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Designing and Maintenance of Pressure and Heat Loss in Production Pipeline to Optimize Electric Power at the Lumut Balai Geothermal Field in Indonesia

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ABSTRACT

Most conventional geothermal wells produce a two-phase flow, namely water and steam. At the head of the well, fluid moves inside the piping system to the separator where steam and water are separated. Piping systems from wells to separators are usually planned as close as possible. In planning a two-phase flow pipe from the well to the separator, it is attempted to have the permitted speed and avoid the slug flow pattern that can cause the water hammer. To run a geothermal power plant, a steam turbine is required. Power generated from this vapor is influenced by the energy in the fluid. The pressure and temperature of the steam are directly related to the energy that will be produced. To optimize the energy generated inside the turbine, it must be designed so that the pipe production line can support high pressure and temperature. Loss can be engineered by changing the flow pattern inside the pipe. Besides that the influence of roughness and diameter of the pipe will also affect the amount of pressure loss that occurs. In addition to pressure loss, energy decline is also strongly affected by heat loss. Heat loss and pressure on geothermal fluid flow from geothermal production wells to power plants is a problem that is often faced in geothermal production. Heat loss along the pipe causes condensation of water vapor which will cause damage to the turbine. During the process of distributing geothermal fluid, heat and pressure loss will occur and the energy value of the fluid at the entry point of the turbine will decrease. Most pressure losses occur due to fluid friction with the pipe walls and elevation differences. The heat loss that occurs is caused by differences in temperature inside and outside the pipe, where geothermal fluid is high temperature while the outside temperature is relatively low. Therefore, the design and planning of the flow pipe must be calculated as well as possible. The comparation is based on the amount of working fluid mass, the generated power, also the safety of surroundings environment.

1. INTRODUCTION

In geothermal power plants, the fluid used to rotate turbines is steam (Hutomo Radhitya, 2015). The energy generated from this vapor is influenced by the internal energy of the fluid; the greater the pressure and temperature of the steam, the greater the internal energy. To optimize the energy produced by a turbine, it is best not to lose a lot of heat and pressure along the production pipe. Pressure loss can be engineered by changing the flow pattern in the pipe. In addition, the design of roughness and diameter of the pipe will also affect the amount of pressure loss that occurs.

In addition to pressure loss, the cause of the decreased internal energy the fluid is heat loss. Heat loss that occurs due to the difference between the temperature inside and outside the pipe. The speed of heat flow that occurs due to temperature differences is not affected by the speed of fluid flow. The faster the fluid flow rate produced, the more heat loss will be insignificant. To reduce heat loss that occurs in geothermal production pipes, the insulator is used along the pipe (Guo B., Duan S., Ghalambor A, 2006).

The steam condensation process can occur in production fluids flowing along the pipe, therefore catchpot is highly recommended to be installed in one phase flow pipe. Catchpot serves to remove the mass of vapor fluid condensed into water so that the fluid flowing to the turbine is completely steam.

Lumut Balai geothermal field is located at Sumatra Island, South Sumatra Province, Penindaian village, the Sea Land Semende sub-district, Muara Enim district, about 292 km southwest of Palembang (Figure 1). Geothermal prospects are located around Gunung Balai, Gunung Lumut and Gunung Pagut. The average altitude of the Lumut Balai geothermal field is around 1000 m above sea level (m a.s.l.). Supporting Lumut Balai geothermal project for power plan unit I x 55MW, have ready done drilled in 3 clusters with 9 wells including 5 wells in cluster 1, 2 wells in cluster 2, and 2 wells in cluster 3 with a cummulative potential of 56 MW.

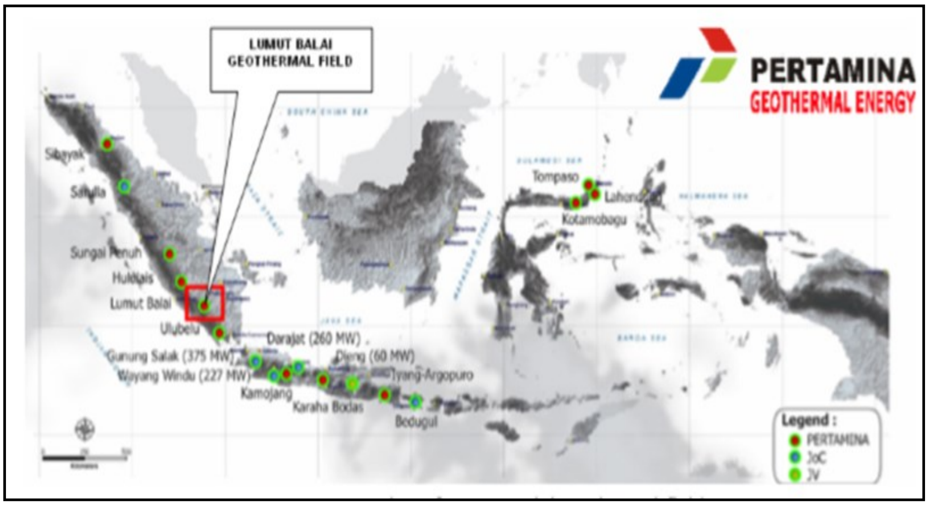

Figure 1: Location map of Lumut Balai Geothermal Field Indonesia

2. DATA AND METHOD

Transmission pipe lines can be divided into two lines: first the pipe line after the separator for steam flow and second the other pipeline for two phase flow. The length of the two-phase flow pipe varies; there are only a few meters from the wellhead because this separator only separates fluid from one well, but some are longer due to separating fluid from several wells so that the separator is placed in the area in between the wells. Fluid flow velocity recommended by Oliver Lyle (1947) for geothermal fluid is 20-40 m/s. The size of the two phase flow pipe depends on many factors, including the magnitude of the mass flow rate, pressure loss, and allowable speed.

