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Performance Analysis of Pressure Reduction System (PRS) for Compressed Natural Gas (CNG) Capacity NM^3/H

Cahyo Wibowo, Iskendar & Dahmir Dahlan

Department of Mechanical Engineering, Pancasila University, Jakarta
Email: cwibow007@gmail.com, cahyo_wibowo11@yahoo.co.id

Abstract

In the study of the analysis of the capacity of Pressure Reduction System as a CNG gas pressure reducing device, a study of the performance of PRS was carried out on a predetermined performance standard with a standard flow rate at 100 Nm3 / h. The study analysed several factors that would influence the performance of PRS in terms of Pressure, Temperature and Joule Thompson Effect on the effect of mass flow rates. Also analyse PRS in terms of techno economy. The study was conducted in July 2018 at the PT. PGN Bekasi, West Java. The research method measures the PRS operation with a capacity of 100 Nm3 / h for 6 times and performs mathematical calculations. From the results of measurements and subsequent calculations, the analysis is done using linear regression to get more accurate research results on regression and its correlation between each parameter. In terms of techno-economics, it is conducted by using the IRR method. From the results of the analysis conducted on the performance of the Pressure Reduction System, it was concluded that the parameters of Pressure, Temperature, Flow-rate have a very significant effect on the PRS (Pressure Reduction System) performance so that it can be used to reference PRS performance with a capacity of 100 Nm^3 / H at gas supply pressure 250 bar as expected.

Key-word: - Pressure, Temperature, Flow-rate and Joule Thompson Effect.

PRELIMINARY

The performance of using CNG (Compressed Natural Gas) for user needs requires low pressure, so the equipment used by using high-pressure gas must be reduced in pressure to operating pressure. Operating pressure on equipment systems is generally pressurized less than 1 BAR, so the equipment in the user must be equipped with a low pressure regulator pressurized into 1 BAR. To reduce the pressure, PRS (Pressure Reduction System) is used, the pressure is lowered from 250 BAR to 1 BAR pressure outlet with the following performance standards: Flow-rate 100 Nm^3/h, Temperature outlet /delivery temperature 27°C-35°C (standard PGN), Pressure inlet maximum 250 BAR, Pressure inlet minimum 20 BAR and Pressure outlet / delivery pressure 0.5-1 BAR.

So that a good PRS is to be able to channel CNG well and reduce pressure without obstacles. However, in the process of reducing the pressure, there are problems that occur that there is often freezing in the regulator due to a drastic drop in pressure where a high flow-rate causes a regulator to freeze. The freezing resulted in a clogged up of regulators and in the end it would disrupt PRS performance which had an impact on operational disruption by users.

The gas usage population is generally in the size of <100 Nm^3/h, especially for medium industries. This capacity has a market that is very open to the development of the CNG market. The investment value is lower than the currently installed capacity, which generally has a capacity of > 300 Nm^3/h with prices reaching > $.10,344.00 while the capacity of 100 Nm^3 / h made by researchers is only US$ 5,172.00 or has lower investment value and can be made domestically at affordable prices. Technically, the PRS capacity of 100 Nm^3 / h has a system that is simpler, easier from the side, installation, maintenance and easier to operate. The problem that is often found is in determining the performance of a PRS which in general is still determined without academic studies, so that the certainty of performance measures related to the level of safety and efficiency is still in doubt.

