STEAM-FIELD DESIGN OVERVIEW OF THE ULUBELU GEOTHERMAL PROJECT, INDONESIA

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ABSTRACT

The Ulubelu geothermal field is located in Lampung province in South Sumatra, Indonesia. Ulubelu is a liquid-dominated system with an average enthalpy of 1100 kJ/kg. It is the largest geothermal power plant in Sumatra with 2×55 MWe capacity from two identical units 1 and 2. Both units have been in operation since September 2012. Another 55 MWe plant was recently introduced in July 2016 which should be followed by a fourth 55 MWe unit in July 2017.

Based on the steam-field topography and terrain characteristics, units 1-2 used hybrid separation system, which is a combination between satellite and centralized separation plant. Units 3-4 are designed with a central separator station that receives the entire flow of two-phase fluid from all the production sectors of the field. The steam field design for all units includes a separator with integrated water drum with baffle plate type, large diameter two-phase pipeline, direct hot brine injection, scrubbing line system and scrubber vessel for moisture removal. In order to make a flexible operation, all of the units are connected with interconnection lines both in two-phase and steam pipelines.

Several technical challenges were experienced in the operation of units 1-2 including; the unknown two-phase flow rate from each production well, water hammer in large two-phase pipeline and brine carry-over at the steam outlet of the separator. Not resolved, these problems are likely to take place during the operation of units 3-4. This work attempts to analyze the cause of problems and provide recommendations for future steam field design in order to optimize and improve the performance of the geothermal field.

1. INTRODUCTION

The island of Sumatra, Indonesia is in urgent need for additional power generation to meet shortfalls that result in frequent load shedding. Geothermal power is one of the best options to increase power generation to facilitate continued economic growth, because it is a clean and renewable base load generation technology for the abundant geothermal resources available throughout Sumatra. Geothermal energy being an indigenous and non-tradable energy source will also enhance the country‘s energy security and serve as a natural hedge against the volatility of fossil-fuel prices.

Pertamina Geothermal Energy (PGE) intends to develop a significant augmentation to the electrical power generating capacity in South Sumatra by constructing and operating 4×55 MWe geothermal power plant at Ulubelu in Lampung province, Sumatra Island. Ulubelu is about 100 km to the north-west side from the provincial capital city Tanjung Karang (Figure 1). PGE have constructed the steam above ground system (SAGS) for supplying steam to the PLN (the government electricity company) geothermal power plant (units 1 and 2) for 30 years operation as stated in the PGE-PLN steam sales contract agreement. The power plants and SAGS of units 3 and 4 will be owned and operated by PGE.

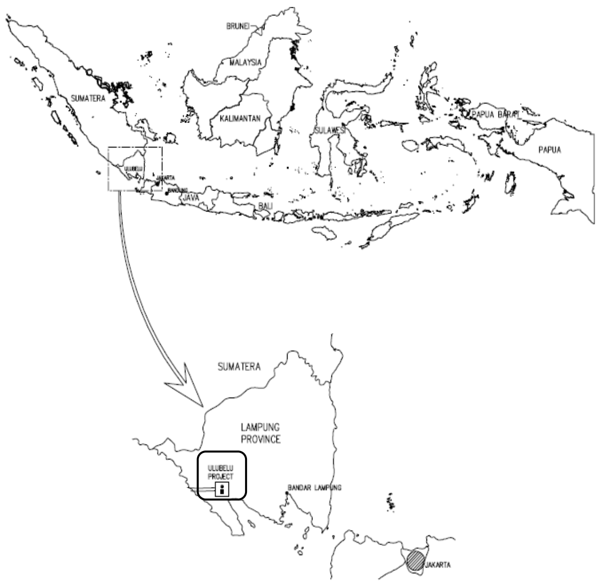

Figure 1: The location of the Ulubelu geothermal field, Indonesia.

The SAGS is designed to convey geothermal two-phase fluid from the production wells to a central separator station or a cluster of separators where the two-phase fluid is separated into steam and brine using vertical cyclone separators. The separated steam is then conveyed to each steam turbine via a steam pipeline with scrubber vessel, while the separated brine and excess plant condensate are sent to dedicated reinjection wells.

2. STEAM-FIELD CONCEPT

In general, the SAGS for liquid-dominated system can be divided into three types; centralized, satellite and individual wellhead separator (DiPippo, 2012).

