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Comprehensive Comparison between Using the Main Big Separator in the Power Plant Site and some Small Separator in the Near of Wells for 25 MWe Power Plant in Sabalan, Iran

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ABSTRACT

The Sabalan geothermal field is a high-temperature area under development. Geothermal exploration was started in 1975 by the Ministry of Energy of Iran. After revolution in 1979 in Iran, it was stopped, and it was started again in 1998 by SUNA – the Renewable Energy Organization of Iran. Three deep exploration wells and two shallow reinjection wells were drilled in 2002-2004 in three sites A, B, and C, by SUNA beside the preparation of two sites D and E for new drilling. This area is about 16 km southeast of the town of Meshkinshahr. There is an overall potential for the generation of about 200 MWe over the greater prospect area. SKM (main consultants 1998-2006) assesses that commercial geothermal power generation can be achieved at Sabalan at a levelized cost of electricity of less than 5 USc/kWh. SUNA is planning to drill thirteen new wells, and build a 50 MWe power plant, when these wells will be drilled. As the first part of project, SUNA will build a pilot power plant in order to confirm that a geothermal power plant can be operated in Iran. Moshanir was the consultant for civil work 1998-2006 and since 2006 the consortium of Moshanir, EDC and Lahmeyer was selected as main consultant for geothermal field and in this part, the new drilling was started since of 2008 till 2011. In this phase one of the pervious well in the sites B was be deeper and 6 deep wells were drilled in three sites D, E and C. Now a 5 MWe power plant is under building near to site D.

In this paper, a power plant with capacity of 25 MWe in site A is assumed, with steam from production wells on pads D and E, and with brine water reinjection at wells on pads B and C. Then pipelines will be designed for transmission two-phase flow from site D and E to site A in one line and separate in Site A with a big separator then assume one separator in each site, D and E, then transmission steam and water from Site D and Site E in two separate lines to site A, then a comprehensive compare will do done between two methods for transmission and separation system, then discussed about the best method based on the minimum cost and minimum drop pressure.

1. INTRODUCTION

Iran is situated in the Middle East and has area of 1,648,195 km^2 with a population of about 85 million. It has big gas and oil reservoirs and also it is one of the world´s main oil producers. There are ample potentials of renewable energies in Iran, such as solar, biomass, wind, and geothermal.

The geothermal activity in Iran started by the Ministry of Energy of Iran (MOEI) in 1975, a contract between MOEI and Ente Nazionale per L' Energia Electtrica of Italy (ENEL) was signed for geothermal exploration in the northern part of Iran (Azerbaijan and Damavand regions). In 1993 SUNA were established to justify priorities of the above mentioned regions. As a result, Meshkinshar and Sarein areas in Sabalan region were proposed for electric and direct use respectively (Figure 1). In 1998 SKM on behalf of SUNA completed a resistivity survey consisting of Direct current (D.C.), Transient electromagnetic (TEM) Magnetotellurics (MT) measurements in Meshkinshahr.

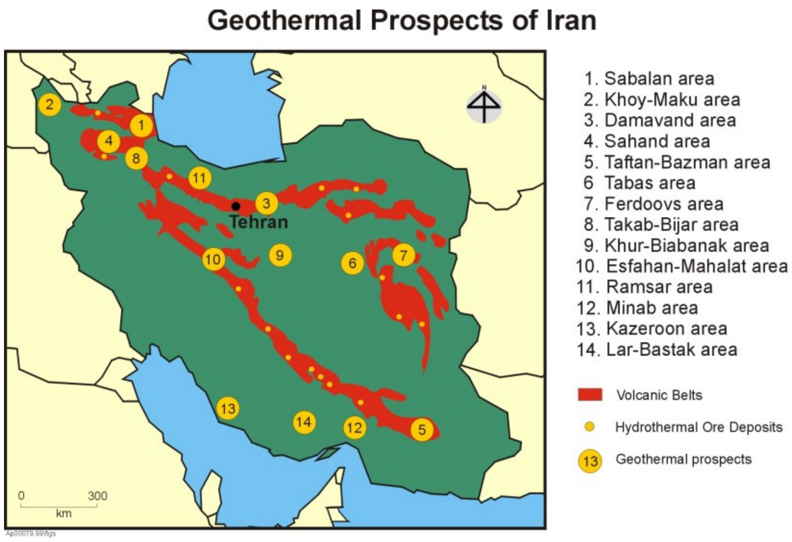


Figure 1: Map of IRAN SKM (2005)

A variety of power generation development options have been formulated and assessed, with generation capacities ranging from 2 to 100 MWe, utilizing both condensing and non-condensing steam turbines by SKM SKM (2005).

The Mt. Sabalan geothermal field is located in the Moil Valley on the northwest flank of Mt. Sabalan, close to the Meshkinshahr town (Khiyav) of Azerbaijan, Iran. The field is located between 38° 11' 55" and 38° 22' 00" latitude and 47° 38' 30" and 47° 48' 20" longitude Yousefi (2004). The resource area has been previously identified by geo-scientific studies as an approximately quadrangular shaped area that covers approximately 75 km^2.

Access to the area is provided by a sealed road from the nearby town of Meshkinshahr to the village of Moil, then to the valley south of the village by an unsealed road. A sealed road connects the Meshkinshahr to the provincial capital city of Ardebil.

The geothermal field is located in an environmentally sensitive area of elevated valley terraces set within the outer caldera rim of the greater Mt. Sabalan complex. Vegetation is limited to light scrub and pasture with some smallholdings and associated arable planting SKM (2005).

Mt. Sabalan is a Quaternary volcanic complex that rises to a height of 4811 m, some 3800 m above the Ahar Chai valley to the north. Volcanism within the Sabalan caldera has formed three major volcanic peaks which rise to elevations of around 4700 m.