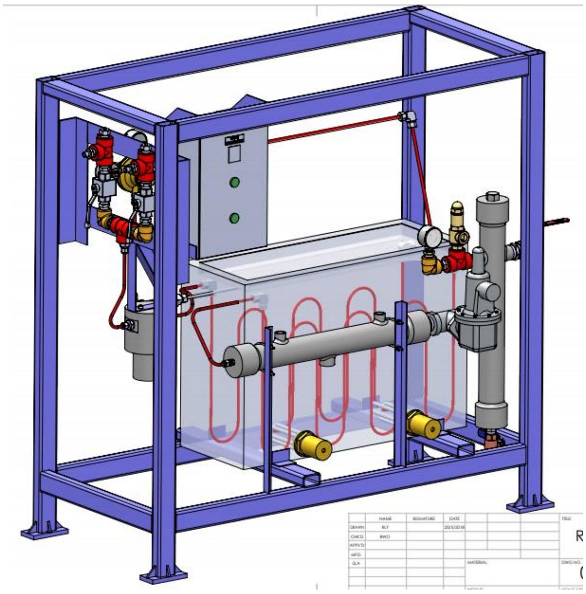


Figure 1. General drawing of Pressure Reduction System 100 Nm^3/h

PRS WORKING PRINCIPLES

The gas flowing from the 250 bar pressure gas flows into the PRS through the Decanting Post, then the incoming gas is filtered through the CNG Filter to ensure that no impurities will be carried into the system, otherwise if there is condensate it will be trapped in the filter, then the filtered gas is then heated inside the Heat Exchanger, up to a maximum gas temperature of 45ºC, the heating process using heated Air + Glycol media uses 2000 Watt electric element, after the gas is heated then the gas pressure will be reduced from 250 bar to 17 bar, then the 17 bar pressure gas will be reheated to increase the superheat so that when the pressure is lowered on stage 2 there is no icing. After the gas is heated to 45ºC-65ºC, then the gas will be reduced from 17 bar to 1-2 bar depending on the customer's needs, in this study it was reduced to 1 bar.

The gas flowing from high pressure to low pressure will result in temperature changes reaching -45ºC, a very large pressure difference will affect changes in temperature, these temperature changes can also be called Joule Thompson Effect [1]. In the case of the CNG (compressed natural gas) gas pressure drop which is very related is, Flow-rate, Pressure, Temperature is very important, from the three parameters interrelated, the main purpose of reducing CNG gas press is to reduce gas pressure to consumption pressure at 27ºC -35ºC with flow-rate as needed. The problem that often occurs in the PRS system is the occurrence of icing on the stage-1 regulator which has an impact on the flow-rate is hampered and the gas temperature decreases. Icing causes gas condensation so that it has an impact on regulator damage at stage-1 and stage-2, gas temperatures that are too low will also be difficult to read by flow meters because flow-meters have an ideal limit of temperature measurement above 15ºC, condensate will affect filters, distribution pipes, regulators to user burners.

Problem Identification: First How does the influence of the parameters of pressure, temperature, and flow-rate on icing phenomena influence the performance of PRS according to API 14.3 Standard (dp flow-meter) [2] & AGA 7 (coriolis flow-meter) [3]. Second How is the economic value of making PRS CNG with a capacity of 100Nm^3 / h [4]. In order for research to focus on the existing PRS performance in terms of Pressure, Temperature and Flow-rates, this study limits the discussion, among others, as follows: Use gas composition at one time to avoid changes in gas composition. The gas used is PGN gas on the side of the distribution gas pipeline and not the transmission pipeline or pipeline from gas wells with sweet gas quality [5]. The PRS used is 2 stages with 2 regulators on the stage 1 and 1 regulator on stage 2 with a capacity of 100 Nm^3 / h. The heating system is a water bath, serpentine heat exchanger without a circulation pump.

This study has a General Purpose, namely: First Analysing PRS performance based on Pressure parameters, Temperature and Flow. Second Economy of PRS Investment. In conducting research on PRS performance, it is hoped that it can produce something useful as follows: Being an information material for using PRS on the use of CNG as an alternative fuel (alternative fuel system). Improve the ability of the engineering sector to improve the performance of domestic PRS manufacturing.

Making the existing PRS design more supported by academic analysis. It is possible to study the manufacture of each component from PRS to increase the value of the Domestic Component Level (Local Content).

MATERIAL AND RESEARCH METHODS

Materials Research

The material / material used is Natural Gas which has been compressed into a CNG tube with a pressure of 250 bar with a total volume of gas used 200 Nm3.

Tools and Instruments

The tools used for measuring flow rate are as follows:
Stopwatch / Timekeeper

Figure 2. Stopwatch, as a timekeeper

Pressure Gauge as a gas pressure gauge at each stage

Figure 3. Pressure Gauge, as a gas pressure gauge at each stage

Thermometer to measure gas temperature

Figure 4. Thermometer Gauge

Flow meter to measure mass flow rates.

Figure 5. Coriolis Flow-meter Endress Hauser

CNG gas tube, for storing pressurized gas.

