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DEVELOPMENT OF A SECURITY DEVICE TO SLUG FLOW DETECTION APPLIED TO THE RICH GAS SUPPLY SYSTEM USING ANSYS CFX®

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Abstract. *The purpose of this paper is to describe the procedures for development of safety device to detect biphasic flow in a rich gas pipeline used to supply gas to the steam generator installed on an on-shore oil production field. This work was divided in three parts, as first: device flowchart engineering definition, second: solid modeling and fluid domain extraction, third: Boundary conditions definitions and run simulation and finally analysis of results. The positive results obtained in this work show that in addition to ensuring operational safety also maintains the integrity of operators and facilities, since the gas condensate is very undesirable in combustion systems.*

Keywords: *CFD, Rich Gas, Fluid Dynamics*

1. INTRODUCTION

The state of Rio Grande do Norte is one of the biggest on-shore oil and gas productor of Brazil, this state also is one of the biggest consumers of its own gas production. Many different industrial processes are responsible to this consumption and the greater consumer process is the secondary oil recovery using steam injection.

The oil production stimulation using steam injection is the best choice in reservoir with low API grade oil, the steam generation can be saturated or superheated and steam injection method can be cyclic or continuous in both methods use natural gas as fuel. When natural gas is burned in steam generators, the gas flow must be free of liquid. A great number of industrial processes also need to be free of liquid in the flow lines to prevent incident and some safety interlocking are necessary to guarantee all process.

Several solutions are covered in specific standards codes to gas processing and gas combustion system for example the (API-556, 2011) and (NBR-12313, 2013). However in these codes a differential pressure device to slug flow detection is not used.

2. RICH NATURAL GAS

The rich natural gas has this denomination because in its chemical composition have a significant amount of heavy hydrocarbon fractions and no previous treatment is used in the same condition as produced.

A rich natural gas composition obtained by gas chromatography is shown in the Tab. 1.

Table 1. Chromatography analysis results of a rich natural gas.

Component	Symbol	Volume fraction (%)
Nitrogen	N_2	0.848
Gas Sulfide	H_2S	8.000
Gas Carbonic	CO_2	0.097
Oxygen	O_2	0.000
Methane	CH_4	75.188
Ethane	C_2H_6	9.333
Propane	C_3H_8	8.537

Butane	C_4H_{10}	4.189
Pentane	C_5H_{12}	1.079
Hexane	C_6H_{14}	0.341
Heptane	C_7H_{16}	0.252
Octane	C_8H_{18}	0.092
Nonane	C_9H_{20}	0.020
Decane	$C_{10}H_{22}$	0.014

In oilfield areas sometimes have fuel gas consumption and rich gas is the main source. The schematic flow diagram shown in the Fig. 1, represents a typical steam generation plant using fuel gas supplied by gas pipeline (Souza Junior, 2007).