Table 2: Wells data, production properties and power output at Lumut Balai geothermal field

No.	Well	WHP (ksc)	Psep Test(kscg)	Enthalpy (kj/kg)	Dryness (fraction)	Total Rate (t/j)	Power (MW)*
1	Loc-1/1	6	5	942	0.12	114	2
2	Loc-1/2	6	5	1150	0,23	16	1
3	Loc-1/3	6	5	1045	0,17	434	9
4	Loc-1/5	6	5	1158	0.22	319	10
5	Loc-1/6	6	5	1188	0,25	264	8
6	Loc 2/1	7	6	1085	0,18	368	8
7	Loc 2/2	7	6	1039	0,16	352	7
8	Loc 3/1	7	6	1014	0,14	412	7
9	Loc 3/2	7	6	1032	0,15	226	4
					Total	2505	56

2.1. Pressure Loss of Two Phase Flow in Pipes

The equation for determining pressure loss due to friction and acceleration can be calculated by the following equation (Harrison & Freeston, 1984):

$$\left(\frac{dP}{dz}\right)_{f\,\&\,acc} = \frac{4\,\tau_w}{D(1-AC)} \tag{1}$$

with :

$$AC = \frac{m^2 . x^2}{P . A_p{}^2 . \alpha . \rho_g} \tag{2}$$

τ_w is a wall shear stress, which is calculated using equations:

$$\tau_w = C_f \frac{1}{2} \rho_L (v_L)^2 = \frac{\lambda}{8} \rho_L (v_L)^2 \tag{3}$$

Liquid phase velocity (v_L) is sought using equations:

$$v_f = \frac{m\,(1-x)\,\upsilon_f}{(1-\alpha)\,A} \tag{4}$$

Pressure loss due to elevation is calculated using the following equation:

$$\left(\frac{dP}{dz}\right)_g = \bar{\rho}\ g \sin\theta \qquad (5)$$

with :

$$\bar{\rho} = \alpha\,\rho_g + (1-\alpha)\,\rho_f$$

sin θ is the difference in height between two points divided by distance.

2.2. Pressure Loss of One Phase Flow in Pipes

The one phase flow model is a model of fluid flow with only one fluid flowing in a pipe and it is assumed that no slip between fluid and the pipe wall occurs and has an average density between the liquid phase and the vapor phase (Saptadji. N.M., 1998).

In accordance with the flow geometry, if the flow pipe is in a horizontal condition, then the sine of that angle is zero. This shows that there is no pressure drop caused by changes in altitude.

Pressure losses in 1- phase flow pipes can be calculated by the following equation Unwin , (Sashi, E. M, 2005)

$$\Delta P = 0.6753^6 x\ M^2 x\ L\ c\ \frac{(1+(\frac{91.4}{di})}{\rho g\ x\ di^5}. \qquad (6)$$

remark :

ΔP = Pressure Loss, bar
M = Mass Flow rate , Kg/jam
L = Pipe Length, meter
ρg = Steam Density, Kg/m^3
di = inside diameter of pipe, mm

2.3. Heat Loss Fluids in Flow Pipes

The heat flow in the transportation process is divided into three, namely: heat transfer from the fluid to the pipe called convection; the flow of heat in the fluid called conduction and the flow of heat from the pipe around it called radiation.

Heat loss of geothermal fluid flow can be calculated using the following equation (J.P. Holman, 1981):

$$Q = U_o\,A(T_i - T_a) \qquad (7)$$

Q = Heat Loss, watt
A = Area of pipe coated with the insulator , m^2
T_i = Inside temperature of pipe, °C
T_a = ambient temperature, °C

For the calculation of heat loss it is necessary to define the heat transfer coefficient along the pipe, which is stated in the following equation (J.P. Holman, 1981):

$$U_o = \frac{1}{\frac{r_3}{r_1\,h_i} + \frac{r_3 \ln(r_2/r_1)}{k_1} + \frac{r_3 \ln(r_3/r_2)}{k_2} + \frac{1}{h_o}} \qquad (8)$$

remarks:

h_i = heat transfer coefficient on the inside of the pipe, W/m^2.°C
h_o = heat transfer coefficient on the outside of the pipe, W/m^2.°C
k_1 = pipe heat conductivity, W/m.°C
k_2 = insulator heat conductivity, W/m.°C
r_1 = Inside radius of pipe = 0,5 d_i, m
r_2 = Outside radius of pipe = 0,5 d_o, m
r_3 = Outside radius of insulator = 0,5 (d_o + 2 h_{ins}), m

but the annular flow is chosen. Because in that flow water is distributed on the surface of the pipe wall, and steam flows at high speed in the pipe. Determination is based on the flow chart patterns Mundhane (1974).

3. RESULT AND DISCUSSION

Flowline planning will be carried out in the Lumut Balai geothermal field. This field has a liquid dominated reservoir, which means that in the planning of the flow pipe, a two phase and separator flow pipe is needed. In the field of Lumut Balai, there are 3 clusters and 9 production wells. In the first cluster, there are 5 production wells and the distance to the geothermal powerplant is 1.2 km.

In the second cluster, there are 2 production wells and a distance of 1.4 km to the geothermal powerplant. In the third cluster, there are 2 production wells and a distance of 1.5 km to the geothermal powerplant. In field the value of scaling, silica is very low so it can be ignored. Lumut Balai Field is targeted to produce 55 MW of electric power. Every 8 tons/hour is assumed to produce 1 MW with temperatures around 180^{o}C, pressure around 0.56 bar, and turbine input pressure of 5 bars.

Superficial velocity gas and liquid (vsg & vsl) are parameters that influence flow patterns. Superficial velocity is the speed of both steam and liquid if it flows itself inside the pipe.

Calculation of vsg and vsl in Loc 1/3 well with a pipe diameter of 20 inches.

$$vsg = \frac{vg * Mv}{3.14 * ID^2 / 4} \qquad vsl = \frac{vl * Mliq}{3.14 * ID^2 / 4} \tag{9}$$

The results of the calculation of vsg and vsl on other wells with various diameter sizes can be seen in Tables 3a-3b.

