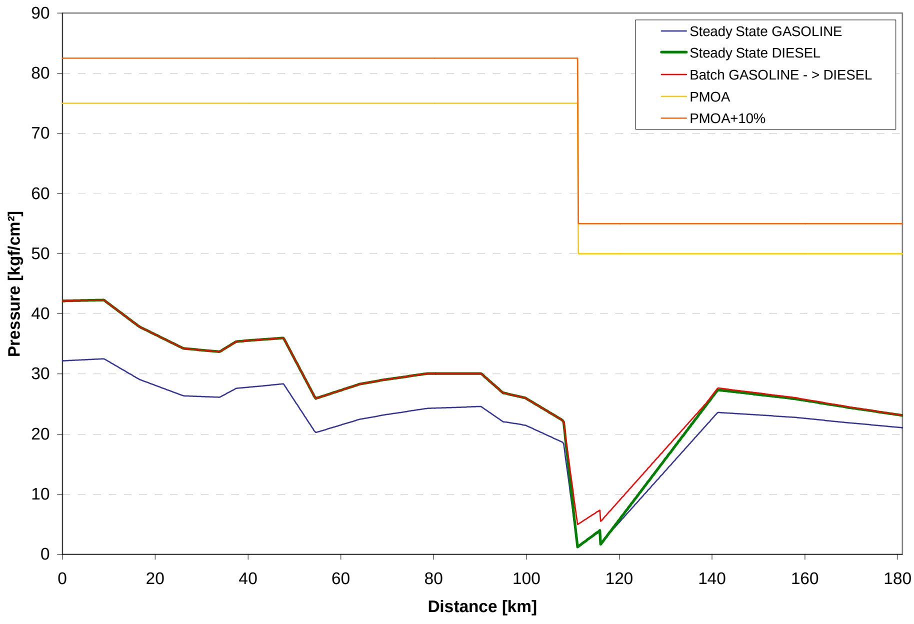

Figure 2. Pressures on the steady state and batch

The maximum pressures of batch are over than the pressures in steady state with a simple product.

4.3. Pressure Control Valve (PCV)

The pressure control valve can have an important role during a transient state. Depending of the control system of the valve, it can reduce the maximum pressure due to an operational glitch. In example, if a block valve at the receiving end of the pipeline closes and the pumps have a PCV in the discharge, it will close as the pressure wave arrives at the sending end of the pipeline, reducing the pressure in said point.

It's recommended to simulate the transient state with the PCV operating and in their fail mode. Usually, the maximum pressure occurs when the PCV has failed. There are, however, three types of fail mode for a PCV: fail close, fail open, of fail stay. Each fail mode can be more or less critical depending on its position on the pipeline and configuration. For a PCV installed at the discharge of the pumps, the fail open is the most critical for the pipe, because it stops controlling the sending pressure, causing it to go higher. In the receiving end, however, the most critical one is the fail closes, because is blocks the pipeline. There for, it's extremely important to know the PCV type on the pipeline to accurately model the transient. When the information is unavailable, the worst case must be considered.

The Figure 2 represents an example of a pipeline with PCV on both ends. The PCV at the pumps discharge has a set-point pressure below the pumps shut off point. This model represents the usual equipments installed on pipelines.