Several parameters were considered when choosing the appropriate SAGS system including; topography, location, operation flexibility, facilities maintenance and most importantly the cost. Units 1-2 SAGS is a hybrid system between centralized and satellite, while units-3-4 has a centralized system. The map of Ulubelu shows the production-reinjection well-pad (cluster) and the power plants are given in Figure 2.

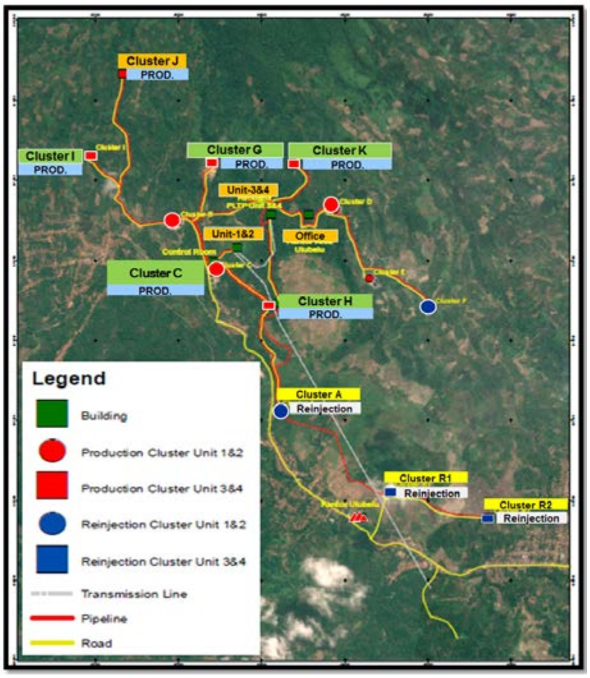

Figure 2: A map of Ulubelu geothermal field showing the location of the plant and the different production and reinjection sectors.

The general layout of the SAGS was determined taking into account the following factors (AECOM, 2011):

- Avoiding uphill two-phase flow from production well pads to separators.
- Use of gravity injection where practical, to avoid additional system complexity and the capital and operating costs associated with reinjection pumps.
- Minimising the costs of pipelines and civil engineering work.
- Minimising the impact on local communities and the environment caused by the SAGS physical piping and equipment, noise and visual appearance.
- Injection of power station condensate in dedicated wells.
- In general, the main SAGS systems should be capable of turndown to 30% of full load flows. This allow for one of the two turbine-generators being off-line while the other running at reduced load.
- The SAGS steam system is designed as "two-half" systems, each nominally serving one turbine-generator unit. The two-halves are normally interconnected and both in service but have isolation valves to allow safe shutdown of one half while the other continues to operate.

2.1 Units 1 and 2 SAGS Concept

To produce 2×55 MWe the steam supply produces from three production clusters, B. C and D (Figures 2-3). While the reinjection at clusters A and F. The location of the reinjection wells will be moved from cluster A to cluster R1 and R2 in order to minimize the water breakthrough risk and the decline of the production wells. Figure 3 show the summary of unit's 1-2 steam field flowchart.

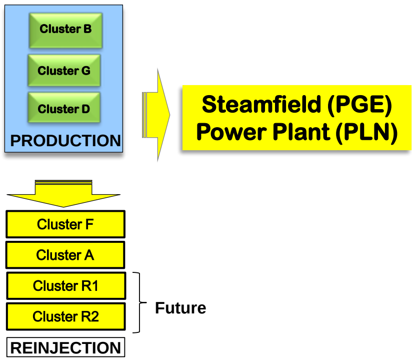

Figure 3: Simplified flowchart diagram of units 1-2.

Two-phase fluid from cluster-B is transported to cluster-C and mixed in a balancing line before interring the separators in cluster-C (Separator 1A and 1B) as shown in Figure 4. Meanwhile, two-phase fluid from production wells in cluster-D is separated in separator that located in the same cluster (Separator 2).

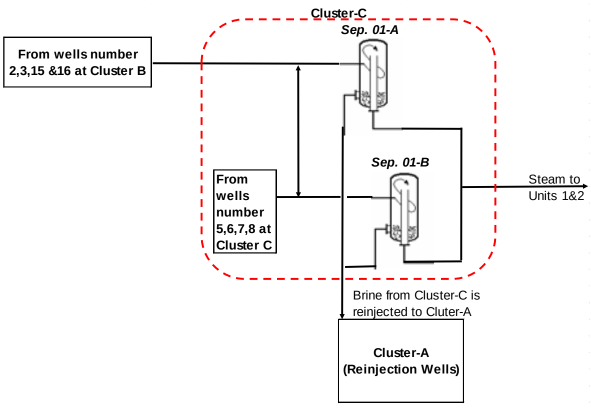

Figure 4: A simplified separation plant in cluster B and C.