Table 3a: Result of Calculation vsg and vsl each Wells data Lumut Balai geothermal field

Loc/Well	vsg 20	vsl 20	vsg 18	vsl18	vsg 16	vsl 16
Loc1/1	19.77752	0.496182	27.86197	0.699006	30.90238	0.775285
Loc1/2	5.320269	0.060935	7.495032	0.085843	8.312921	0.09521
Loc1/3	106.6656	1.781647	150.2673	2.509929	166.665	2.783823
Loc1/5	101.461	1.230663	142.9352	1.73372	158.5328	1.92291
Loc1/6	95.41788	0.979307	134.4218	1.379618	149.0904	1.530167
Loc2/1	82.77705	1.502398	116.6138	2.116532	129.3391	2.347496
Loc2/2	70.38048	1.472127	99.14987	2.073887	109.9695	2.300198
Loc3/1	72.08001	1.764083	101.5441	2.485185	112.625	2.756379
Loc3/2	42.36325	0.956424	59.68005	1.347381	66.19258	1.494413

Table 3b: Result of Calculation vsg and vsl each Wells data Lumut Balai geothermal field

Loc/Well	vsg 14	vsl 14	Vsg 12	Vsl 12	Vsg 10	Vsl 10
Loc1/1	40.36229	1.012617	54.93757	1.378284	79.11009	1.984729
Loc1/2	10.85769	0.124356	14.77853	0.169263	21.28108	0.243739
Loc1/3	217.6849	3.636014	296.2934	4.949018	426.6625	7.126586
Loc1/5	207.0633	2.511556	281.8361	3.418507	405.844	4.922651
Loc1/6	194.7304	1.998586	265.0497	2.720298	381.6715	3.917229
Loc2/1	168.9328	3.066118	229.9362	4.173327	331.1082	6.009591
Loc2/2	143.6336	3.00434	195.5013	4.089241	281.5219	5.888507
Loc3/1	147.1021	3.600169	200.2223	4.900229	288.3201	7.05633
Loc3/2	86.45562	1.951886	117.6757	2.656734	169.453	3.825697

After calculating vsg and vsl then the values of each vsg and vsl are plotted into the Mundhane graph and selected which have the annular flow pattern, as seen in Figure 2.

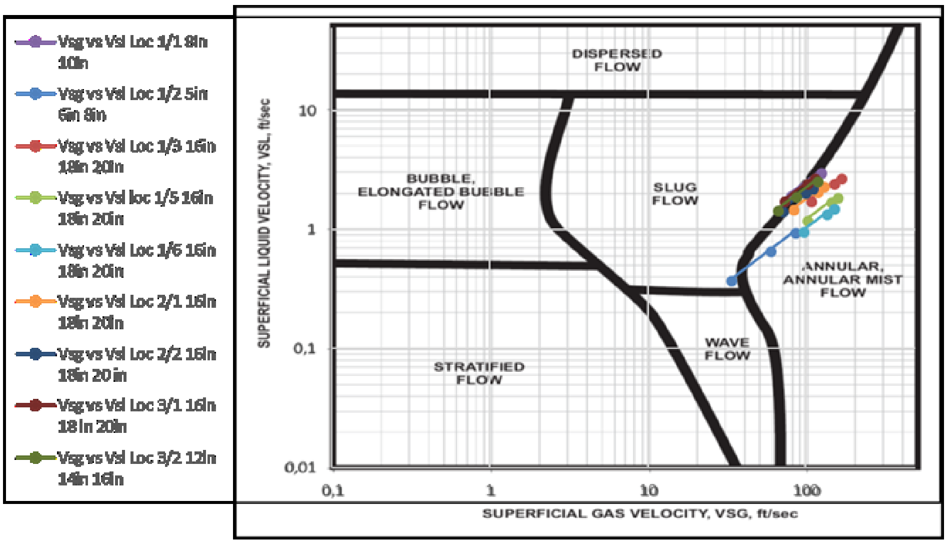

Figure 2: Graph of Flow Patterns of Each Diameter

3.1. Making a Field Scheme X

Making the X field scheme can be made using the simulator can be seen at Figure. 3.

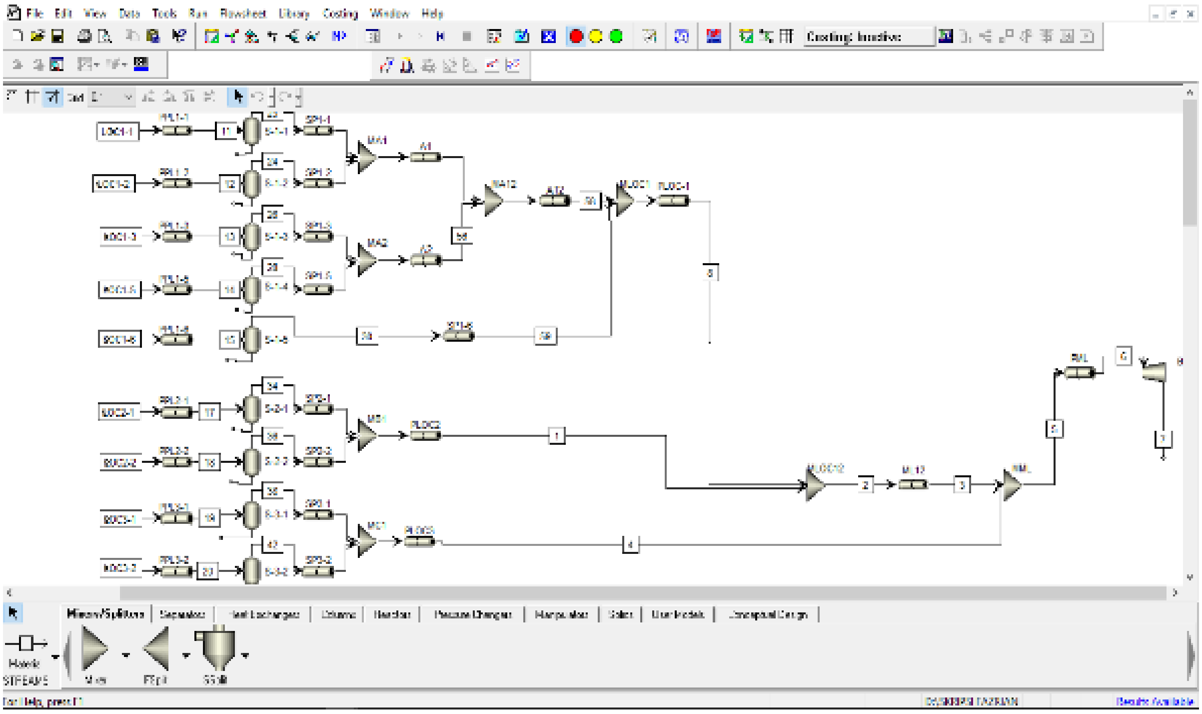

Figure 3: Well Scheme using simulator Lumut Balai Geothermal field

After using the simulator, it can be seen how much pressure and temperature loss occurs in the flow pipe. Calculation of pressure and temperature loss begins by calculating the pressure loss and temperature from each well to the separator. After being separated in the steam, mass fluid separator will be flowed and put together into the pipe segment which will be flowed in one main pipe line pipe (PML) segment. Some segments that will be combined include:

In Cluster Loc 1 :
• SP1-1 segment and SP1-2 segment into MA1 mixer and flowed through A1 segment
• SP1-3 segment and SP1-5 segment into MA2 mixer and flowed through A2 segment

• Segment A1 and segment A2 into the MA12 mixer and flow through the A12 segment
• SP1-6 segment and segment A12 into the MLOC1 mixer and flow through the PLOC1 segment which will be combined with the fluid from the PLOC2 segment into MLOC12
• Steam mass fluid from cluster 1 is 57.28 kg / s

In Cluster Loc 2
• SP2-1 segment and SP2-2 segment into mixer MB1 and streamed through PLOC2 segments which will be combined with fluid from PLOC1 segment into MLOC12.
• Steam mass fluid from cluster 2 is 30.88 kg / s

In Cluster Loc 3
• SP3-1 segment and SP3-2 segment into MC1 mixer and flowed through PLOC3 segment which will be combined with fluid from PL12 segment in MML.
• Steam mass fluid from cluster 3 is 23.08 kg / s

After all are combined into 1 segment, namely the main pipe line (PML) segment, steam is flowed into the turbine with a total steam mass fluid of 111,246 kg / s and can rotate the turbine blades so that it can generate electricity.

In this calculation, the pressure loss is calculated at Loc 1/3 well into the separator with well data and fluid data as follows:

<u>Well Loc 1/3 :</u>

WHP = 5.883 bar
h = 1045 Kj/Kg
x = 0.17
di = 20 inch= 0.4778 m
L = 50 m
Mt = 120.56 kg/s

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Mg = 20.5 kg/s
Mf = 100.06 kg/s
vf = 0.0010997 m^3/kg
vg = 0.321 m^3/kg
pf = 909.3279 kg/m^3
μf = 0.0172
pg = 3.11 kg/m^3
ε = 0.00015

Calculation Step:
Calculating Pipe Surface Area (A)

$$A = \frac{1}{4} 3.14\, x\, di^2$$
$$= \frac{1}{4}\ 3.14\, x\, 0.4778^2$$
$$= 0.1792\ m^2$$

Calculating Void Friction (α):

$$\alpha = \frac{1}{1+\left(\frac{1-x}{x}\right)^{0.8} \left(\frac{vf}{vg}\right)^{0.515}}$$
$$= \frac{1}{1+\left(\frac{1-0.17}{0.17}\right)^{0.8} \left(\frac{0.0010997}{0.321}\right)^{0.515}}$$
$$= 0.839$$

Calculating the Speed of a Liquid Phase:

$$Vf = \frac{Mt\,(1-x)vf}{(1-\alpha)A}$$
$$= \frac{120.56\,(1-0.17)0.0010997}{(1-0.839)0.1792}$$
$$= 3.829\ m/s$$

Calculating Friction Factors:

$$N_{re} = \frac{M(1-x)di}{\mu f\ A}$$
$$A = \left[2.457 \ln \frac{1}{\left(\frac{7}{Nre}\right)^{0.9}+0.27\left(\frac{\varepsilon}{di}\right)}\right]^{16}$$
$$B = \left(\frac{37530}{Nre}\right)^{16}$$
$$\Lambda = 8\left[\left(\frac{8}{Nre}\right)^{12} + \frac{1}{(A+B)^{\frac{3}{2}}}\right]^{1/12}$$
$$N_{re} = \frac{120.56(1-0.17)0.4778}{0.0172\ 0.1792}$$
$$= 15510.33122$$
$$A = \left[2.457 \ln \frac{1}{\left(\frac{7}{15510.33122}\right)^{0.9}+0.27\left(\frac{0.00015}{0.4778}\right)}\right]^{16}$$
$$= 5.026 \times 10^{19}$$
$$B = \left(\frac{37530}{15510.33122}\right)^{16}$$
$$= 1380765.343$$
$$\lambda = 8\left[\left(\frac{8}{15510.33122}\right)^{12} + \frac{1}{(5.026x10^{19}+1380765.343)^{\frac{3}{2}}}\right]^{1/12}$$
$$= 0.0276$$

Calculating Pressure Loss Due to Friction and Acceleration:

Friction Coeficient (C_f) $= \lambda/4$

Wall Shear Stress (τw) $= C_f \frac{Vf^2}{2\,vf}$

AC $= \frac{m^2 x^2 vg}{P\ A^2\ \alpha}$

Friction coefficient (C_f) = 0.0276/4
= 0.006892

Wall Shear Stress (τw) $= 0.006892 \frac{3.829^2}{2\ 0.001109}$
= 45.945

AC $= \frac{120.56^2 0.17^2 0.3214}{5.883\ 0.1792^2\ 0.839}$
= 0.008511

Calculating Pressure Losses Along the Flow Pipe :

$$\left(\frac{dP}{dZ}\right)_{f\ \&\ acc} = \frac{4\tau_w}{di(1-AC)}$$
$$= \frac{4x\ 45.945}{0.4778(1-0.008511)}$$
$= 387.9452$ Pa/m
$= 0.003879$ bar/m

The length of the pipe at Loc 1/3 to the separator well is 50 m

P_{final} = P - (L x P2)
= 5.883 – (50 x 0.003879)
= 5.689 bar

After we calculate the pressure loss that occurs, the next step is to calculate the temperature loss that occurs.
In this calculation the temperature loss is calculated in the Loc 1/3 well to the separator with well data and fluid data as follows:

Well Loc 1/3

Pipe Diameter : 20 in
Inlet Diameter of Pipe (d_i) : 0.4778 m
Insulation Thickness (h_{ins}) : 8 cm = 0.0508 m
Insulation Type : Rockwool
Pipe Heat Conductivity (k_1) : 54 W/m.°C.
Insulation Heat Conductivity (k_2): 0.033 W/m.°C
Environmental Temperature(T_a): 18 °C = 291 K
Steam Flowrate (M_s) : 20.5 kg/s
Condensate Flow Rate (M_c) : 100.06 kg/s Dryness (x) : 0.17
Outlet Diameter of Pipe (d_o) : 0.50
Pipe Length (L) : 50 m
Pipe Temperature (T_w) : 20 °C
Fluids Temperatur (T_s) : 171 °C
Pipe Material : Carbon Steel
Total Mass Flowrate (M_{total}): 120.56 kg/s

Calculating the Heat Transfer Coefficient Outside the Pipe:

From water properties on T_a=18 °C = 291 K
ρ_a : 1.21552 kg/m^3
μ_a : 1.8024 x 10^{-5} kg/m.s
C_{pa} : 1004.504 J/kg °C
k_a : 2553.44x10^{-5} = 0.0255344 W/m °C

Calculating Prandlt Number (P_r):

$$P_r = \frac{C_{pa}\ \mu_a}{k_a} = \frac{1004.504 \text{ x } 1.8024 \text{ x } 10^{-5}}{0.0255344} = 0.70905054$$

Calculating Grashof Number (G_r):

$$\beta = \frac{2}{T_w+T_a} = \frac{2}{20+18} = 0.052631579$$
$$d_o' = d_o + (2.h_{ins}) = 0.508 + (2(0.08)) = 0.6096 \text{ m}$$
$$G_r = \frac{\beta\ g\ (d_o')^3(\rho_a)^2(T_w-T_a)}{(\mu_a)^2} = \frac{0.052631579\ (9.8)(0.6096)^3(1.21552)^2(20-18)}{(1.8024x10^{-5})^2} = 1062818746$$

Calculating Nusselt Number (N_u):

$$N_u = 0.525(Gr.Pr)^{0.25} = 0.525(1062818746x0.70905054)^{0.25}$$
$$N_u = 86.9848$$

Heat Transfer Coefficient Outside the Pipe (h_o) :

$$h_o = \frac{N_u.k_a}{d_o'} = \frac{86.9848x0.0255344}{0.508} = 3.6435 \text{ W/m.°C}$$

Calculating the Heat Transfer Coefficient Inside the Pipe (h_i) :

From steam table on P=5.886 bar and T=158.067 °C
v_f: 0.0011 m^3/kg
ρ_f: 909.3279 kg/m^3
v_g : 0.321352 m^3/kg
ρ_g : 3.11 kg/m^3
k_f: 3.19 x 10^{-4} kW/m °C
Cpg : 2.47 kJ/Kg°C
μ_f : 172 x 10^{-6} kg/m.s

Cpf : 4.33 kJ/Kg°C

$$h_i = 0.8\left[0.951k_f\left(\frac{\rho_f(\rho_f-\rho_g)g}{\mu_f M_c}\right)^{1/3}\right]$$

$$h_i = 0.8\left[0.951(3.19x10^{-4})\left(\frac{909.32(909.32-3.11185)9.8}{172x10^{-6}\ 100.06}\right)^{1/3}\right]h_i\ =\ 18879.59\ \text{W/m.°C}$$

Calculating the Overall Heat Coefficient (U_o) :

r_1 = 0.5 d_i = 0.5(0.4778) = 0.239 m
r_2 = 0.5 d_o = 0.5(0.508) = 0.254 m
r_3 = 0.5 (d_o + 2 h_{ins}) = 0.5(0.508+2(0.08)) = 0.334 m

$$U_o = \frac{1}{\frac{r_3}{r_1 h_i} + \frac{r_3 \ln\left(\frac{r_2}{r_1}\right)}{k_1} + \frac{r_3 \ln\left(\frac{r_3}{r_2}\right)}{k_2} + \frac{1}{h_o}}$$

$$U_0 = \frac{1}{\frac{0.334}{0.239x18.879} + \frac{0.334\ln\left(\frac{0.254}{0.239}\right)}{54} + \frac{0.334\ln\left(\frac{0.0.334}{0.1270.254}\right)}{0.033} + \frac{1}{3.6435}}$$

U_o = 0.038393 W/m^2.°C

Calculating Heat Loss (Q):

Heat loss (Q) = U_o A_o (T_i – T_a) L
= 0.038393 0.202 (158.06-18) 50
= 54.467 kW

Calculating Final Temperature:

$$T2 = T1 - \frac{Q}{M\ Cp}$$
$$= 158.06 - \frac{54.467}{20.5\ 2.47}$$
$$= 156.9°C$$

The results of calculations on other wells can be seen from the following figure 4.