Figure 6. CNG gas cylinders filled with 200 Nm3 of gas

The object used is PRS (Pressure Reduction System) with a capacity of 100 Nm^3 / h, PRS is a system used to reduce gas from high pressure to low pressure, PRS is an instrumentation system consisting of : Decanting post, serves to regulate gas supply operations. Filter, serves to filter out impurities that will be carried into the system. Gas heater using hot water heated by element heater then the gas is passed into a serpentine pipe so that heating occurs. A pressure regulator that serves to reduce pressure from high pressure to lower pressure. Control Panel, which functions to control the temperature of hot water and operate the element heater. Thermometer, to find out gas temperature and water temperature. Pressure gauge, to find out the gas pressure at each stage. Pressure Safety Valve (PSV), to secure pressure so that there is no excessive pressure on the system. The specifications are shown in Table 1. And The PRS image is shown in Figure.7, 8, 9 and

Table 1 PRS-Specification

Spesifikasi PRS 100 Nm^3/h

No	Description	Specification
1	Inlet pressure maximum	250 BAR
2	Outlet Pressure	0-1.5 BAR
3	Capacity	100 Nm3/h at 20BAR
4	Ball valve Inlet	Gemels, 1/2 " NPT-300PSI
5	Filter Inlet	Casing 4", S45C , Port connection ½"NPT, 0.5micron, 350BAR, Local
6	Heat exchanger	Serpentine 1/2OD, SS316L x 0.049, 2 buah x 3000 mm, 6 phase
7	Regulator Stage-1	2 buah, Belgas P39-15.5 bar out, Orifice 5/65" Cv 0.1, ½ NPT
8	Regulator Stage-2	1 buah Belgas 627, 5-15 psi, 1"
9	Header stage-1, Horizontal	Pipa Seamless SCH 40, Gr-B Diameter 2"
10	Separator outlet, Vertical	Pipa Seamless SCH 40, Gr-B Diameter 2"
11	Digital Thermostat	Autonics TK4
12	Electric Immersion Heater	2 buah, 1000 watt
13	Water Tank – 72L	SS 304 450 x 250 x 640 mm
14	Heating Media	Water, Glycol 60%
15	Operating temperature	Max 75° C
16	Dimension	L x W x H, 1100 x 500 x 1000 mm
17	Weight	90 Kg
18	Threaded Fittings	Both Weld # 3000 PSI, electro plated, Carbon Steel
19	Stainless Steel Fittings	316.L
20	Thermometer	½ MNPT SS
21	Pressure Gauge	Belgas, Dial 2.5" x ½" MNPT
22	Ball valve outlet	Kitz 1"#300 PSI
23	Frame	Square Pipe 40x60x1.2mm

Pressure Reduction System A complete front view with front-view instrumentation is shown in Figure 7-9.

Figure 7. Pressure Reduction System front-view

The visible Pressure Reduction System Front complete with panel control and front-view instrumentation is shown in Figure 8.

Figure 8. Pressure Reduction System Front View.

Pressure Reduction System (PRS) along with measurement instruments are shown in Figure-3.

Figure 9. Placement of measuring instruments and instrumentation for experiments.

The stage-1 regulator uses the Belgian High Pressure P39 Regulator as shown in Figure 10.

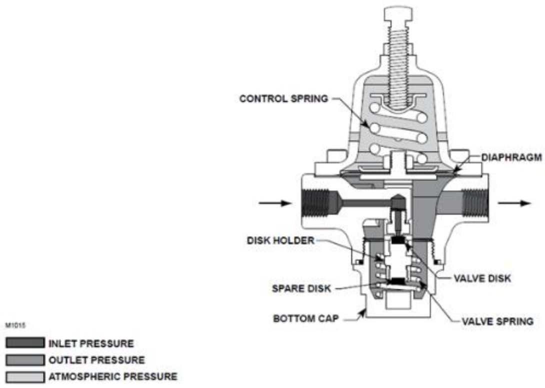


Figure 10. Regulator Stage 1 Belgas P.39 15 BAR, Orifice 5/64”, Cv 0.10 m/sec [8].

The stage-2 regulator uses the Belgian / Fisher 627 Regulator as shown in Figure 11.