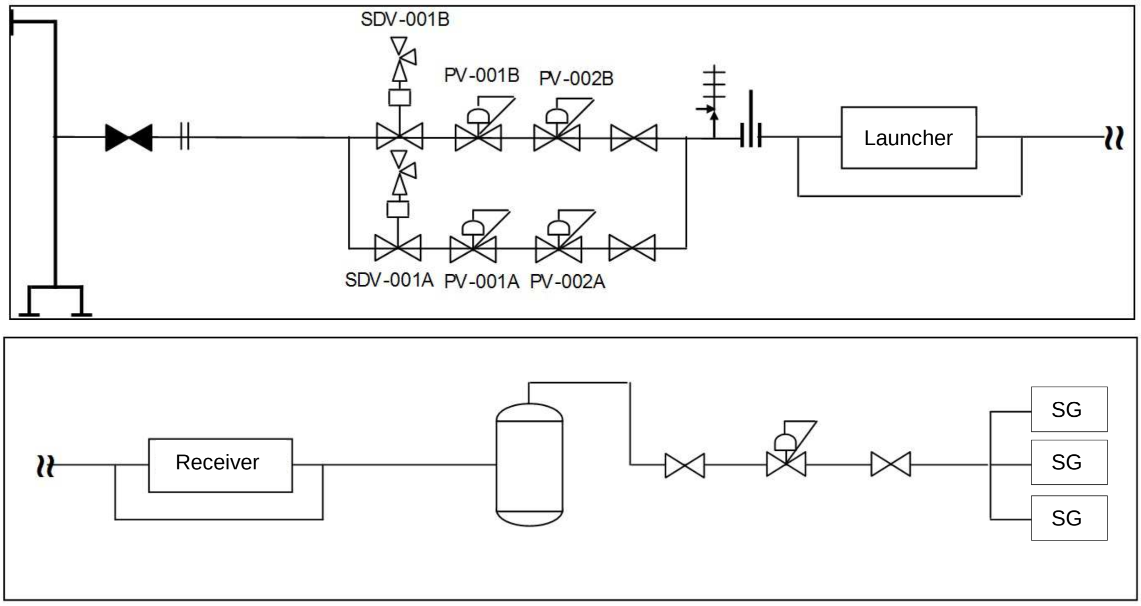


Figure 1. Schematic flow diagram to the typical steam generation plant using rich natural gas.

3. SLUG FLOW DETECTION DEVICE

The development of new devices to use in industrial combustion plant using rich-gas is very important to growing installation reliability and operator's safety guarantee.

The device proposed in this work is similar to an orifice flange meter run designed for use on many different process applications and conditions, its construction is composed of 2 orifice flange and an orifice plate connected to Pressure Differential Indicating Transmitter (PDIT) controlled by PLC (Programmable logic controller) as shown in the Fig. 2.

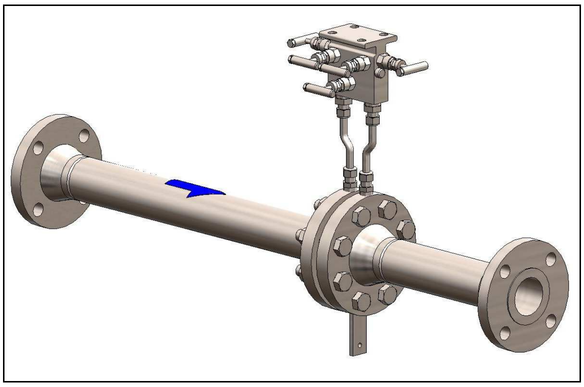


Figure 2. Example of orifice flange meter run (source: idsolutions-acp.com).

The automation principle is based in alarms and interlocks programed to shut down the gas supply when the pressure drop is higher than normal flow without liquid content. The Figure 3 shows a typical engineering process flow diagram to this automation architecture.