The climate in the area is relatively dry, especially during the summer months. The site is exposed to severe winter weather, including very high wind speeds of up to 180 km/hr. Temperatures over the past 4 years have been measured as low as -30°C SKM (2005).

After the geological exploration phase, the project was divided into two-phases; the first phase (1998-2006) was aiming to build drilling pads at sites A, B, and C including excavation and construction concrete pad, Figure 2, accesses roads from Moil village to sites, a pump station, water reservoir, water intake and water pipelines from pump station to reservoir and all sites. This phase includes also to repair the existing road between Meshkinshahr and Moil village and to drill five exploratory wells. In the second phase, SUNA wants to drill 14 production or reinjection wells, including preparations of well pads A and B, for additional drilling, and well pads D and E, for new drilling. This phase includes also the accesses road to site E, water pipeline and new pump station in order to provide water for drilling in site E. After deeping 5th well and drilling 6 new wells in this phase, drilling operations were shut down because of lack of budget, now SUNA is planning to build a 5 MWe power plant in order to reach generating electricity.

2. EXPLORATION OF SABALAN GEOTHERMAL AREA

2.1. Exploration Drilling Programme (first phase)

In this phase the drilling and testing programme was carried out between November 2002 and December 2004. The three deep exploration wells which were drilled are coded to as NWS-1, NWS-3 and NWS-4 on well pads A, C, and B, respectively. The wells vary in depth from 2265 to 3197 m MD. Well NWS-1 was drilled vertically while NWS-3 and NWS-4 are directionally drilled with throws of 1503 and 818 m, respectively. Additionally, two shallow reinjection wells have been drilled to 600 m depth, NWS2R, located on pad A alongside well NWS-1, and NWS-5R on pad B alongside well NWS-4. The basic well completion data are summarized in Table 1:

2.2. Well Testing and Reservoir Results (first phase)

Well NWS-1 was discharged in May 2004 for a period of 21 days with reinjection of waste brine into shallow well NWS-2R. And well NWS-4 was discharged by airlift stimulation in September 2004 and was flow tested for the next four months with reinjection of waste brine into shallow well NWS-5R. Output curves for well NWS-1 and well NWS-4 are shown in Figure 3. These show variations in total mass and enthalpy with flowing wellhead pressure. Both wells discharged with enthalpies in the range of 950-1000 kJ/kg, which is consistent with production from liquid-only feed zones with temperatures of 230°C (for NWS-1) and 220°C (for NW-4). These are both lower than the maximum temperatures measured in the two wells of 245 and 230°C, respectively.

Shallow well NWS-2R Output curves for well NWS-1 and well NWS-4 are shown in Figure 3. These show variations in total mass and enthalpy with flowing wellhead pressure. Both wells discharged with enthalpies in the range of 950-1000 kJ/kg, which is consistent with production from liquid-only feed zones with temperatures of 230°C (for NWS-1) and 220°C (for NW-4). These are both lower than the maximum temperatures measured in the two wells of 245 and 230°C, respectively.

Table 1: Basic completion information of NWS wells SKM (2005)

Well	Spud date	Completion date	Depth (mMD / mVD)	Product. casing		Product. liner	
				Size (in)	Depth (mMD)	Size (in)	Depth (mMD)
NWS-1	22 Nov 02	1 Jun 03	3197	9⅝	1586	7	3197
NWS-3	2 Jul 03	27 Nov 03	3166 / 2603	13⅜	1589	9⅝	3160
NWS-4	17 Dec 03	27 Mar 04	2255 / 1980	9⅝	1166	7	2255
NWS-2R	7 Jun 03	25 Jun 03	638	13⅜	360	9⅝, 5	638
NWS-5R	7 Apr 04	2 May 04	538	20	139	9⅝	482