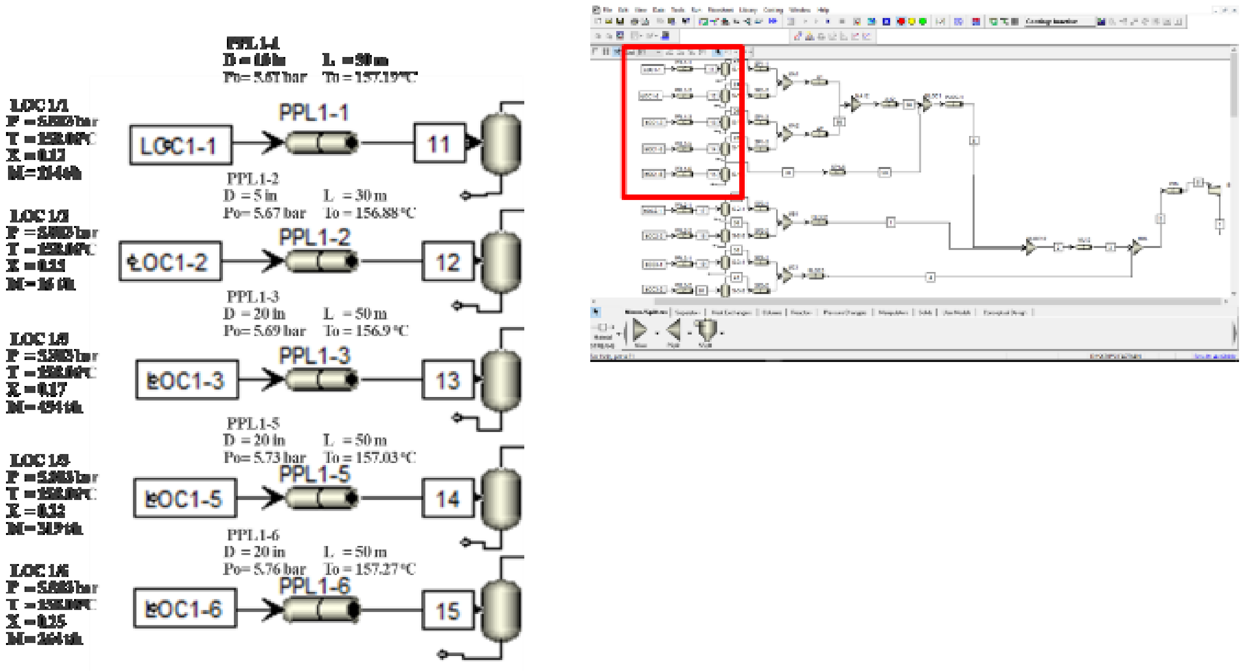

Figure 4: Pressure and Temperature flow in pipe 2-Phasa at Cluster LOC 1

After the fluid mass passes through the separator, the fluid phase resulting from the separation is divided into 2, namely the vapor phase and the water phase. Plumbing planning only plans flow pipes for steam mass fluid. After passing through the separator, the diameter of the flow pipe used is equal to the diameter of the flow pipe used when the mass fluid flows from the well to the separator.

Pressure loss on fluid 1 phase is calculated using the equation Unwin. In the calculation example, this time uses data from the SP1-3 segment with the following data:

Pressure	= 5.5 bar
Mass Flowrate (W)	= 18.59kg/s = 66932.0886 kg/jam
Pipe Length	= 50 meter
Inlet Diameter of Pipe	= 0.4778 meter = 477.8 mm
∂g	= 2.9189 kg/m^3

$$\Delta P = 0.6753x10^6\, L\, W^2 \frac{1+(91.44/Di}{\partial g\, Di^5}$$

$$= 0.6753x10^6\ 50\ 66932.0886^2 \frac{1+(91.44/477.8}{2.9189\ 477.8^5}$$

= 2479.1346 Pa

= 0.00248 bar

$$P_2 = P_1 - \Delta P:$$

= 5.5 – 0.00248

= 5.475 bar

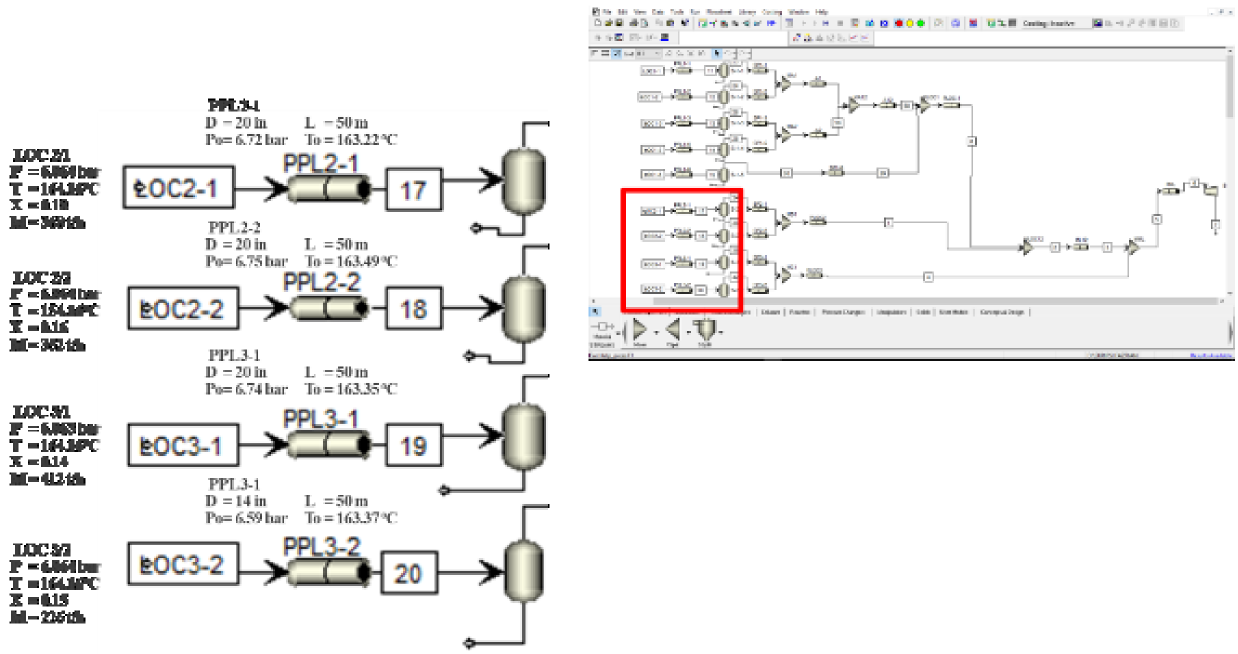

Figure 5: Pressure and Temperature flow in pipe 2-Phasa at Cluster LOC 2 and LOC 3

After passing through the separator, several segments were put together such as from SP1-1 segment with SP1-2, SP1-3 segment with SP1-5 segment, SP2-1 segment with SP2-2, and SP3-1 segment with SP3-2. From the SP1-1 and SP1-2 segments will enter the MA1 mixer and enter into the A1 segment with a diameter of 12 inches of flow pipe with a length of 30 meters. From the SP1-3 and SP1-5 segments, they will enter the MA2 mixer and enter into A2 segment with a diameter of 24 inches with a length of 30 meters and can be seen in Figure 5.