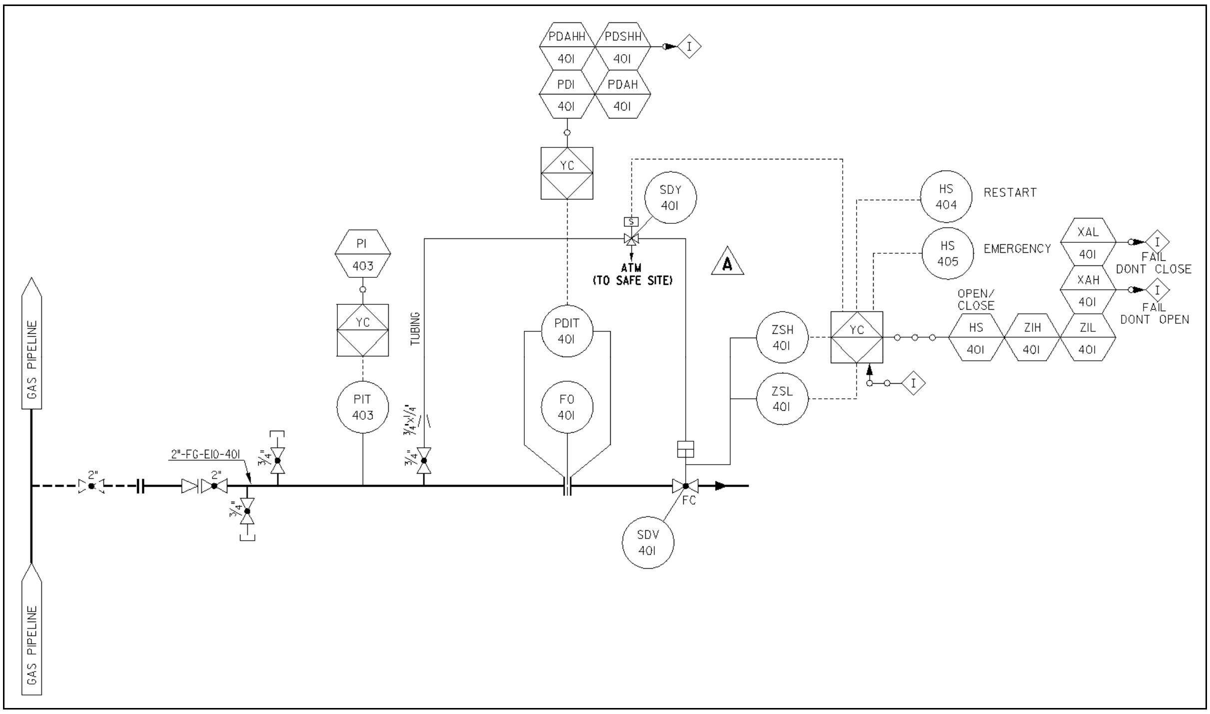


Figure 3. Slug flow detection P&ID.

4. NUMERICAL SIMULATION

In this work the numerical simulations was totally performed using the Ansys-CFX® (Commercial Computational Fluid Dynamic Software Program - CFD) that uses the Finite Volume Method (FVM) to solve all governing equations. The three basic steps are described as:

a) Pre-processing
   Fluid domain modeling and unstructured mesh generation;
b) Solver:
   Setup of boundary conditions and solve differential equations systems;
c) Post-processing:
   Reports and graphical results.

The fluid domain extraction was generated using "fill by caps" tool in design modeler of Ansys Workbench software and the final appearance is shown in Fig. 4.

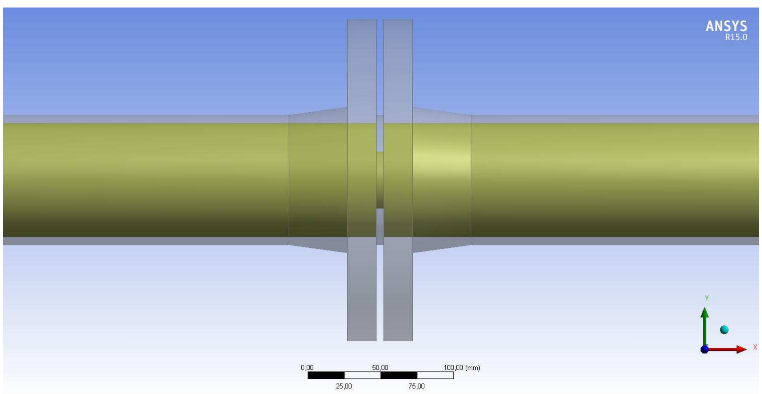
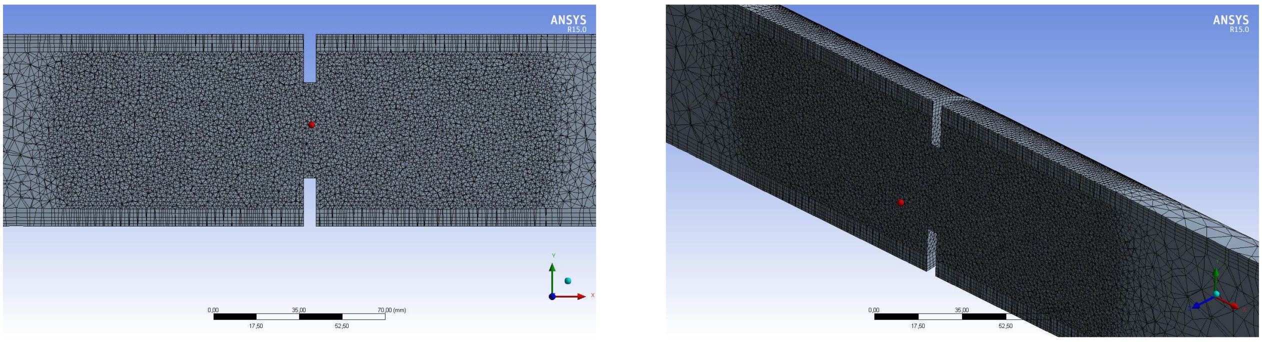


Figure 4. Flow domain extraction in orifice flange pipe run.

Initially the mesh generation choice was set to automatic and the mesh refinement method option “sphere of influence” was applied in the orifice plate proximity regions. As default a great number of elements of fluid domain discretization are triangular type, but in proximity of curved surfaces we used the "inflation method" with five layers prismatic elements (ESSS, 2013).

The Figures 5a and 5b show details of the final mesh.



(5a) (5b)

Figure 5. Unstructured mesh detailing used in fluid domain discretization.