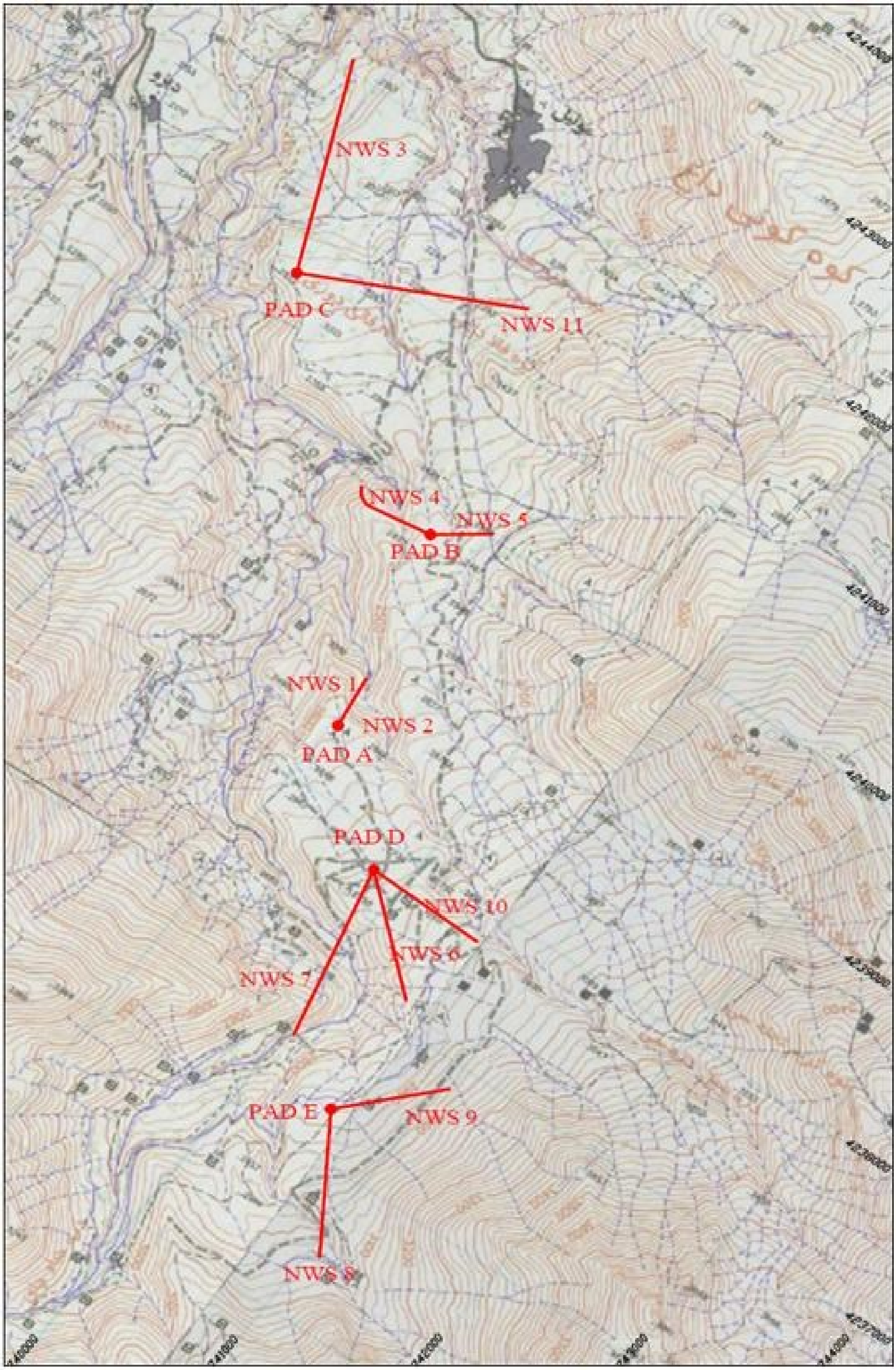


Figure 2: Plan of Sabalan area

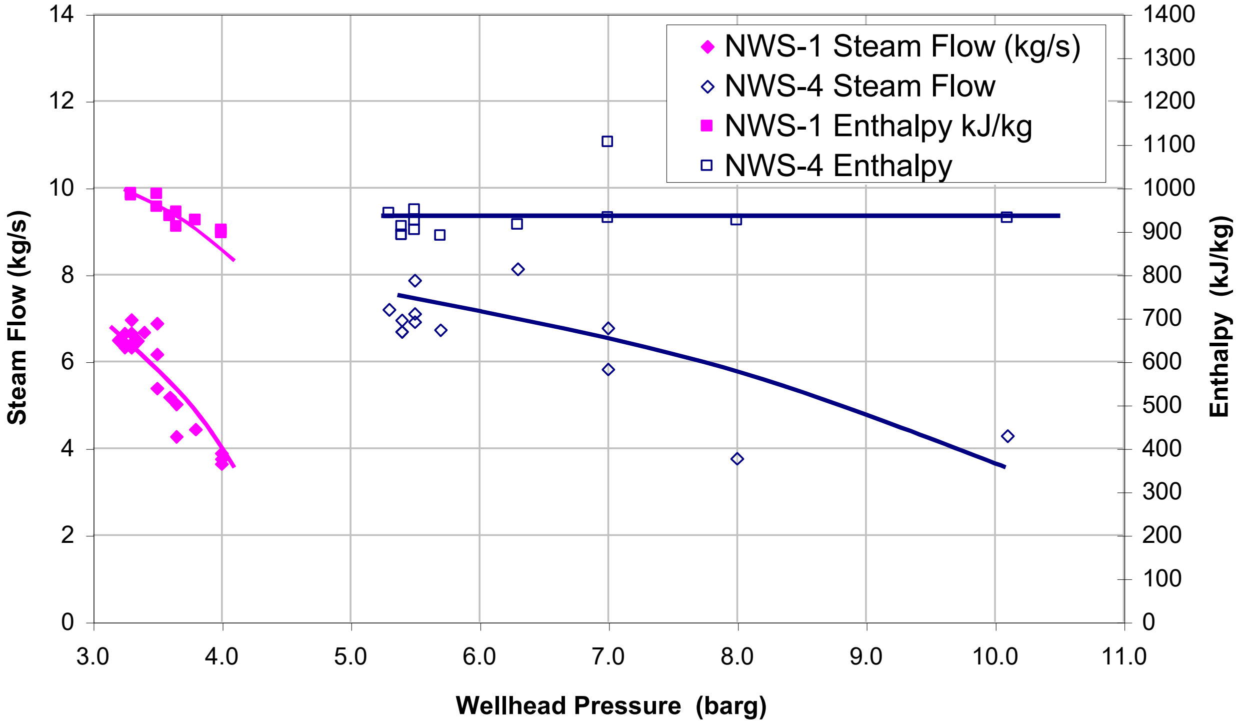


Figure 3: Output curve for wells NWS-1 & NWS-4 SKM (2004)

2.3. Delineation Drilling Programme (second phase)

In this phase the drilling and testing programme was carried out between May 2008 and October 2012. The well NWS-5R was deepened to 1901 m and the five deep Delineation wells and one reinjection well which were drilled are coded as NWS-5D, NWS-6D, NWS-7D, NWS-8D, NWS-9D, NWS-10D and NWS-11R on well pads D, E, B and C, respectively. The wells vary in depth from 1901 to 2813 m MD. All of wells were drilled directionally. The basic well completion data are summarized in Table 2.