The steam is supplied from three clusters (B, C and D) and the separated brine is injected along with condensates from power plants into wells in cluster A and F. The SAGS are consists of:

- Cluster B production well: 4 wells
- Cluster C production well: 4 wells
- Cluster D production well: 3 wells
- Separator at cluster C: 2 units
- Separator at cluster D: 1 unit
- Cluster A reinjection well: 3 wells
- Cluster F reinjection well: 3 wells
- Two-phase and steam pipelines.
- Brine and condensate reinjection line.
- Steam scrubbing line.
- Vent stations.

Two-phase flow from production wells in cluster B flows to join those in cluster C. The steam from the separator station flows to the single flash (pressure) power plant. The brine and the power plant condensates are reinjected into the wells in cluster A.

Wells in cluster D connects to the separator on cluster D (a satellite separation system). The separated steam flows to the power plant and the brine is reinjected by gravity into the wells in cluster F.

Near the power plant, the two steam lines and pressure balancing line connects the two steam lines also act as scrubbing lines. After the steam has been scrubbed, they join together into one single steam line to flow to the power plant. The single steam line is then divided into two lines toward units 1-2.

2.2 Units 3 and 4 SAGS Concept

The SAGS for Ulubelu units 3-4 consist of all pipeline and distribution header from production well cluster I, G, K, C and H, separator area, scrubbing line, steam vent station, brine reinjection wells, steam-field drainage system, condensate reinjection wells, and inter connection piping between units 1-2 and units 3-4 in cluster B and cluster C. The simplified of units 3-4 system is described in Figure 5.

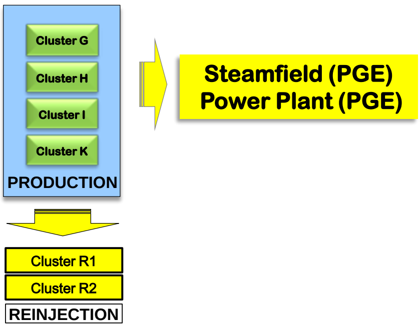

Figure 5: Simplified flowchart diagram of units 3-4 system.

The two phase geothermal fluid originates from 5 Clusters (Cluster I, G, C, H, and K):

Cluster I consists of two production wells (UBL-34 and UBL-38),

Cluster G consists of two production wells (UBL-29 and UBL-31),

Cluster K consists of three production wells (UBL-K1, UBL-K2, and UBL-K3),

Cluster C consist of one production well (UBL-27), and Cluster H consists of four production wells (UBL-25, UBL-30, UBL-28, and UBL-26).

A crossover line connects Cluster B to existing production wells for unit 1-2 is also installed.

The geothermal fluid transported from the production well is collected in cluster pipe headers. The geothermal fluid is then transported in headers and then collected to a (52 inch) main header to a central separator station.

The central separator station (Figure 6) consists of three separator vessels, each designed for a steam flow of 350 tones/hours). All three separators operate at common pressure set point of 9.05 bar abs maintained constant by discharge of steam through vent valves. The two-phase geothermal fluid is separated in the central separator station with design separator efficiency of 99.98% (AECOM, 2012). The produced steam is transferred through the scrubbing line header, while the brine is transferred to the reinjection header.

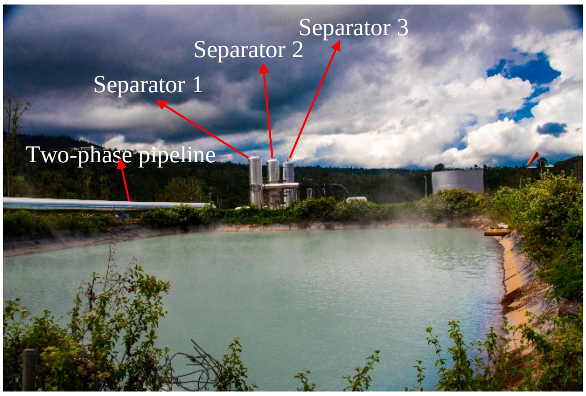

Figure 6: A picture of central separator station for units 3-4

All separators are provided with isolation valves upstream and downstream of each vessel to allow isolating individual separators. In addition to the isolation valves downstream of the pressure safety valves (PSV) and flanged spools (manholes) are provided for safe access into the vessels during inspection and maintenance. Annubar flow meters that connected to distributed control system (DCS) valve are installed on all of the steam pipelines. While an orifice plate flow meters are installed on the common brine reinjection header pipeline.