The pipe specification used in the orifice plate meter run was carbon steel ASTM API 5L-Gr. B Sch. 40, nominal diameter 3 inches and the orifice plate was stainless steel AISI-304 thickness 5 millimeter with β = 0,50 (ratio between orifice diameter and internal pipe diameter).

In Table 2, boundary conditions are specified according to the following scenarios.

Table 2. Boundary conditions used in the numerical simulation.

Inlet		**Scenario**
Gas mass flow rate (kg/s)	0,2057	1 - 6
Liquid mass flow rate (kg/s)	0,0000	1
	1,6667	2
	3,3333	3
	5,0000	4
	6,6667	5
	8,3333	6
Outlet		
Outlet relative pressure (kPa)	101,325	1 - 6
Walls	Non-slip wall	1 – 6
Total Time of Simulation (s)	60	1 - 6

5. RESULTS

The differential pressure was measured between probe points 1 and 2 positioned in D and D/2 distance to orifice plate (Delmee, 2003) as shown in Fig. 6.

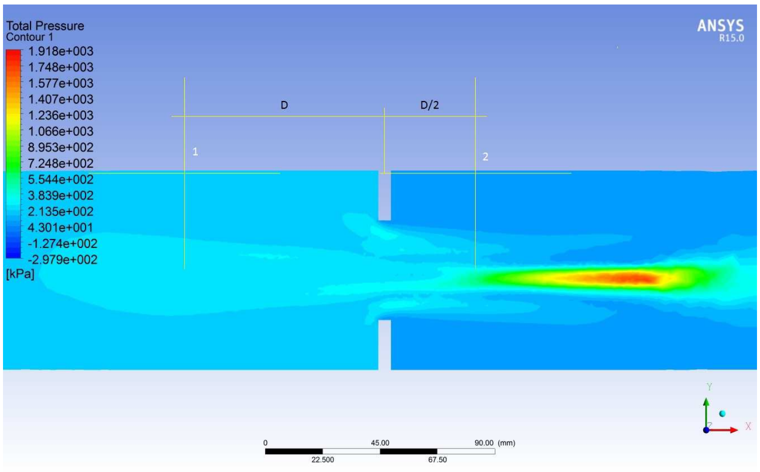


Figure 6. Contour graph for total pressure (scenario 1).

The Figure 7 shows the differential pressure measured between probe points 1 and 2 in total simulation time of 60 seconds and 0 kg/s of mass flow of liquid and 0.2057 kg/s mass flow of gas as setting in scenario 1.

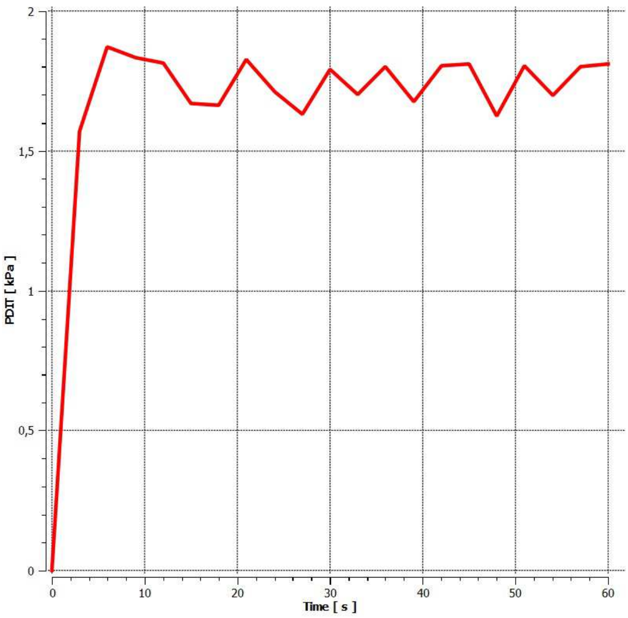


Figure 7. Differential pressure to 0 kg/s mass flow of liquid

Along simulation time the differential pressure measure oscillated between 1,6-1,9 kPa. This low range for differential pressure occurs due the fluid flow without liquid fraction.

The Figure 8 shows the differential pressure measured between probe points 1 and 2 in total simulation time of 60 seconds and 1,6667 kg/s of mass flow of liquid and 0.2057 kg/s mass flow of gas as setting in scenario 2.