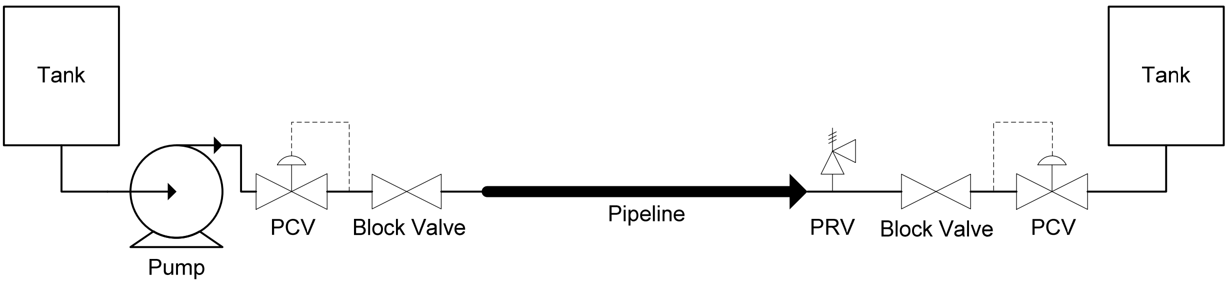

Figure 2. Model workflow

The Figure 3 represents the elevation profile of the pipeline and the thickness variation. The elevation has a peak that causes a need for a higher pressure control on the receiving end. The thickness variation explains the MAOP change at the peak point. The thickness, the material, the diameter can all influence the MAOP value.

The Figure 4 represents the pressure along a pipeline during the steady state, the maximum pressure during the closing of the receiving end block valve with and without the PCV working at the pump's discharge.