2.4. Well Testing and Reservoir Results (second phase)

Well NWS-6D was discharged by airlift stimulation in Jan 2011 for a period of 146 days with reinjection of waste brine into shallow well NWS-2R. And well NWS7-D was discharged by two phase flow from well NWS6-D in June 2011 for a period of 82 days with reinjection of waste brine into shallow well NWS-2R. And well NWS10-D was discharged by two phase flow from well NWS7-D in Aug 2011 for a period of 135 days with reinjection of waste brine into shallow well NWS-2R. And well NWS5-D was discharged by airlift stimulation in Sep 2012 for a period of 5 days with reinjection of waste brine into shallow well NWS-4. Well NWS9-D was discharged by airlift stimulation in Sep 2012 for a period of 76 days with reinjection of waste brine into Well NWS-2R. Well NWS-6D is the sixth drilled well in the second phase of drilling and third to be discharged. The injection well for this process was NWS2-R and it was 110 m lower than NWS6-D therefore the brine flow and injection to this well were implemented by gravity. Test apparatus included a full flow atmospheric silencer associated with required piping, valves & fittings and instruments. A weir box provided in the bottom of silencer, which it was used for measuring of separated brine water flow, the brine water transfer with a channel to cuttings pit and transfer with a 6 inch pipeline to NWS2-R. According to test results at five steps corresponding to five throttle valve (installed in well outlet pipeline) positions well head pressure (WHP), pH and chloride content of brine water remained constant according to water flow record and lip pressure (pressure of entering fluid to the silencer) which were applied for calculation of total mass flow (TMF) and Enthalpy of outlet fluid from the well. We used a webre separator in order to get some steam samples. The result of test is shown in Figure 4 and Figure 5. There is some scatter in the enthalpy of these five results, it may be related to well behavior.

Table 2: Basic completion information of NWS wells EDC (2013)

Well	Spud date	Completion date	Depth (mMD / mVD)	Product. casing		Product. liner	
				Size (in)	Depth (mMD)	Size (in)	Depth (mMD)
NWS-5D	May-30-2008	Aug-31-2008	1901	9⅝	745	7	1901
NWS-6D	Oct-16-2008	Feb-19-2009	2377	9⅝	1250	7	2371
NWS-7D	Mar-26-2009	Aug-17-2009	2705	9⅝	1313	7	2705
NWS-8D	Aug-21-2009	Jan-21-2010	2640	9⅝	1438	7	2640
NWS-9D	Feb-08-2010	Mar-19-2010	500	9⅝	-	7	-
NWS-10D	Apr-10-2010	Sep-o5-2010	2300	9⅝	977	7	-
Re-NWS-9D	Sep-16-2010	Dec-16-2010	2703	9⅝	1101	7	2703
NWS-11R	Dec-25-2010	May-10-2010	2813	9⅝	1286	7	2813

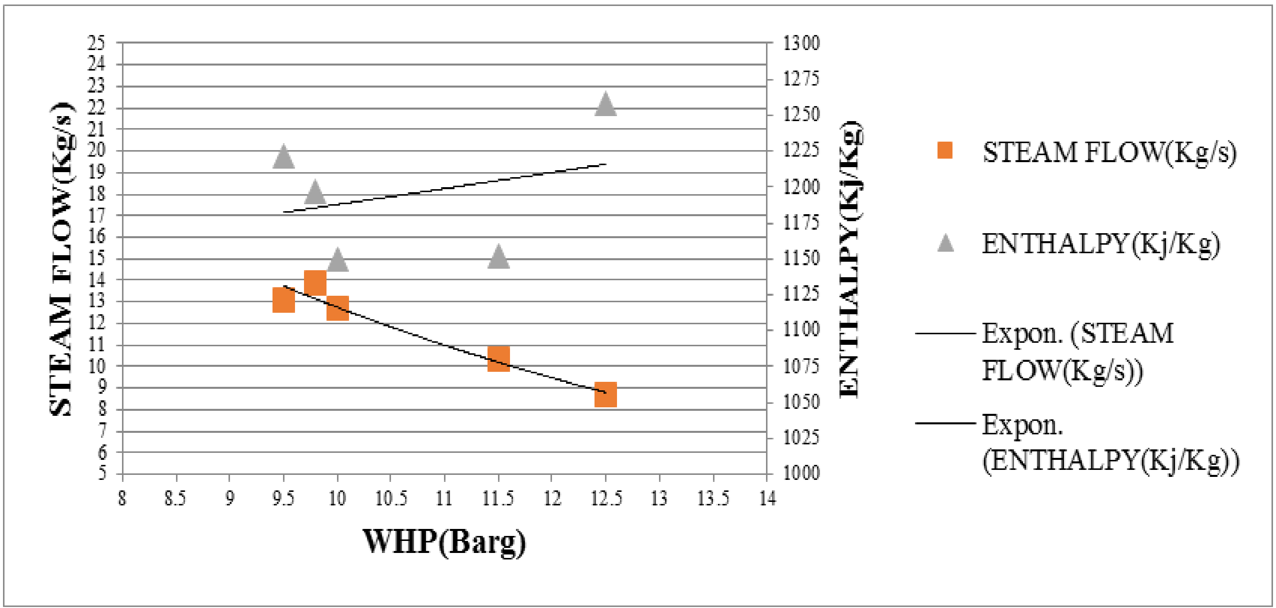


Figure 4: Steam flow output curve for well NWS-6D EDC (2013)