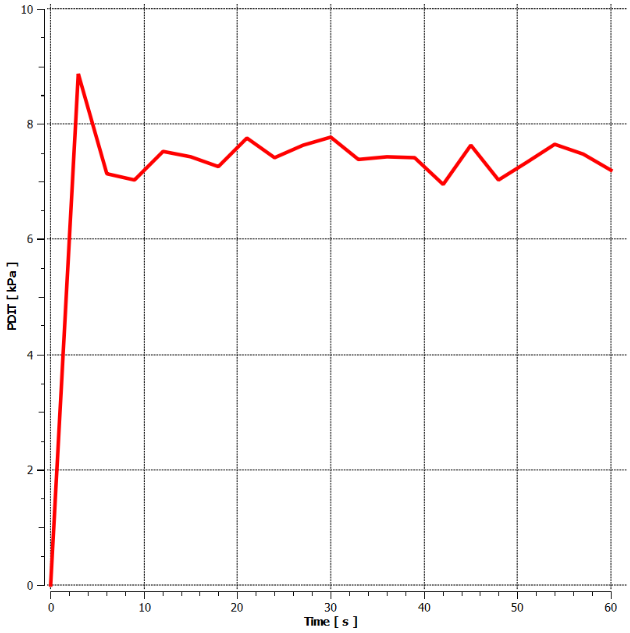


Figure 8. Differential pressure to 1,6667 kg/s mass flow of liquid

With liquid content in fluid flow a noticeable increase in the differential pressure measure occurs and there is a tendency to establish the differential pressure levels between 7-9 kPa.

The Figure 9 shows the differential pressure measured between probe points 1 and 2 in total simulation time of 60 seconds and 3,3333 kg/s of mass flow of liquid and 0.2057 kg/s mass flow of gas as setting in scenario 3, this represents about 235 l/min of liquid into the gas scrubber.

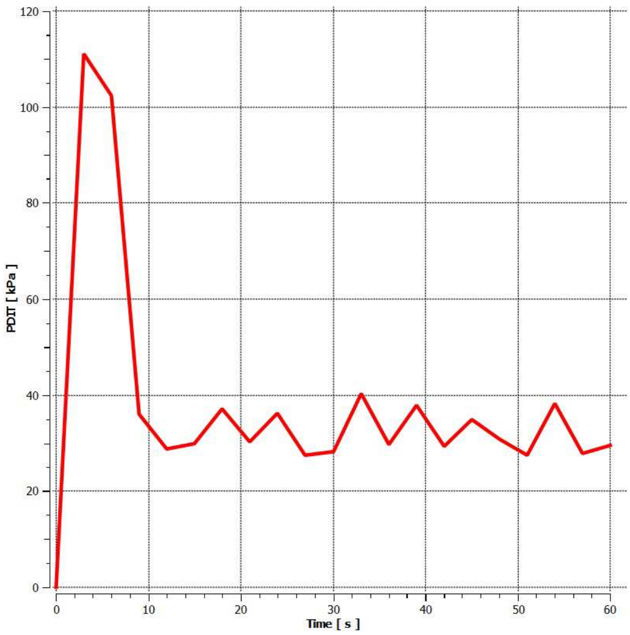


Figure 9. Differential pressure at 3,3333 kg/s mass flow of liquid

In this scenario the differential pressure oscillated between 30-40 kPa. This range is the better point to shut down the SDV-401 because is close to the maximum gas scrubber capacity.

The Figure 10 shows the differential pressure measured between probe points 1 and 2 in total simulation time of 60 seconds and 5,0000 kg/s of mass flow of liquid and 0.2057 kg/s mass flow of gas as setting in scenario 4.

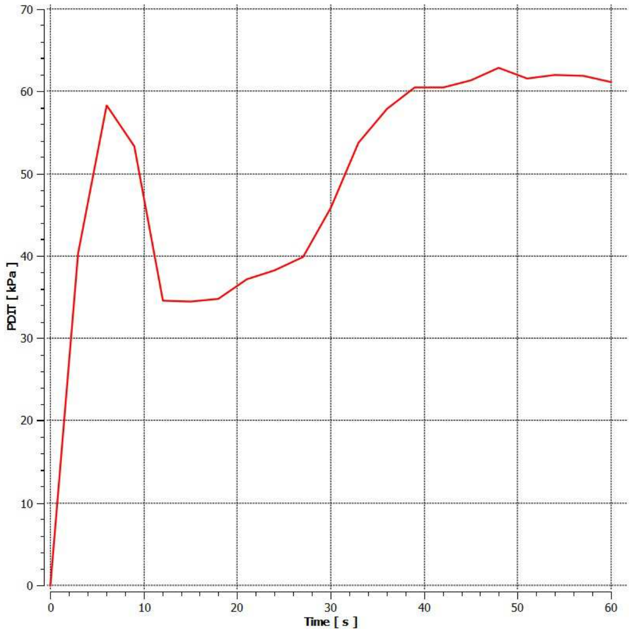


Figure 10. Differential pressure at 5,0000 kg/s mass flow of liquid

In this scenario the differential pressure has a tendency to oscillate between 60-65 kPa.