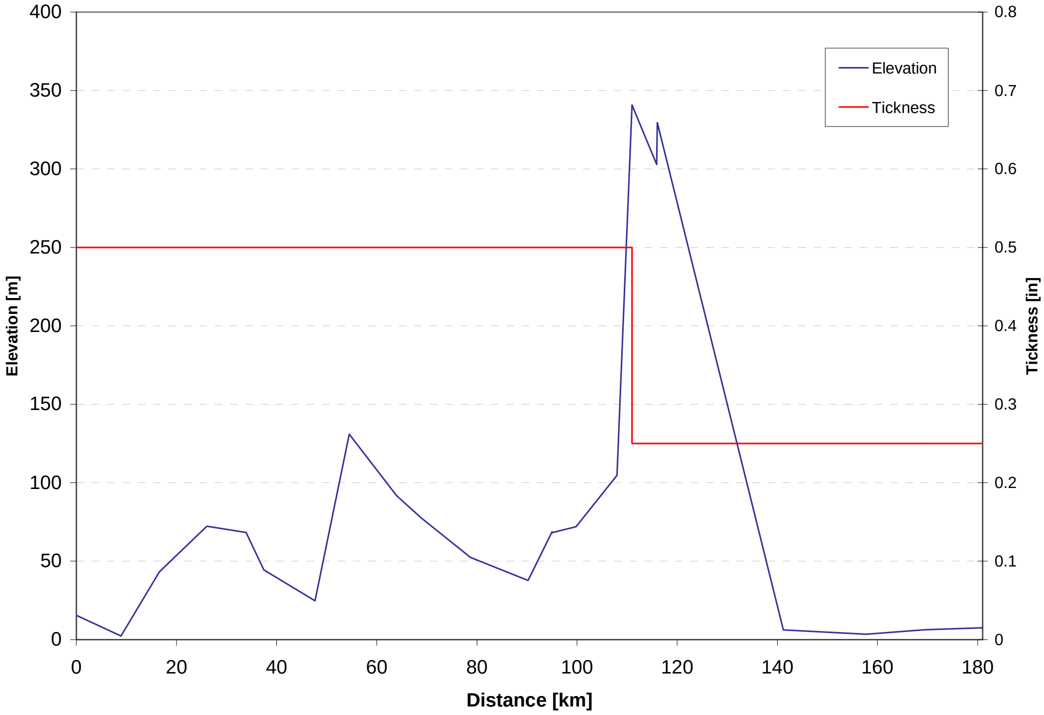

Figure 3. Elevation profile and thickness variation along the pipeline

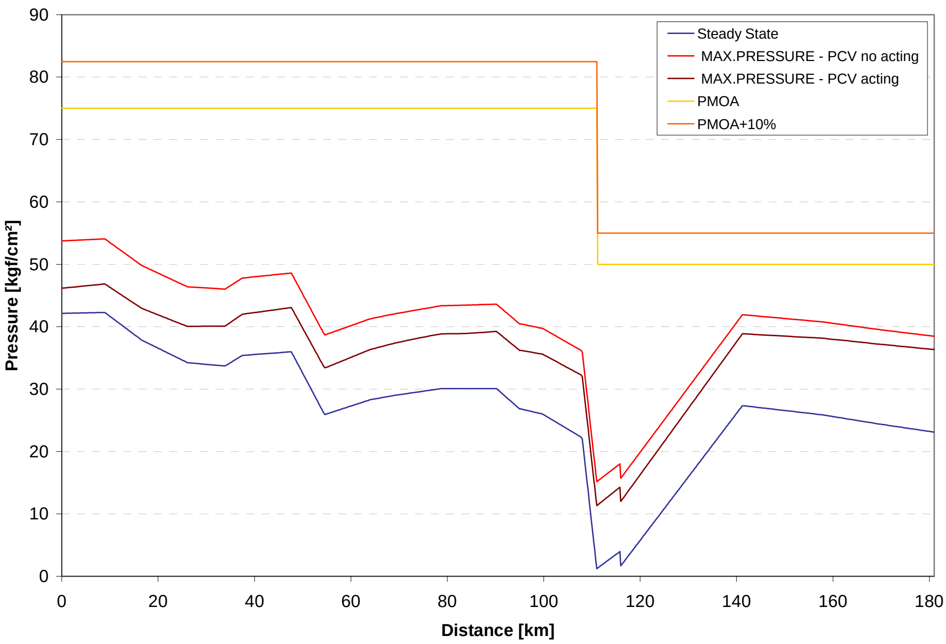

Figure 4. Maximum pressure of the scenario of receiving block valve closing with and without an acting PCV

Another important characteristic of the PCV are the PID parameters and the actuator speed installed. They define the valve response time during a transient state, which in turn will directly influence the maximum pressure during the transient state. This matter is exposed in the paper "Análise das Variáveis Relacionadas ao Projeto de Operação de Oleodutos com Coluna Cheia" by Silva et al., quoted on the references, which focus on the pressure during the starting and stopping procedures of a pipeline.

4.4. Pressure Relief Valve (PRV)

The pressure relief valves are the usual security components design to act during abnormal transient state and avoid that the pressure along the pipeline reaches MAOP+10%. There are several models of relief valves, although in Brazil, the most commonly used is the spring relief valve. Most of commercial pipeline simulator doesn't have this kind of equipment model, making it necessary to adapt the existing equipment to have a similar response of an actual spring relief valve. Other types of relief valves also suffer from the same problem, which make the modeling a complicated affair when comes to relief valve. Most programs do have an idealized relief valve, but it doesn't have the same response of any actual relief valve, making it difficult to acquire a precise solution.

Usually it's necessary to have more than a single valve to assure that the pressures during the most sever transient states stay below the MAOP+10% line. When there are multiple PRV installed on a pipeline, they are installed in parallel.

It's recommended to have at least more than one PRV installed on a single location in order to allow a maintenance schedule without having to stop the pipeline operation. The PRV needs to be periodically checked for maintenance and calibration. If the possibility exists for the pipeline to operate without a PRV removed for these reasons, then it shouldn't be consider during the transient state simulation to obtain the MTP.

Another important point is the pipes that link the relief valve to the relief tank. It will determine the back pressure of the relief valve, along with the relief tank's pressure. If the relief pipe is extensive, the pressure drop will increase the back pressure of the relief valve reducing it's efficiency. The Figure 5 show maximum pressure profile of pipeline when de receive valve close considering a small and an extensive relief pipe with 10" diameter and 500 m of equivalent length. This example pipeline has 32" of diameter and 1350 m³/h of standard flow