Each separator is provided with a pressure safety valve (PSV) installed in the steam line upstream of the isolation valve, to protect the equipment from overpressure (Figure 7). The discharge pressure of the PSV is set higher than the control valve at the Vent Station but lower than the pressure safety devices (PSDs) station at the main steam header pipeline so that the PSV will open prior to the PSD. The PSV is set to discharge/open at 9.5 bar gauge pressure. The PSDs are comprising of a number of rupture disks with sequential relief pressure settings installed on the two phase pipeline upstream of the isolation valves to the separators, to protect the SAGS facilities against over pressure (beyond design limits)

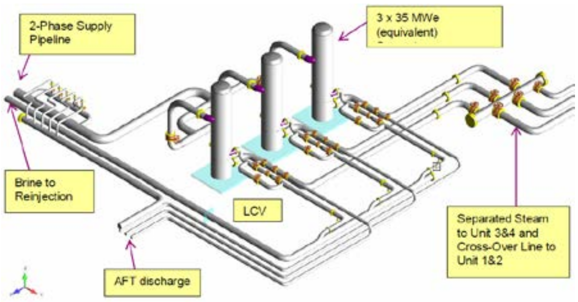

Figure 7: A schematic diagram of central separator station for units 3-4

2.3 Steam-field Fundamental Design and Process Philosophy of Ulubelu Field

In order to have a more flexible operation and steam supply, of units 1-2 and units 3-4, the SAGS was designed with an interconnection system and similar turbine inlet pressure. Moreover, the place of the new units 3-4 is adjacent to units 1-2 (Figure 8).

Figure 8: Units 1-2-3-4 power plant bird view.

2.3.1 Cluster Surface Facilities

All production wells are provided with a two-phase flow control valve (FCV). The FCV is installed upstream of the branch isolation valves with a warming by-pass valve. The FCV is used to control the two phase geothermal fluid flow to the main pipe header. Only one well (with the biggest flow) on each production cluster are provided with an electric motor actuated FCV. The motorized FCV can be operated manually from local position or remotely from the control room. The production wells with the motorized FCV are well UBL-16 in cluster B, well UBL-7 in cluster C, well UBL-11 in cluster D, well UBL-34 in cluster I, well UBL-31 in cluster G, well UBL-K1 in cluster K and well UBL-25 in cluster H.

All pipelines drains in the cluster are connected to an Atmospheric Flash Tank (AFT) at each cluster. A start-up line with isolation valve is provided in all production wells and connected to a portable test separator with AFT and Rock Muffler. The start-up pipeline is connected to the wellhead branch line and upstream of FCV then discharge through the AFT during well start-up and for well simulation purposes (if needed in the future).

A bleed line is connected to one of the side valves on each well head to keep the well hot when the master valve is closed and the well is off-line. The bleed line contains isolation and a throttling valve and connects to a header pipe which discharges the bleed off fluid through the AFT. The wellheads are also provided with a pressure transmitter (digital transducer) and a local pressure indicator for monitoring purpose.

2.3.2 Safety and Emergency Protection System

The two-phase pipelines between the production well branch line, isolation valves and isolation valve upstream of the separators are protected by a PSD Station (Figure 9). The PSDs are designed to permit 100 % relief capacity as required for turbine and gas removal system (GRS) plus 10% with one PSD out of service. The burst disks are fitted with instrumentation to detect a burst remotely to the DCS. The PSD station is located at the main header pipe and the discharge lines are connected to the emergency dumped valve (EDV) (Figure 9).

A pneumatically operated emergency brine dumping valve (EDV) is provided for each separator to discharge brine to EDV in case the brine level in the separator is too high to prevent separator flooding (Figure 9). The EDV is provided with a motorized isolation valve (MOV). The MOV is set normally open. In case of malfunction close of the valve, the brine emergency line is provided with a bypass valve that can be operated from DCS. The EDV is configured to fail to open on loss of air or control signal. The EDV will open based on high-high level (HHL) and will close when the level switch no longer gives the high-high signal.