The Figure 11 shows the differential pressure measured between probe points 1 and 2 in total simulation time of 60 seconds and 6,6667 kg/s of mass flow of liquid and 0.2057 kg/s mass flow of gas as setting in scenario 5.

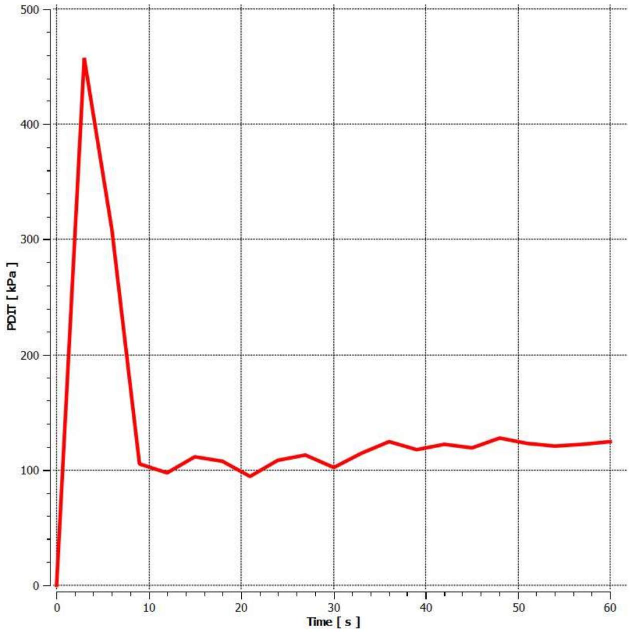


Figure 11. Differential pressure at 6,6667 kg/s mass flow of liquid

In this scenario the differential pressure oscillated between 100-120 kPa.

The Figure 12 shows the differential pressure measured between probe points 1 and 2 in total simulation time of 60 seconds and 8,3333 kg/s of mass flow of liquid and 0.2057 kg/s mass flow of gas as setting in scenario 6.

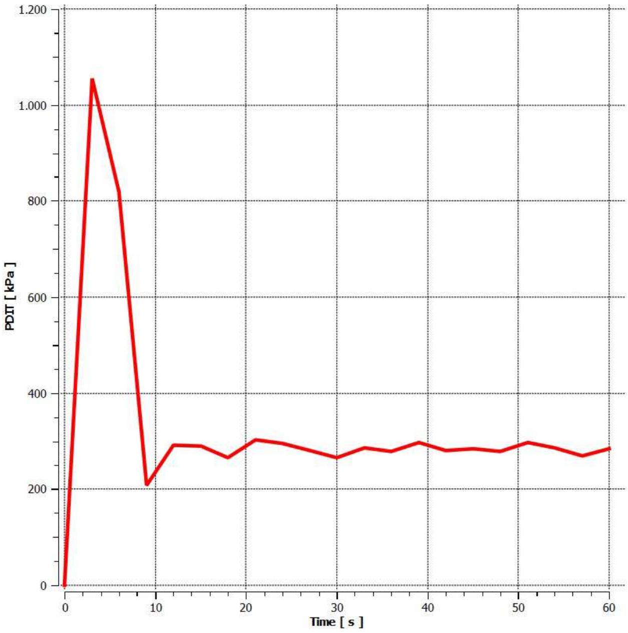


Figure 12. Differential pressure at 8,3333 kg/s mass flow of liquid

In this scenario the differential pressure oscillated between 200-300 kPa.

6. CONCLUSIONS

The main conclusion in this work is the ability to identify what the differential pressure levels should be programmed in the safety interlock system for closing the automatic shutdown valve SDV-401 shown in Fig. 3. For differential pressure values up to 10 kPa is evident that almost there isn't liquid fraction in the flow. For differential pressure values higher than 30 kPa should be considered undesirable presence of liquid in the flow, in this case the safety interlock system must actuate to close fuel supply. Is strongly recommended to the future works perform experimental studies to validate the results shown in this paper.

7. ACKNOWLEDGEMENTS

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9. RESPONSIBILITY NOTICE

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