http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience, Engineering, Environment, and Technology
Vol 08 No 02-2 2023 Special Edition
Special Issue from "*The 1st International Conference on Upstream Energy Technology and Digitalization (ICUPERTAIN) 2022*"

RESEARCH ARTICLE

Possibilities Study of a Non-condensable Gas Exhaust System through the Condensate Injection Pipe at PLTP Wayang Windu

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May 20, 2023. Revised : May 31, 2023, Accepted: June 10, 2023, Published: July 31, 2023
DOI: 10.25299/jgeet.2023.8.02-2.13878

Abstract

Wayang Windu Geothermal Power Plant, located in Pangalengan, Bandung regency, West Java with an installed capacity of 227 MWe has two units to generate electricity and deliver to the Jawa, Madura, and Bali grid. The steam extracted from the reservoir contains non-condensable gas of about 1-1.2% of total steam extracted, with the gas composition is CO_2 92%, H_2S 2%, NH_3 0.1%, and residual gasses 4.9%. Possibilities study of a non-condensable gas exhaust through the condensate injection pipe was created as the efforts in the environmental conservation aspect for reducing carbon released to the atmosphere and reinjected back into the reservoir. This study was simulated in Wayang Windu Unit 2 by calculating the non-condensable gas flow rate from the gas removal system into the condensate injection pipe near of cooling tower blowdown power station area. The analysis result of this study indicates that the non-condensable gas requires a higher flow rate of condensate to dissolve the entire non-condensable gas, and may cause the slug flow pattern which would endanger the condensate pipeline system also destabilize the non-condensable gas exhaust operation process from the condenser through the gas removal system. To deal with this problem, the possibility of exhausting the non-condensable gas produced by the gas removal system can be alternated by flowing its non-condensable gas into a flash absorber system and converting its non-condensable gas into other eco-friendly products and power plant safe.

Keywords: Non-Condensable Gas, Condensate, Gas Removal System, Geothermal, Carbon Capture, Reservoir, Condensate Reinjection, Pipeline, Flash Absorber, Power Plant, Eco-friendly.

1. Introduction

Every power plant almost always impacts the environment to a different degree depending on the technology used. Gas emissions from power plants come from non-condensable gases carried by steam from the reservoir. The geothermal fluid that comes out of the well usually still contains gas that cannot be condensed in the condenser so if left unchecked it can cause the pressure in the condenser to rise and decrease turbine efficiency.

PLTP Wayang Windu is equipped with a gas exhaust system consisting of a two-stage steam jet ejector and a vacuum pump, so it is called a two-stage hybrid gas exhaust system. The gas that is carried along with the steam from the well that is not condensed in the condenser is sucked in by the GRS and then discharged into the atmosphere through the cooling tower with the help of a fan drive.

1.1 Solubility of NCG in Water

Absorption is the process of dissolving the components of the gas phase into the liquid phase. Gas has a small density, if the gas is in contact with a liquid, a number of gas molecules will seep into the liquid with different solubility. The concentration of dissolved gases is highly dependent on the specific temperature and pressure. According to Henry's law, the solubility of a gas in a liquid is directly proportional to the pressure of the gas before it enters the solution.

Dalton's law of partial pressures states that, for a mixture of non-reacting gases, the total of the partial pressure of each gas is equal to the total pressure exerted by the mixture, at constant temperature and volume. The pressure in the transfer medium is the sum of the gas pressure and the water pressure. This applies according to Dalton's law of partial pressure.

Make sure that placing and numbering of equations is consistent throughout your manuscript. Eqn. 1, 2, and 3 are written as follow:

$$P_{total} = P_{gases} + P_{H_2O} \quad (1)$$

$$P_{gas} = P_{CO_2} + P_{H_2S} + P_{NH_3} \quad (2)$$

$$pV = nRT \quad (3)$$

The pressure of the gases on the NCG can be found using Henry's law equation (Eqn. 4).

$$P_{gas} = K_{gas}\ x\ C_{gas} \quad (4)$$

With:

P_{gas} = Partial pressure of the gas (Pa)
K_{gas} = Henry's constant value (L.atm/mole)
C_{gas} = Mole fraction of the gas