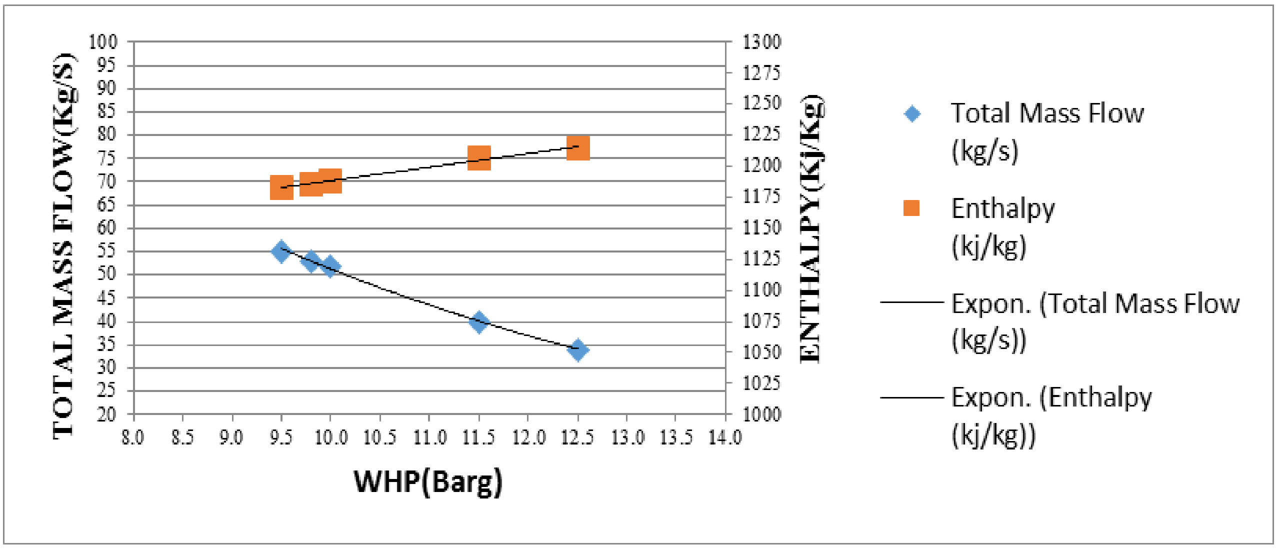


Figure 5: Total mass flow output curve for wells NWS-6D EDC (2013)

3. THEORY AND METHOD OVERVIEW OF DESIGN

3.1. Pipeline design

Standard design process for pipeline in geothermal as follows:

• Topology and route selection.

• Demand and flow analysis.

• Pipe diameter optimization minimum cost due to head loss.

• Thickness and pressure classes.

• Mechanical stress analysis supports, type and distance between supports.

• Thermal stress analysis anchors, expansion loops and expansion units.

• Pump size and arrangement.

There are different processes and design criteria, which depend on the fluid that will be transmitted through the pipeline whether it is water, steam or two-phase flow, these processes and criteria are discussed in the following section.

3.1.1. Route selection

There are many considerations that should be made in selecting the route of pipeline. These considerations depend on the pipe installed whether underground or above the ground. Since the cost of pipe above the ground is less than the underground pipeline, it will be used for pipeline design in this project. Some of the most important considerations for above the ground pipeline route selection are Efotg (2007):

• The pipeline route should have the shortest distance between two points, and the number of high and low spots should be minimized. High spots require avoid pressure more than saturation pressure and low spots require drains, and also the pressure should be checked as pressure design. In order to design of two-phase flow pipeline do not need to attention for pressure in the top point.

• Routing the pipeline over moderate slope terrain makes it easier to installation the pipe. And high slope could be used, but not too much.

• There must be access to all portions of the route by piping equipment.

• Avoid landslide areas and avoid crossing watercourses that they are eroding.

• Avoid crossing Federal or State land where possible. Permits are required for crossing these lands and the permitting process takes a considerable amount of time or cost and effort to complete.

• The pipeline route should be selected to minimize the environmental impacts.

• Full consideration should be given to the possibility of future expansion to the system. If a pipeline extension is anticipated then pipe size and rating should be appropriate for the ultimate extension.

And the finally the route with minimum cost is the best route.

3.1.2. Pipe diameter for water or steam pipelines

In order to select a proper diameter of water or steam pipeline, these two factors should be considered Jónsson (2007):

• Maximum allowable velocity.

• Minimize the Total Update Cost min [C_t].

Total Update Cost (C_t) is:

$$C_t = C_c + C_e (1 - 1/(1+i)^T)/i \quad (1)$$

Where C_c = Capital cost;

C_e = Annual cost;

T = Life time;

i = Index rate.

The capital cost is equal to:

$$C_c = L_p k_p + n_b k_b + n_c k_c + n_u k_u + n_v k_v + n_d k_d + L_p k_e \quad (2)$$

Where L_p = Pipe length (m);

k_p = Cost of pipe (Euro/m);

n_b = Number of bends;

k_b = Cost of bends (Euro);

n_c = Number of connections;

k_c = Cost of connections (Euro);

n_u = Number of expansion units;

k_u = Cost of expansion units (Euro).

n_v = Number of valves;

k_v = Cost of valves (Euro);

n_d = Number of pumps;

k_d = Cost of pumps (Euro);

k_e = Cost of insulation (Euro/m).

The annual cost is equal to:

$$C_e = k_e o_h P \quad (3)$$

Where k_e = Cost of electrical energy (Euro/Wh);

o_h = hours in one year is equal 365 times 24 (8760 hours);

P = Power of pump (W).

The power of pump was calculated using equation:

$$P = g\rho H_f Q / \eta \tag{4}$$

Where g = Gravity constant (m/s^2);

ρ = Density of fluid water or steam (kg/m^3);

H_f = Friction head (m);

Q = Flow rate of fluid (m^3/s);

η = Efficiency of pump.

In order to calculate the friction head (H_f), the first velocity of fluid (V) should be calculated using equation:

$$V = Q/(\pi D_{in}^{\ 2}/4) \tag{5}$$

Where V = Velocity of fluid (m/s);

D_{in} = Pipe inner diameter (m).

The second equivalent length (L_e) can be calculated using equation:

$$L_e = L_p + n_b h_b D_{in} + n_c h_c D_{in} + n_u h_u D_{in} + n_v h_v D_{in} \tag{6}$$

Where L_p = Pipe length (m);

D_{in} = Inner diameter (m);

h_b = Equivalent length of bends;

h_c = Equivalent length of connections.

h_u = Equivalent length of expansion units;

h_v = Equivalent length of valves.