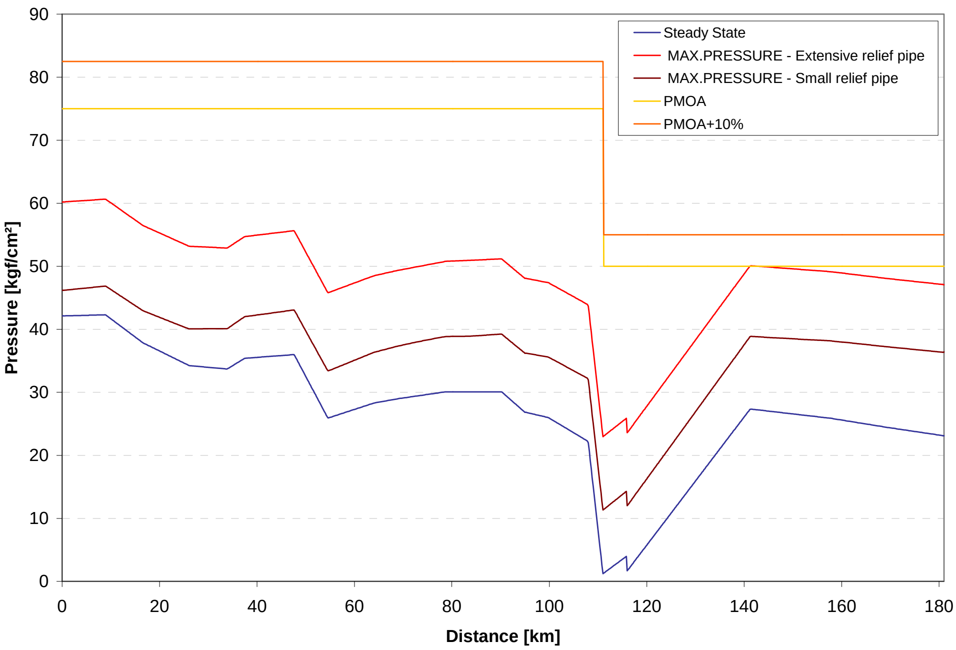

Figure 5. Maximum pressure with a small and an extensive relief pipe

4.5. Shut Down Valve (SDV)

During some transient states the pressure on the internal lines of the stations may cross the pressure limits without affecting the pipeline, because the internal lines are usually of a smaller class then the pipeline. The Shut Down Valve (SDV) is usually located on the receiving station, and is set to protect the station from high pressure on the pipeline. When the pressure hits the set point, they immediately close, separating the station from the pipeline. The SDV can also be located on the suction end of the pumps, to prevent high pressures on a transient state. They can be linked with interlocks, stopping pumps or closing valves to protect the pipeline and the stations.

Therefore, if a pipeline has an SDV, it must be considered in the pipeline modeling and in the simulation of the abnormal transient states. For example, on a case where the pipeline has a much higher MAOP then the receiving station, it's more interesting to have a SDV then a PRV. The PRV requires internal pipes, a relief tank and several equipments, while the SDV has no need for more equipment, which is extremely useful in areas of difficult accessibility.

4.6. Interlocks

Interlocks are programmed actions that occur with several equipments when certain conditions are met. The interlocks exist to protect the pipelines and the stations. There most usual function is to close strategic valves and shut down pumps. Unlike the SDV, the interlocks are link with several electronic sensors, communications devices and actuators that can have an effect along any place on the pipeline. An interlock can both close the receiving end valve and stop the pumps at the sending end of the pipeline.

The interlock is called remote interlock, for example, when the pressure is measure in the receiving end and the action is taken at the sending end (i.e. stopping the pumps). Because this actions depends on several power based communication and actuators devices that can fail during a power shortage, they cannot be consider during the gathering of the transient state MTP.

When the measure point and the acting point of the interlock are close together and in the same station, they are called local interlock. The local interlock should be consider in the MTP simulations, as long as there are redundancy in the measurement process and the energy supply is guarantee sing a back-up system (i.e. No-break).

4.7. Pumps

If there isn't any local interlock shutting down the pumps, they must be kept turned on during the transient state simulations, because they provide the energy to obtain the maximum pressure on all the intended scenarios. The procedures to keep the pumps running emulates a slow response time from the pipeline operator to shut the pumps down during an abnormal transient state.