This equation also applies to other gases by including the number of moles from the Henry constant which has been applied based on the partial Henry gas law (Eqn. 5).

$$S_g = K_h\ x\ P_g \quad (5)$$

With:

S_g = Solubility of the gas
K_h = Henry's constant value (L.atm/mole)
P_{gas} = Partial pressure of the gas (atm)

1.2 Horizontal Flow of a Two-Phase Fluid

When two phases flow in a pipe, the different phases can contribute in terms of flow pattern which will cause different flow hydrodynamics, as well as the mechanisms of momentum, heat, and mass transfer around the fluid. The two-phase flow pattern has two flow models: homogeneous and separable. In the homogeneous model, the steam and water are assumed to be completely miscible, so that the water and gas mixture acts like a single-phase fluid with properties averaging depending on the properties of the individual phases. With this assumption, the flow pattern is considered a calculation method for single-phase flow

In the separated flow model the flow pattern is assumed to flow together in the pipe separately, each phase distributed in an occupying part of the pipe flow (Saptadji, 2001). Beggs and Brill grouped the two-phase flow patterns in the horizontal plane into 3 groups, namely: segregated flow, intermittent flow, and distributed flow. The segregated flow pattern is divided into three, namely stratified flow, wavy flow, and annular flow (Beggs and Brill, 1973). Intermittent flow patterns are divided into slug flow and plug flow, while the distributed flow pattern is divided into flows bubbles and mist flow. Segregated flow patterns occur when $F_{rm} < L_1$, distributed flow patterns occur when $F_{rm} > L_1$ and $F_{rm} > L_2$, and intermittent flow pattern occurs when $L_1 < F_{rm} < L_2$. Fig. 1. shows the flow patterns on the Beggs and Brill correlations.

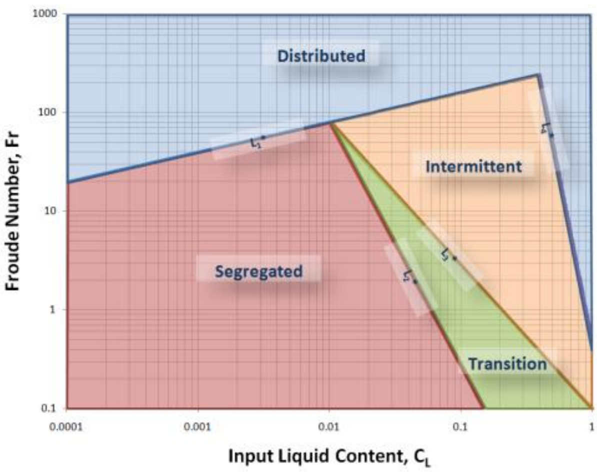

Fig. 1. Beggs and Brill flow pattern (Beggs and Brill, 1973).

The value of the *froud number* and *Liquid content* can be determined by the Eqn. 6-11.

$$C_L = \frac{Q_{Condensate}}{Q_{Condensate} + Q_{NCG}} \quad (6)$$

With:

C_L = Liquid Hold Up
$Q_{Condensate}$ = Flow of condensate
Q_{NCG} = Flow of the Non-Condensable Gas

$$F_{r_m} = \frac{V_m^2}{g \; x \; D} \quad (7)$$

$$L_1^* = 316 C_L^{0.302} \quad (8)$$

$$L_2^* = 0.000925 C_L^{-2.4684} \quad (9)$$

$$L_3^* = 0.1 C_L^{-1.4516} \quad (10)$$

$$L_4^* = 0.5 C_L^{-6.738} \quad (11)$$

With:

F_{Rm} = Froud number
V_m^2 = Flow of condensate
g = Flow of the Non-Condensable Gas
D = Inside diameter of pipe
L = Liquid content

2. Material and Methods

The NCG flow rate at the GRS output fluctuates depending on the gas content in the steam flowing from the well. In this study, the data to be analyzed as reference data is the daily average data of the monitoring system in real-time human-machine interface (HMI) from the distributed control system (DCS), while the NCG content data contained in steam is the monthly average data of the results testing by laboratory technicians. NCG content in the steam is seen in Table 1. NCG data, condensate data, and injection pipe data pressure are shown in Table 2, Table 3, and Table 4, respectively. Gas removal system PLTP Wayang Windu is shown in Fig. 2.