After the A1 and A2 segments are combined in the MA12 mixer and enter the A12 segment with a diameter of 30 inches and a length of 30 meters, the A12 segment will be combined with the SP1-6 segment into the MLOC1 mixer into the PLOC1 segment and become the pipe end of the LOC1 cluster. The fluid from SP 2-1 and SP 2-2 segments will be combined in mixer MB1 before entering into PLOC2 segment can be seen in Figure 10. After that fluid from cluster 1 will be combined with fluid from cluster 2 in MLOC12 mixer and enter into ML12 segment.

The fluid from the SP 3-1 segment will be combined with the SP 3-2 segment in the MC1 mixer before entering the PLOC3 segment can be seen in Figure 10. The fluid from the PLOC3 segment will be combined with the fluid from the MLOC12 segment in the MML mixer before entering mainline pipe or PML segment. After all fluids are put together in 1 segment, namely the PML segment and can be seen in Figure 6 and Figure 7. The fluid is flowed into the turbine to rotate the turbine blades so that the turbine can produce electrical energy.

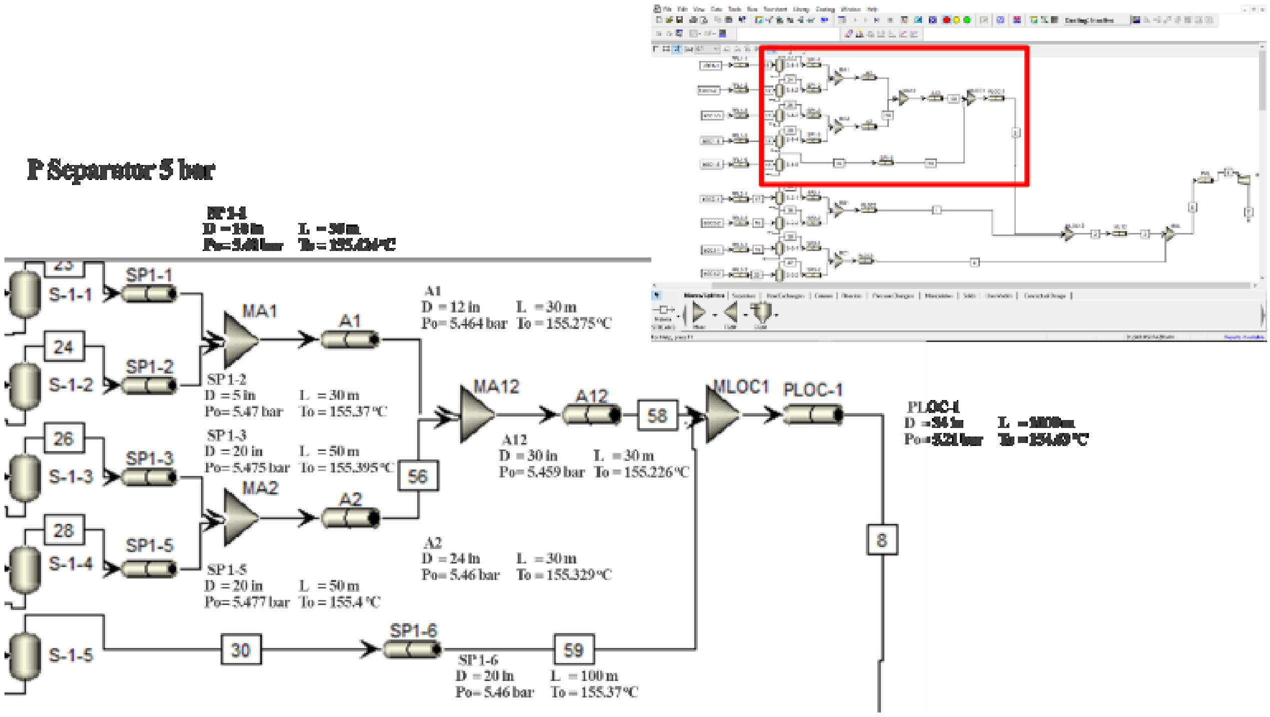

Figure 6: Pressure and Temperature at Cluster 1

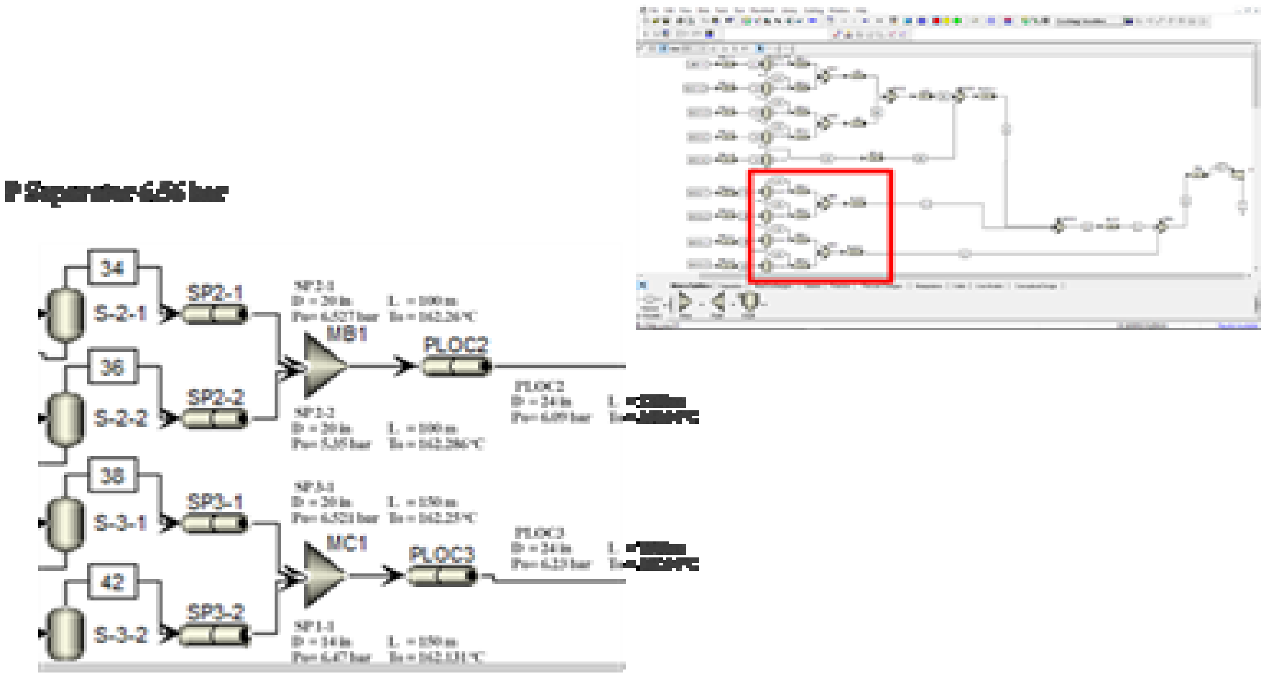

Figure 7: Pressure and Temperature at Cluster 2 and Cluster 3

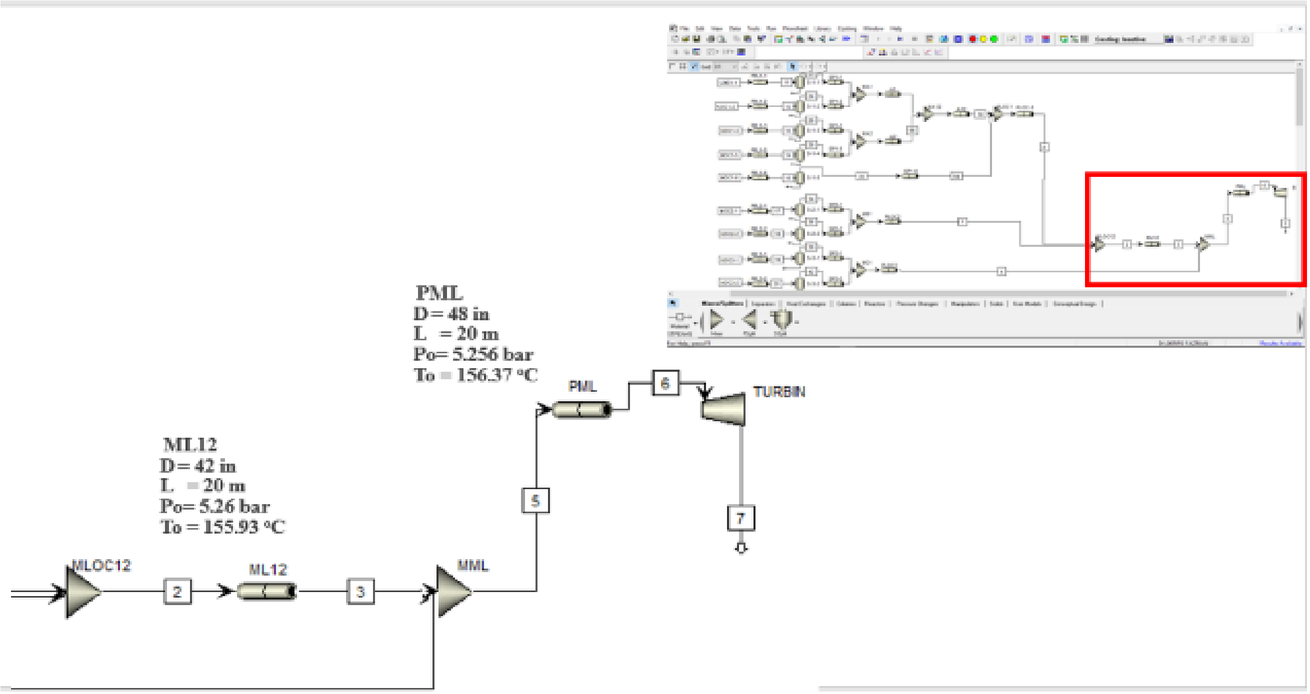

Figure 8: Pressure and Temperature before entering the Turbine

With the total fluid mass of steam being flowed at 111,246 kg/s, the fluid pressure entering the turbine is 5,256 bar and the temperature is 156.37°C with turbine efficiency of 80% and turbine exit pressure of 0.08 bar figure 8. We can calculate the electric power that can be generated from field X as follows:

P input turbin = 5.256 bar
Steam Enhalpy = 2750.42 kJ/Kg
Steam Entropy = 6.823 kJ/Kg °C

P output turbin = 0.08 bar
Steam Enhalpy = 2576.21 kJ/Kg
Water Enthalpy = 173.84