The third Reynolds number *(R_e)* should be calculated using equation:

$$R_e = V D_{in} / \nu \tag{7}$$

Where ν = Viscosity of fluid (m^2/s).

The end based on the amount of Reynolds number, friction factor (f) should be calculated from the one of these equations:

$$R_e \le 2100 \qquad f = 64/R_e \tag{8}$$

$$R_e > 2100 \qquad 1/\sqrt{f} = 1.14 - 2\log_{10}\left(k/D_{in} + 9.35/\left(R_e\sqrt{f}\right)\right) \tag{9}$$

Where R_e = Reynolds number;

k = Absolute roughness (m).

Friction head (H_f) can be calculated by using the data from Equations 5-9 as follow:

$$H_f = \frac{f V^2}{2g} \frac{L_e}{D_{in}} \tag{10}$$

Where H_f = Friction Head (m of fluid);

f = Friction factor;

L_e = Equivalent length (m).

The pressure that we need to pump (P_P) can be calculated according to equation:

$$P_P = (\Delta Z + H_f)\rho g \tag{11}$$

Where P_P = Pump pressure (Pa);

ΔZ = Elevation difference between end and start points of line $\Delta Z = H_s - H_e$ (m).

When the (P_P) is negative that shows it is not necessary to pump the fluid, and it goes by gravity.

For each diameter, the Total Update Cost based on above Equations will be calculated. Total Update Cost is the main parameter for selecting the optimum diameter as shown in Figure 6. When the diameter increasing the Total Capital Cost increasing and the Updated Annual Cost decreasing, and there is an optimum diameter with the minimum Total Updated Cost. But in this project the brine water and two phase go by gravity, and it is not necessary to pump, hence the annual cost is the same. The diameter will be selected by a proper velocity. In order to avoid corrosion and erosion in water pipeline the velocity should be less than 3 m/s, but for steam pipeline the velocity should be less than 40 m/s.

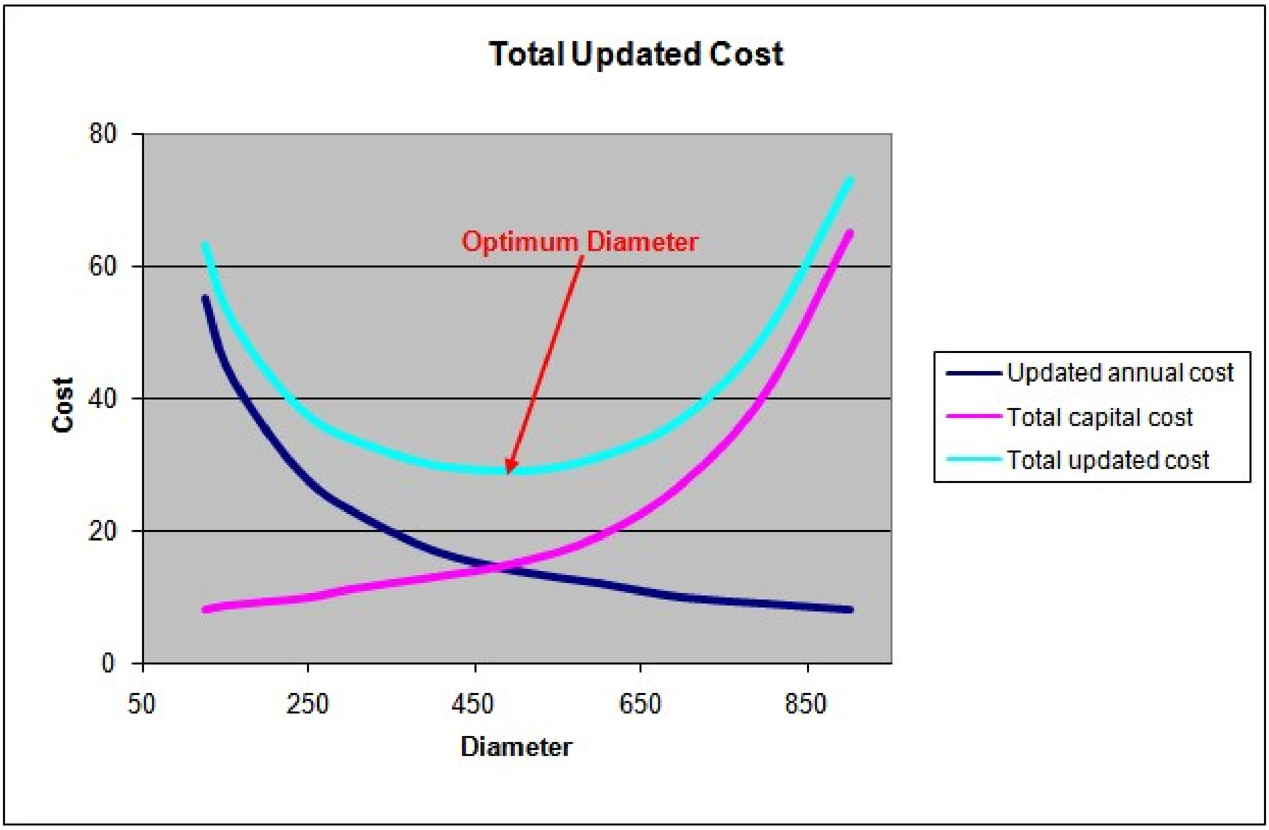


Figure 6: Total updated cost

3.1.3. Pipe diameter two-phase flow pipelines

It is important to determine diameter of two-phase flow pipeline as efficiently as possible. If there is a high drop pressure in pipeline, the separator station should be close to wellhead, and then the steam and the water should be transmitted separately in two pipelines. Because drop pressure in steam pipeline and water pipeline are less than in two-phase flow pipeline. A two-phase mixture can flow through a pipe in a variety of flow regime as shown in Figure 7. These regimes depend on various conditions.