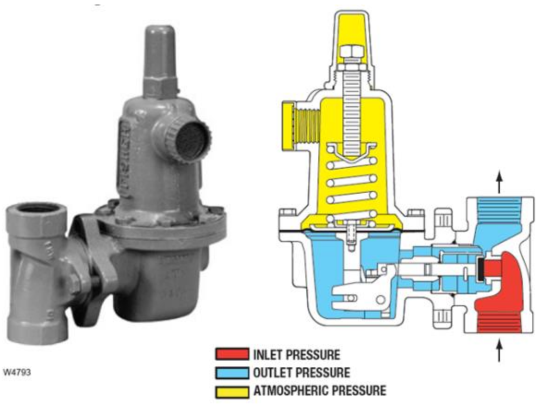


Figure 11. *Regulator Belgas P627* [8]

The equation used to calculate the gas flow rate uses the following equation:

- Bernoulli Equation [6]:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \quad (1)$$

- Reynold Number [6]

$$\mathrm{Re_D} = \frac{\mathrm{v.D}}{\mathrm{u}} = \frac{\rho.\mathrm{v}.\mu}{\mathrm{u}} \quad (2)$$

Where :

$\mathrm{Re_D}$	:	Reynold number	
v	:	velocity	m/s
D	:	Internal Diameter	m
ρ	:	Density	Kg/m^3
μ	:	Dynamic Viscocity	Kg.m/s

- Gas flow Calculation [6]

$$\mathrm{Q_g} = \frac{\mathrm{C_v}\sqrt{\Delta \mathrm{P} \times \mathrm{P_2}}}{\sqrt{\mathrm{S_g}}} \quad (3)$$

- Coeficient Velocity Calculation (Cv: coeficient of velocity) [6]

$$\mathrm{C_v} = \frac{\mathrm{Q_g} \times 2\sqrt{\mathrm{S_g}}}{\mathrm{P_1}} \quad (4)$$

The equations used to calculate the Joule Thompson Effect coefficient are as follows [7]

$$\mu\mathrm{JT} = \left(\frac{\vartheta \mathrm{T}}{\vartheta \mathrm{P}}\right)_h = \frac{1}{c_p}\left[\mathrm{T}\left(\frac{\vartheta \mathrm{v}}{\vartheta \mathrm{T}}\right)_p - \mathrm{v}\right] \quad (5)$$

The variables to be examined from this study are shown in Figure 12.

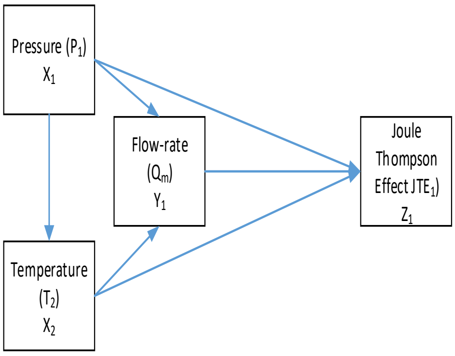


Figure 12. Path diagram of parameter analysis.

The research procedure is described in the form of a flow chart shown in Figure 13.

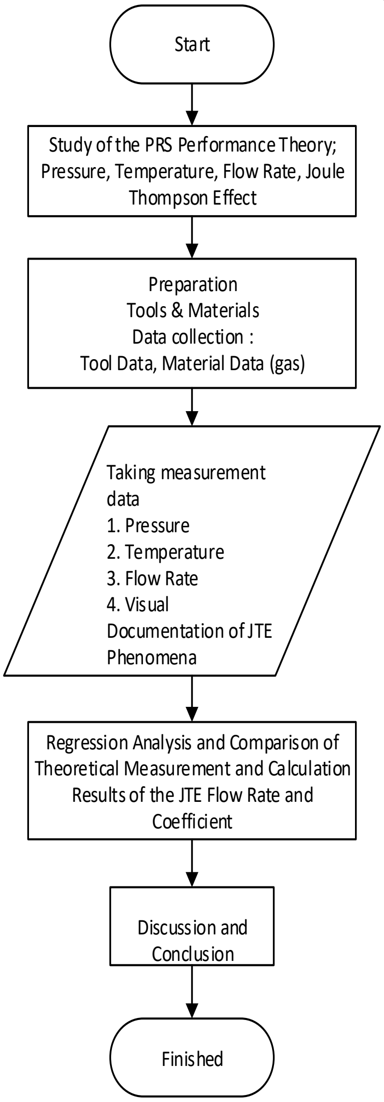


Figure 13. Flow Chart of Research Method.