Steam Entropy = 8.22 kJ/Kg °C
Water Entropy = 0.59 kJ/Kg °C

Calculates the Xg out of the turbine:

$$Xg = \frac{Sg1 - Sf2}{Sg2 - Sf2}$$
$$Xg = \frac{6.8 - 0.59}{8.22 - 0.59} = 0.814$$

Calculating the turbine exit enthalpy:

$$H_2 = Xg.Hfg2 + Hf2$$
$$= 0.814\ (2576.21+173.84) + 173.84$$
$$= 2129.36918 \text{ kJ/Kg}$$

Calculating the turbine exhaust enthalpy:

$$dH_S = H_2 - H_1$$
$$= 2129.36918 - 2750.42$$
$$= -621.05082 \text{ kJ/Kg}$$

Electric Power generated by the turbine:

Electric Power = M x turbine efficiency x $-dH_s$
= 111.246 x 0.8 x -(-621.05082)
= 55.271 MW

4. CONCLUSION

As any data based on the result and explanation above there are some conclusion as seen :

- Based on the study, it can be concluded that the pressure and temperature loss must be minimized as much as possible so that it can produce optimum electric power where the planning of the flow pipe of each well can be determined by finding the optimum fluid velocity and the corresponding flow pattern. This prevents the occurrence of water hammer.
- The greater the diameter of the flow pipe used, the smaller the loss of pressure that occurs. By planning the diameter of the flow pipe above, there is no back pressure in the separator or in the turbine. Plumbing planning is designed as close as possible to the power plant so that not too much pressure is lost.
- The mass vapor fluid before entering the turbine is 111,246 kg/s with the distribution of clusters 1,2, and 3 of 57.28 kg/s, 30,886 kg/s, and 23.08 kg/s. With a turbine P input of 5,256 bars and a turbine output P of 0.08 bar and turbine efficiency of 80%, X geothermal field can produce electric power of 55,271 MW. With the above planning can be said to be optimum because it can meet the minimum electric power production of 55 MW.

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