Fig. 2. Gas removal system PLTP Wayang Windu.

Table 1. NCG Content in the steam.

Month	Output Flow	NCG Content in the steam					
		pH	H_2O	U-1 TGC	CO_2	H_2S	NH_3
	[kg/s]		[w%]	[w%]	[w%]	[w%]	[w%]
Aug-2022	2.56	4.84	99.25	0.750	0.729	0.015	0.071
Sept-2022	2.21	5.18	99.2	0.800	0.668	0.013	0.072
Oct-2022	2.49	4.77	99.1	0.900	0.632	0.009	0.064

Table 2. NCG data.

Month	Atmosfer Pressure	Dry bulb Temp	Wet bulb Temp	NCG GRS Flow	NCG GRS Temp	NCG GRS Pressure
	[Bar]	[Deg C]	[Deg C]	[kg/s]	[Deg C]	[Bar]
Aug-2022	0.832	18.78	16.97	2.56	46.46	0.2
Sept-2022	0.833	18.8	17.02	2.21	44.56	0.2
Oct-2022	0.832	17.89	16.64	2.49	44.56	0.2

Table 3. Condensate data.

Month	U-1 Cond. Flow	U-2 Cond. Flow	Total Cond. Flow	U-1 Cond. Temp	U-2 Cond. Temp
	[kg/s]	[kg/s]	[kg/s]	[Deg C]	[Deg C]
Aug-2022	63.45	33.16	96.61	51.82	44.41
Sept-2022	82.09	1.86	83.95	49.53	44.61
Oct-2022	77.05	14.76	91.81	50.14	44.88

Table 4. Injection pipe data pressure.

Month	Scrubber Header	SS1 Area	J5 Low Point	Branchline Well	Cond. Inj Wellhead
	[Bar]	[Bar]	[Bar]	[Bar]	[Bar]
Aug-2022	-0.51	-0.08	2.17	0.14	-0.70
Sept-2022	-0.51	-0.19	2.05	-131.92	-0.69
Oct-2022	-0.52	-0.18	2.18	0.32	-0.70

3. Results and Discussion

3.1 Injection Point Selection

Based on Table 4, Injection Pipe Pressure Data at various points, it is possible to remove NCG output from GRS in the Scrubber Header area, SS1 area, and the condensate injection wellhead considering that the pressure at these locations is lower than the NCG pressure output from GRS. The scrubber header area was chosen as a possible location for gas injection considering that this location is the closest distance from the GRS, so that back pressure on the vacuum pump which can disrupt the generation and NCG extraction process from the condenser will not occur. In addition, the cost of piping installation is also reduced. This point is also a branch point for mixing condensate water from Unit-1 and Unit-2. Injection point selection is seen in Fig. 3.

Fig. 3. Injection point selection.

3.2 Non-Condensable Gas Solubility

The solubility of gases in water can be done by Henry's law, but the Henry constant used is not Henry's constant in standard conditions but Henry's constant due to the influence of temperature, so the calculation results for Henry's constant in August-October for each gas are as follows (Table 5). Table 6 shows solubility of gases to the condensate.

Table 5. Henry's constant.

Month	Gas	Temp (K)	C	*K_h (L.atm/mole)*	K_h (mole/L.atm)	K_h' (L.atm/mole)	K_h (mole/L.atm)
Aug-22	CO_2	319.46	2400	29.41	0.034	17.12	0.0198
	H_2S		2100	11.49	0.087	7.16	0.0542
	NH_3		4100	0.0169	0.61	0.0067	0.2421
Sept-22	CO_2	317.56	2400	29.41	0.034	17.91	0.0207
	H_2S		2100	11.49	0.087	7.44	0.0564
	NH_3		4100	0.0169	0.61	0.0072	0.2614
Oct-22	CO_2	317.56	2400	29.41	0.034	17.12	0.0207
	H_2S		2100	11.49	0.087	7.16	0.0564
	NH_3		4100	0.0169	0.61	0.0067	0.2614

Table 6. Solubility of gases to the condensate.