The Figure 6 show maximum pressure profiles of pipeline when de receive valve close and the operator response in 5 min, 10 min and no response stopping the pumps

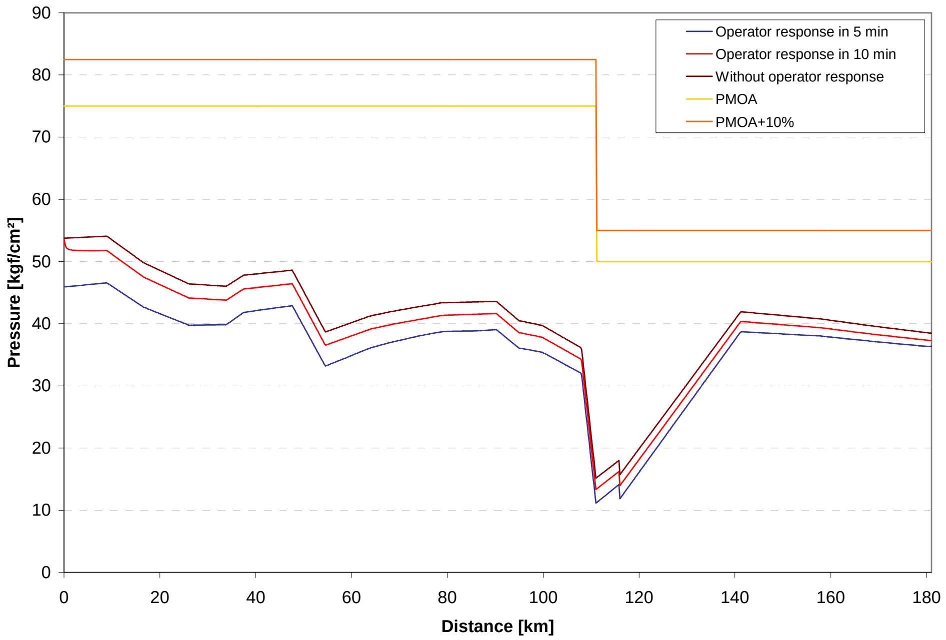

Figure 6. Maximum pressure with and without a response from pipeline operator

5. Composition of Maximum Pressures in the Transients Simulations (MTP)

After the simulations are finish with the correct model and considering all the necessary scenarios, criteria and procedures relevant to pipeline in study, the maximum pressure in each scenario must be treated to obtain the Maximum Transient Pressure (MTP) curve along the pipeline.

The pipeline simulation software generally have a internal function to store the maximum pressure during a simulation on a given period of time. To create the maximum pressure of all scenarios simulated it's necessary to add a column using a commercial spreadsheet software to search for the highest value on a given position. For that, is also necessary to have to pipeline elevation profile to determine each point. The following columns are the results of each scenario and after that the maximum value of each line. The Table (1) shows an example of a MTP composition. The

MAOP and MAOP+10% value along the pipeline where also added. In this case, the pressure used was the project pressure, but after an hydrostatic test, the MAOP tends to very accordingly with the elevation profile.

Table 1. MTP Composition

Lengh [km]	Scenario A [kgf/cm²]	Scenario B [kgf/cm²]	Scenario C [kgf/cm²]	MTP [kgf/cm²]	MAOP [kgf/cm²]	MAOP+10% [kgf/cm²]
0	12	14	15	15	20	22
1	11	13	15	15	20	22
2	10	12	15	15	20	22
3	9	11	15	15	20	22
4	8	10	16	16	20	22
5	7	9	7	9	20	22
6	6	8	6	8	20	22
7	5	7	5	7	20	22
8	4	6	4	6	20	22
9	3	7	3	7	20	22
10	2	8	2	8	20	22

6. Conclusions

To obtain the maximum pressure on a pipeline a termo-hidraulic simulation must be carefully study. In this study it's necessary to have faithful numeric model of the pipeline, using an adequate simulator and defined which scenarios must be simulated. It's extremely important to not only define the models and scenarios but also the operating procedures during the simulations to guarantee that the results found will corroborate real life maximum pressure results, which can prevent and secure future problem on a pipeline operation. If the model, scenarios or procedures aren't as close to reality as possible, it may result in misunderstanding that can have catastrophic accidents.

7. Acknowledgements

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