RESULTS AND DISCUSSION

The results of measurements of P, T, first Qm on PRS are shown in Table 2.

Table 2 Results of measurement of P, T & Qm.

Time [min]	P1 BAR	T2 °C	T1 °C	P2 BAR	P3 BAR	T3 °C	$Q_{m\text{-Actual}}$ Nm3/h
1	250	-45	11.00	15	1	26	111
2	230	-39	32.00	15	0.9	28	105
3	200	-20	33.00	15	0.9	33	107
4	183	-17	33.00	15	0.7	33	104
5	162	-12	33.00	14	0.7	34	101
6	138	-7	31.00	13.5	0.6	33	98
7	114	-3	32.00	12	0.6	34	89
8	102	-0.2	33.00	11	0.5	37	86
9	77	6	32.00	10	0.5	37	107
10	53	19	35.00	8	0.4	35	102
11	31	26	37.00	5	0.2	38	86
12	20	28	38.00	4	0.2	40	70

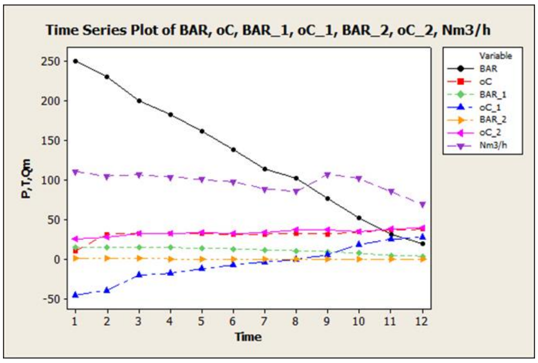
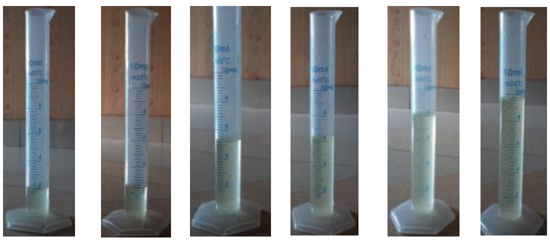


Figure 14. Graph of pressure drop followed by changes in temperature until changes in temperature at a certain point from negative to positive.

Observation Results and Condensate Measurements for 6 measurements with ± 200 Nm^3 of gas obtained at 9.8 ml of condensate shown in Figure 15.



Pengukuran ke-1	Pengukuran ke-2	Pengukuran ke-3	Pengukuran ke-4	Pengukuran ke-5	Pengukuran ke-6
1.8 ml	2.4 ml	5.2 ml	6.2 ml	8.0 ml	9.8 ml

Figure 15. Results of measurements for 6 times obtained condensate of 9.8 ml. from 200 Nm^3.

JTE Calculation at 250 bar pressure [7]

$$\mu = \left(\frac{\vartheta T}{\vartheta P}\right)_H = -\frac{\left[V - T\left(\frac{\vartheta V}{\vartheta T}\right)_P\right]}{C_P} = -\frac{\left[\hat{V} - T\left(\frac{\vartheta \hat{V}}{\vartheta T}\right)_P\right]}{\hat{C}_P} =$$

$$\hat{C}_P = \left(\frac{\vartheta \hat{H}}{\vartheta T}\right)_P$$

Heat Capacity Calculation $\hat{C}_P$:

$$\hat{C}_P = \left(\frac{\vartheta \hat{H}}{\vartheta T}\right)_P = \frac{\hat{H}(39.47℃) - \hat{H}(-45℃)}{\big(39.47 - (-19)\big)℃}$$

$$= \frac{(-140.2893 - (-175.5794)\,\frac{kJ}{kg}}{58.47\ K} = \frac{35.2901}{58.47\ K} = 0.6035\,\frac{kJ}{kg.K}$$