Gas	Month	S	S	Flow gas	Flow Cond.	Dissolved gas	Solubility	Required condensate
		mole/L_{H2O}	gr/kg_{H2O}	kg/s	kg/s	kg/s	%	kg/s
CO_2	Aug	0.004	0.199	2.49	96.61	0.019	0.772	12517.54
	Sept	0.004	0.217	1.85	83.95	0.018	0.989	8484.94
	Okt	0.004	0.208	1.75	91.81	0.019	1.092	8409.41
H_2S	Aug	0.010	0.582	0.05	96.61	0.056	109.880	87.92
	Sept	0.011	0.630	0.04	83.95	0.053	147.267	57.01
	Okt	0.011	0.606	0.02	91.81	0.056	223.326	41.11
NH_3	Aug	0.030	1.657	0.24	96.61	0.160	66.064	146.24
	Sept	0.035	1.932	0.20	83.95	0.162	81.557	102.93
	Okt	0.032	1.789	0.18	91.81	0.164	92.786	98.95

Based on the calculation of solubility gases to the condensate, for the solubility of CO_2 gas which has a small solubility, the condensate flow rate required to dissolve the CO_2 gas released from the Gas Removal System is not large enough to dissolve all of the CO_2 gas. For the solubility of H_2S and NH_3 gases, both gases based on calculations can dissolve into the condensate stream with fairly high solubility.

3.3 Fluid Flow Pattern

Based on the calculation of the two-phase fluid flow pattern using the Beggs and Brill calculation method, the flow pattern obtained is as follows (Table 7).

Table 7. Superficial velocity of fluid.

A	Vcondensate	V_{CO2}	V_m	C_L	Fr_m
1.4 ft^2	2.46	33.68	36.14	0.068	30.520

By entering C_L and Fr_m values in the liquid content (L) formula, the flow pattern using the Beggs and Brill method can be determined. Table 8 shows liquid content.

Table 8. Liquid content.

L_1^*	L_2^*	L_3^*	L_4^*
140.308	0.705	4.953	36,814,698.19

From the results of the Liquid Content (L) calculation, the condition is obtained (Eqn. 12):

$$0.01 \le C_L < 0.4 \text{ and } L_3 < Fr_m \le L_1 \quad (12)$$

The type of flow that occurs when CO_2 from the gas removal system flows through condensate water pipes in this condition is intermittent flow, namely slug flow and plug flow. Intermittent flow patterns consisting of slug flow and plug flow can result in unstable flow conditions in the pipeline. If the superficial velocity of the gas is high then the type of flow is slug flow, whereas if the superficial velocity of the gas is low then the type of flow is plug type flow (Rogero, 2009).

From the results of the calculation of the data above it is known that the superficial velocity of the gas is very high, so it can be concluded that the type of fluid flow from this type of intermittent flow is the slug flow type. This type of slug flow can cause vibration and be dangerous to the pipe structure (Rogero, 2009) so it will interfere with the NCG removal process from the GRS and the condensate reinjection process from the condenser and cooling tower.

In the absence of an absorber and packing column, the contact time between the gas stream and the condensate in the pipe is fast at the point of injection. With poor diffusion of gas into the condensate or a small amount of gas that can be absorbed, the gas will further endanger the condition of the pipeline with high superficial gas velocities.

4. Conclusion

Based on the results of the solubility analysis and fluid flow pattern, the non-condensable gas requires a higher flow rate of condensate to dissolve the entire gas because of its low gas solubility and large superficial fluid velocity. It also may cause the slug flow pattern which would endanger the condensate pipeline system and destabilize the non-condensable gas exhaust operation process from the condenser through the gas removal system. Solubility is also affected by pH, it would be better for further research to look for the effect of pH on gas solubility in condensate.

As a way to increase the solubility of the non-condensable gas in condensate, a flash absorber column can be installed, and the solubility of the gas that dissolves into the condensate can become larger. Another solution is to utilize the CO_2 gas contained in non-condensable gas to be produced into dry ice products. Dry ice is made by lowering the temperature and applying high pressure so that CO_2 gas can become a solid and turn into dry ice. By this carbon capture method and utilization of the gas, CO_2 as one of the greenhouse gasses can be useful and turn into eco-friendly products.

Acknowledgements

This work was supported by Star Energy Geothermal Wayang Windu Ltd. Therefore, we are grateful for this funding and support of this research.

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