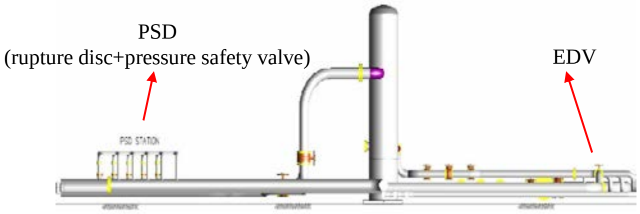

Figure 9: A schematic diagram of PSD and EDV configuration at the separation plant.

2.3.3 Separator and Scrubbing Line System

The separator type that used in Ulubelu field is a cyclone separator with integrated water drum. This design is similar to that in Te Mihi and Nga Awa Purua power station in New Zealand (Zarrouk and Purnanto, 2014). A baffle plate is used to separate the steam and brine inside the separator (Figure 10).

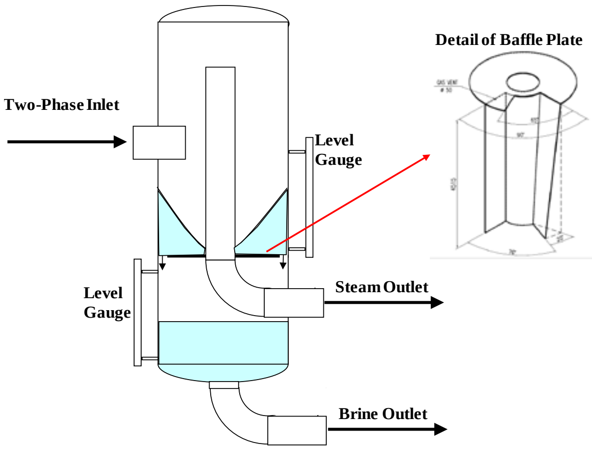

Figure 10: A schematic diagram of separator with integrated water drum (baffle plate type).

The produced steam from each of separator is transferred to the 52 inch scrubbing line header and from this header steam is divided into two lines dedicated for each vertical cyclone scrubbers. Each steam line upstream of the scrubbers have approximately 500 m long scrubbing section with pipe diameter increased to lower the velocity to 25 m/s for scrubbing purposes to remove dissolved silica and chloride (AECOM, 2011). To create condensate required for the scrubbing action to occur, the thickness of pipe insulation is reduced to increase heat loss from the pipe. Scrubbing pots are located approximately 50 m apart in scrubbing lines and at low points in other steam lines to collect the condensate at the bottom of the pipe. Each condensate pot has a steam trap to discharge the fluid, a blow down line to occasionally blow out the condensate pot and a large diameter flanged clean out connection (Figure 11). The scrubbing line is protected against overpressure by the steam venting system using pressure transmitter that installed in scrubbing line header. The transmitter will send signal to the vent valve in vent station to open or close for release excess steam into the rock mufflers.

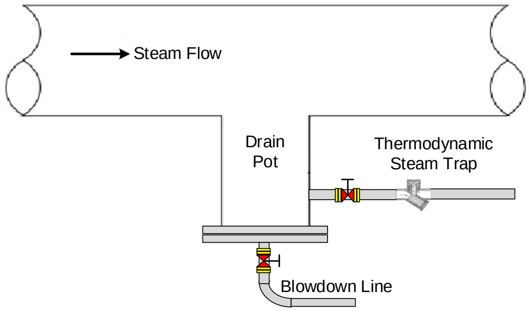

Figure 11: schematic diagram of typical condensate pot.

3. TECHNICAL CHALLENGES DURING THE OPERATION OF UNITS 1-2

3.1 Separator Performance and Brine Carry over

The minimum design efficiency of separator is about 99.95% in design parameter (Lazalde-Crabtree, 1984). However, two of three unit separators in units 1-2 have lower efficiency than the design. Based on the chemical analysis data of fluid, the efficiency of separator and brine carry over can be calculated by the sodium concentration on the brine and steam (Zarrouk and Purnanto, 2014).

Zarrouk and Purnanto (2014) gave expressions for separator efficiency and brine carry-over as follows:

$$\eta_s = \left[1 - \frac{C_s^{Na}}{C_{sb}^{Na}}\right] \times 100\% \quad (1)$$

$$m_{bc} = \frac{C_s^{Na}}{C_{sb}^{Na}} \quad (2)$$

where $m_{bc}$is the brine carry over in kg/s $\eta_s$is separator efficiency in %, $C_s^{Na}$is the mass flow rate of sodium in the separated steam in mg/s and $C_{sb}^{Na}$is the concentration of sodium in separated brine in mg/kg.