$$\left(\frac{\vartheta \hat{V}}{\vartheta T}\right)_P \approx \frac{\hat{V}(39.47℃) - \hat{V}(-45℃)}{\big(39.47 - (-45)\big)℃} = \frac{(0.00611 - 0.07366)\,\frac{m^3}{kg}}{84.47\ K} = \frac{-0.0675}{84.7} = -7.975\ \times 10^{-4}\ \frac{m^3}{kg.K}$$

$$\mu = \left(\frac{\vartheta T}{\vartheta P}\right)_H = -\frac{\left[\hat{V} - T\left(\frac{\vartheta \hat{V}}{\vartheta T}\right)_P\right]}{\hat{C}_P}$$

$$\mu = -0.090108614\ \frac{m^3.K}{kJ}$$

Since 1 kJ = 10^{-3} MPa.m^3, and 1 MPa = 10 bar [9]

Then the Joule Coefficient of Thompshon Effect Natural Gas at a pressure of 250 bar and 39.47^{o}C is :

$$\mu = -0.090108614\ \frac{\mathrm{K}}{\mathrm{MPa}} = -0.9\mathrm{x}10^{-2}\,\frac{\mathrm{K}}{\mathrm{bar}}$$

On value $-0.009010861\,\frac{\mathrm{K}}{\mathrm{bar}}$ or -273.159 ^{o}C/Bar, Icing happened.

With the same calculation technique, the JTE values obtained on the 2nd to 6th measurements are shown in Table 3

Table 3. Table of measurement data that has been processed for JTE analysis.

Time [min]	X1-P1 (BAR) X1	X2- T2oC X2	T1oC	P2 (BAR)	P3 (BAR)	T2oC	Y1-Qm (Nm3/h) Y1	Qm Std	TwoC	Z1-JTE K/Mpa Z1	Z2= Quantifikasi JTE
1	250	-45	11	15	1	26	111	100	28	-0.09011	3
2	230	-39	32	15	0.9	28	105	100	28	0.171428	4
3	200	-20	33	15	0.9	33	107	100	55	0.222937	5
4	162	-12	33	14	0.7	34	101	100	48	0.066683	4
5	77	6	32	10	0.5	37	107	100	46	0.050233	2
6	53	19	35	8	0.4	35	102	100	46	0.054792	1

An example of a visual observation of the gas cylinder when gas flows and in the PRS section is shown in Figure 16 and Figure 17.

Figure 16. Example of a photo of the observation of the Joule Thomson Efect phenomenon that occurs when gas flows from a Cylinder CNG with a pressure of 250 BAR to PRS.

Figure 17. Joule Thomson Effect phenomenon that occurs when gas flows from the Stage 1 regulator when the gas is lowered from 250 BAR to 15 BAR with flow-rate 102 Nm^3 / h.

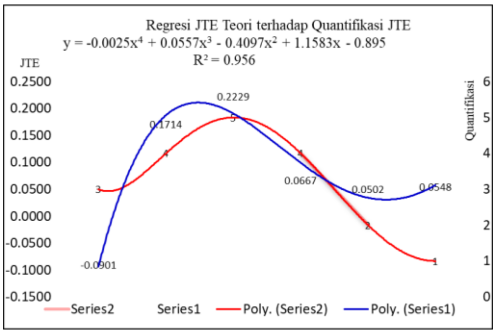


Figure 16. Joule Thompson Effect calculated using theory and compared with JTE quantification.

In calculating the mass flow rate or flow-rate using a calculation assuming the orifice meter or commonly called the differential pressure flow calculation. The comparison of measurements with orifice and the results of measurements with flow-meters is shown in Figure 19.

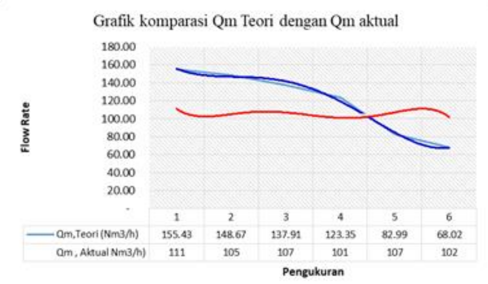


Figure 17. Comparison of measurements with orifice and measurement results with flow-meters.