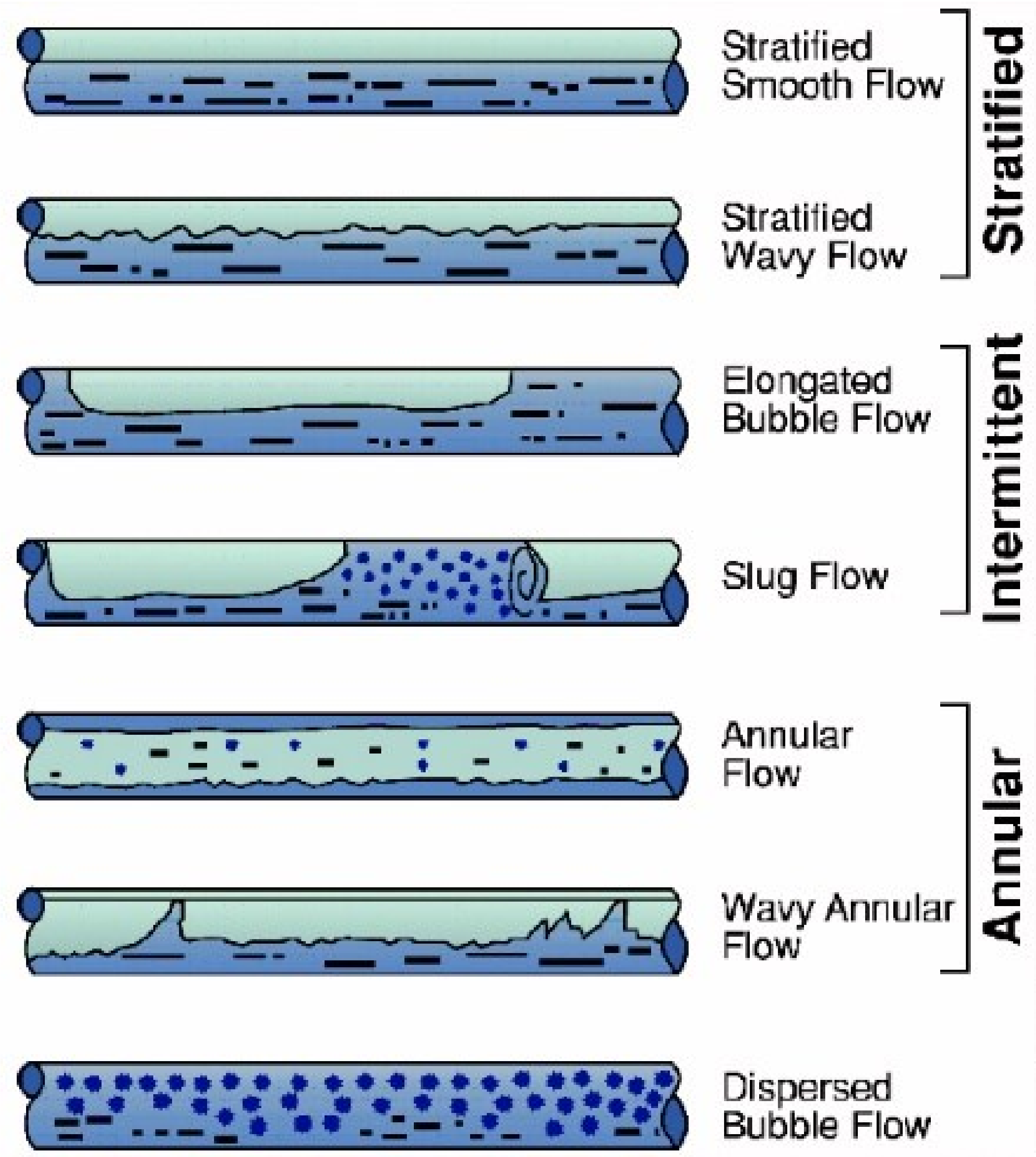


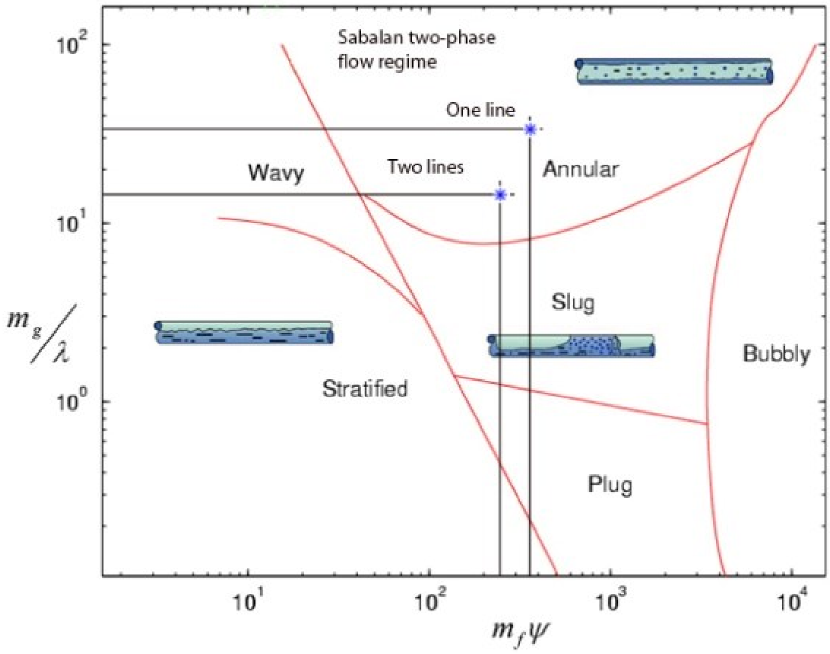
Figure 7: Flow regime

• Transport properties of fluids.