Table 1 shows the result of separators efficiency and brine carry-over during operation testing of units 1-2. The sodium concentration in a brine and steam condensate were taken from chemical analysis of fluids during the two-phase tracer flow test (TFT) in the production wells and separators e**Table 1: Measured separator efficiency and brine carry-over for units 1-2**

Separator	Location	m_s (tph)	m_b (tph)	C_s^{Na}	C_{sb}^{Na}	η_s (%)	m_{bc}-Brine Carry Over (kg/s)
1-A	Wellpad-C	252.2	1060.7	94	627	85.01	0.150
1-B	Wellpad-C	204.2	1418.7	20	627	96.81	0.032
2	Wellpad-D	193.7	863.6	1.2	684	99.82	0.002

From the Table 1, m_s and m_b are the steam and brine mass flow rate in tones/h. It shows that all the separators have lower measured efficiency compare to the design efficiency. The lowest efficiency is separator 1-A with 85.01% and followed by separator 1-B (96.81%) and 2 (99.82%). The lower efficiency means the steam and brine in the separator is not separated to the design condition of 99.95%, thus more carry-over is taking place. The brine carry-over at the steam outlet will be reduced as it is scrubbed in several drain pots along the steam pipeline from the separator to the power plant. Brine carry-over should be mostly removed from scrubbing line through the thermodynamic steam trap placed at several drain pots (Figure 11). However, reducing the brine carry-over at the separator is more important because some of the condensate pots have approximately 40% efficiency (Morris et al., 2015). The low efficiency in the separators can be due to high velocity of two-phase flow at the inlet or due to the large separator size (Zarrouk and Purnanto, 2014). Also having large diameter (52 inch) steam scrubbing line (pipeline) means that the carried over brine droplets, will take longer time fall to the bottom of the line (Arifien et al, 2015)

3.2 Two-Phase Flow Measurement

The measurement of the two-phase mass flow rate is a mandatory to manage and maintain a sustainability of the field. Unfortunately, all of the production wells in units 1-2 cannot be monitored during operation because the two-phase orifice plate flow meter that installed on every well did not work properly. This can be related to the fluctuating pressure downstream of the orifice plate, thus it is difficult to measure the mass flow-rate with Murdock equation. A new technique for measuring two-phase flow using sharp edge orifice plates have been developed by Helbig (2012) with a high accuracy. This method can be implemented in SAGS of Ulubelu, however, other research still needed to enhance the correlation in order to increase the accuracy, reduce cost and to simplify its application in geothermal steam field.

3.3 Vibration Problem in Two-Phase Pipeline

Two-phase flow from cluster B is transferred to cluster C through a pipeline with (36 inch) pipe 850 m long. During operation, some vibration occurs at the downstream of the two-phase pipeline (Figure 12).

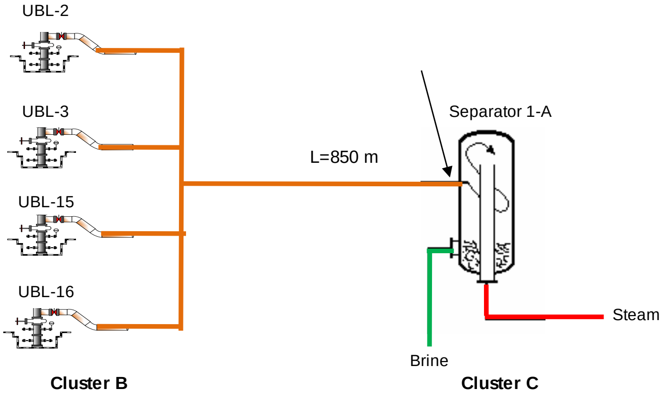

Figure 12: Simplified schematic diagram of two-phase pipeline from cluster B to C.

The vibration in the downstream of two-phase pipeline at cluster C is related to the slug flow inside the pipe. At that point, the operation parameter condition is given in Table 2.