Resumes from the results of the discussion above know that based on the regression results the regression equation is obtained as follows: Regression Equation Effect of Pressure (X1) on Temperature (X2): X1 = 113 - 3.20 X2. Effect of Pressure Regression (X1) on Mass Flow Rate (Y): Y1 = 82.6 + 0.112 X1. Effect of Temperature Regression (X2) on Mass Flow Rate (Y): Y = 104 - 0.0842 X2. Effect of Regression on the Effect of Pressure (X1) on Temperature (X2) on Mass Flow Rate (Y): Y = 113 - 0.322 X2 - 0.074 X1. Effect of Temperature on JTE: X2 = - 16.1 + 11 X3. Effect of Pressure on JTE: X1 = 159 + 33 X3. Effect of Pressure, Temperature and Flow Rate on JTE X3 = 0.49 + 0.00341 X1 + 0.0105 X2 - 0.0076 Y. Individually, the pressure affects temperature, this proves that the higher the CNG pressure then when it flows it will produce a low temperature to a certain pressure limit the temperature will rise. Pressure has an effect on flow-rate, this is proven that at a pressure of 250bar the flow-rate will flow more than linearly when the pressure decreases, the flow-rate will decrease further. Together the pressure and temperature have an effect on the flow-rate, but the temperature has no significant effect on the flow-rate. And together pressure, temperature and flow-rate affect the JTE, the higher the pressure, the higher the JTE, the lower the temperature will affect the JTE, the thicker the icing, the greater the flow rate, the faster the JTE will occur. To reinforce the results of the study, it is compared graphically between the JTE graph theory and the JTE graph of the results of the research shown in Figure 20 and Figure 21.

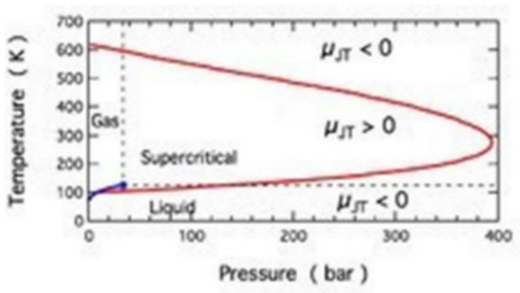


Figure 18. Reference Chart of JTE of Methane [10]

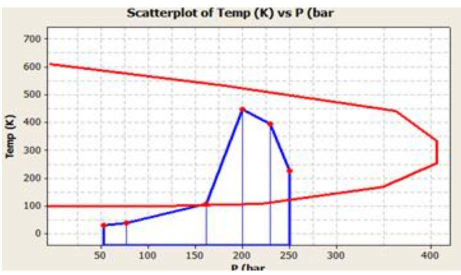


Figure 19. JTE graphs from theoretical calculations

Figure 20. JTE of Methane Reference Graph (above) with Figure 21. JTE graphs as a result of theoretical calculations While economically, PRS has a capacity of 100 Nm^3 / h with a selling price of US$ 5,172.00 is feasible to be used as an investment in the long term > 4 years with an IRR of Bank 13%.

CONCLUSION

From the results of measurements and analysis carried out on the Pressure Reduction System, it was concluded that the parameters of pressure, temperature, and flow-rate influence the emergence of JTE / icing phenomena and influence the PRS performance. This is generated from the results of the regression equation: Y1 = 82.6 + 0.112 X1, with the regression results of the value R-Sq = 0.439 and the value of P = 0.000. PRS can operate at a 100 Nm^3 / h flow-rate capacity, at a gas supply pressure of 250 bar as expected. The condensate obtained during the study was 9.8 ml, or 0.049 ml / Nm^3 still below the standard maximum of 0.06 ml / Nm^3, this indicates that the quality of the gas used is quite good along with an outlet temperature that reaches > 27ºC.

While in terms of economic value the production of a CNN PRS with a capacity of $100Nm^3$ / h can be commercially competitive with the example of the simulation results of the initial investment value in the first year of US$ 5,172.00 then by leasing for 4 years at a rental price of US$ 448.00 / month for a minimum of 4 years, then within 4 years in the first year the value of investment will be BEP, then in the second year and so on will get a profit of US$ 5,172 / year.

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