Table 2: Parameter conditions of two-phase flow regime at the inlet pipe of separator

Conditions			
Pressure	P	bara	9.27
Enthalpy	H	kJ/kg	1152
Mixture Flux	m_{TP}	tones/h	1313
		kg/h	1,312,850
Pipe Diameter	D	inch	36
		m	0.91

From the parameters in Table 2, the two-phase flow regime is predicted by Mandhane map (Mandhane et al., 1974). The result of the flow regime given in Figure 12 suggests slug flow conditions, because the superficial steam velocity is much higher than superficial brine velocity. Slug flow causes severe vibration of two-phase pipeline which can damage a pipeline and its supports.

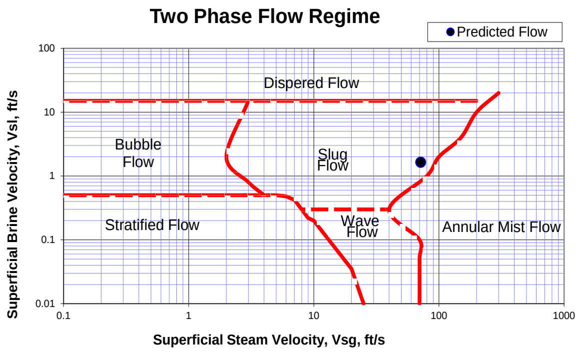

Figure 12: Simplified schematic diagram of two-phase pipeline from cluster B to C

It is possible to increase the pipe size diameter or decrease the mass flow rate to prevent the slug flow effects. However this comes at a high cost. Zarrouk and Purnanto (2014) stated that the Mandhane map (Figure 12) was developed for a small pipe sizes and may not accommodate large pipe diameter. Large diameter two-phase pipelines such as those used in units 1-2 cannot apply the Mandhane pattern map accurately. A new map should be developed that can used for large pipe diameters.

4. CONCLUSION

Ulubelu geothermal field will be the largest geothermal power plant in the Sumatera Island by 2017 with 220 MWe total installed capacity consisting four identical single flash 55 MWe units.

Based on the steam-field concept design, the SAGS of units 1-2 used a hybrid system which is the combination of satellite and centralized separator system. Whereas units 3-4 are designed with centralized separator located about 600 m to the power plant.

All the units use a typical cyclone separator design, consisting of separator stations with integrated water drum. A baffle plate is installed inside the vessel in order to separate the fluid and also to prevent unstable water level in the water drum. Other typical SAGS design also used in all units, including scrubbing line, emergency dump system and safety protection systems.

Units 1-2 witnessed some technical problems since operation started including; brine carry-over (separator breakdown), unknown mass flow rate from production wells and pipeline vibration due to slug flow regime. Given that the design parameters and considerations of units 1 and 2 will not be changed for units 3-4, it is expected that the same technical challenges will be encountered in units 3 and 4.

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REFERENCES

AECOM: Geothermal Training Workshop, Geothermal Power Plants, *FS and FEED for Preparing Geothermal Fields for Development PT. Pertamina Geothermal Energy*, Indonesia, 2011.

AECOM: Ulubelu Units 3&4 (2x55MW) SAGS Design Report, *FEED for Preparing Geothermal Fields for Development PT. Pertamina Geothermal Energy*, Indonesia, 2012.

Arifien, B.N., Zarrouk, S.J. and Kurniawan, W.: Scrubbing lines in Geothermal Power Generation Systems, *Proceeding the 37th New Zealand Geothermal Workshop*, Taupo, New Zealand, 18-20 November 2015.

DiPippo, R.: Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact, *third ed. Elsevier Ltd.*, United States of America, 2012.

Helbig, S. & Zarrouk S.J.: Measuring two-phase flow in geothermal pipelines using sharp edge orifice plates, *Geothermics*, Vol. 44, 52-64, 2012.

Lazalde-Crabtree, H.: Design approach of steam-water separators and steam dryers for geothermal applications. *Geotherm. Resour. Counc. Bull.*, 11–20. 1984.

Mandhane, J.M., Gregory, G.A., Aziz, K.: A flow pattern map for gas–liquid flow in horizontal pipes, *Int. J. Multiphase Flow* 1, 537–553. 1974.

Morris C. and Mroczek E.: Turbine Scaling, *Proceeding the 37th New Zealand Geothermal Workshop*, Taupo, New Zealand, 18-20 November 2015.

Zarrouk S.J. and Purnanto M.H.: Geothermal Steam Water Separators: Design Overview, *Geothermics* , Vol. 53, 236-254, 2014.