• Mass and volume fraction in pipes.

• Velocity fraction between phases.

Flow regime maps determine the most likely regime by using the parameters above. There are three kinds of maps, Baker map, Nukherjee and Brill map and Spedding and Nuguyen map. Based on characteristics of fluid of Sabalan project with Baker map, the annular regime in this project for flow of five wells is shown in Figure 8.



$$\psi = \left(\frac{0.0724}{\sigma_f}\right)\left(\frac{\mu_f}{0.0009}\left(\frac{1000}{\rho_f}\right)^2\right)^{1/3}$$

$$\lambda = \left(\frac{\rho_g}{1.2}\frac{\rho_f}{1000}\right)^{1/2}$$

Figure 8: The Baker map

In two-phase flow pressure drop prediction by the separated flow model, void fraction (α) is the most important fundamental parameter. It is the ratio of the gas flow cross-section to the total cross

$$\alpha = A_g / A \tag{12}$$

Where A_g = Area of gas or steam;

A = Total area.

Zhao et al (2000) found a new void fraction correlation, that it is derived from the analysis of two-phase flow velocity distribution using the Seventh Power Law as:

$$\frac{1-\alpha}{\alpha^{7/8}} = \left[\left(\frac{1}{x}-1\right)\left(\frac{\rho_g}{\rho_f}\right)\left(\frac{\mu_f}{\mu_g}\right)\right]^{7/8} \tag{13}$$

To predict the two-phase pressure drop, an equivalent pseudo single-phase flow having the same boundary layer velocity distribution is assumed. The average velocity of the equivalent single-phase flow is used to determine the wall friction factor and hence the two-phase pressure drop. This method gives very good agreement with the experimental data. The average velocity of the equivalent single-phase flow is also a very good correlating parameter for the prediction of geothermal two-phase pressure drops in a horizontal straight pipe.

The void fraction determines other two-phase parameters such as the liquid phase velocity ($\overline{V}_f$), and the mean density (ρ). These in turn determine the two-phase pressure drop. The liquid phase velocity ($\overline{V}_f$), can be expressed as:

$$\overline{V}_f = 1.1(1-x)\frac{W(1-x)}{\rho_f(1-\alpha)A} \tag{14}$$

Where W = Total mass flow rate (kg/s);

x = Steam quality;

ρ_f = Density of water (kg/m^3);

$1.1(1-x)$ = Correction factor mainly for entrainment.

At this stage, a correction factor is introduced to account for the entrainment effect and the simplification made in deriving void fraction correction. It can be explained as *1.1(1-x)* fraction of the liquid phase is left in the liquid phase boundary layer. The other fraction is entrained inside the gaseous phase as water droplets. When the steam quality decreases, the gaseous phase can carry less than liquid. This means a higher percentage of the liquid is left in the boundary layer. The choice of factor is mainly to give a good result rather than having a rigorous theoretical justification in Zhao et al (2000). The average velocity of the equivalent single-phase flow ($\overline{V}$) can be calculated using equation:

$$\frac{\overline{V}_f}{\overline{V}} = \frac{\left(1-\sqrt{\alpha}\right)^{(8/7)}\left(1+\frac{8}{7}\sqrt{\alpha}\right)}{\left(1-\alpha\right)} \tag{15}$$

By using Equation 7 to 9, based on the average velocity of the equivalent single-phase flow ($\overline{V}$) and density of fluid (water), the Reynolds number (R_e) and friction factor (f) can be calculated. Then drop pressure due to the length of pipe (Δ_{PL}) can be calculated from Equation 16 in Zhao et al (2000).

$$\Delta_{PL} = \frac{f\rho_f \overline{V}^2}{2D_{in}\left(1-AC\right)} \tag{16}$$

Where Δ_{PL} = Drop Pressure due to length (Pa);

ρ_f = Density of fluid (water) (kg/m^3);

AC = Acceleration correction, $AC = m_g / \rho_g \left(pA^2\alpha\right)$;

m_g = Mass of gas (steam) (kg/m^3);

p = Pressure (Pa);

A = Inner area (m^2).

In order to calculate drop pressure for an installation such as bends, connections, Expansion units and valves, the first two-phase multipliers ($\varphi^2{}_{BLO}$) for each one should be calculated by Chisholm (1983).

$$\varphi^2{}_{BLO} = 1 + \left(\frac{\rho_f}{\rho_g} - 1\right)\left(Bx\left(1-x\right) + x^2\right) \tag{17}$$

Where x = Quality of steam;

B = $1 + 2.2/\left(K_{BLO}\left(2 + r/D_{in}\right)\right)$;

K_{BLO} = $1.6fh$;

h = Equal length (m);

r = Bend radius (m).

Then drop pressure can be calculated from this Equation:

$$\Delta_{PI} = \frac{f\rho_m \overline{V}^2}{2}\left(\varphi^2{}_{BLO,b}n_b h_b + \varphi^2{}_{BLO,c}n_c h_c + \varphi^2{}_{BLO,u}n_u h_u + \varphi^2{}_{BLO,v}n_v h_v\right) \tag{18}$$

Where Δ_{PI} = Drop Pressure Installation (Pa);

ρ_m = Density of mixture of fluid and gas (water and steam) (kg/m^3);

$\varphi^2{}_{BLO,b}$ = Two-phase multiplier for bends;

$\varphi^2{}_{BLO,c}$ = Two-phase multiplier for connections.

$\varphi^2{}_{BLO,u}$ = Two-phase multiplier for expansion units;

$\varphi^2{}_{BLO,v}$ = Two-phase multiplier for valves.

Finally, Total drop pressure (Δ_{PT}) can be calculated from this Equation:

$$\Delta_{PT} = \rho_m g \Delta_Z - \left(\Delta_{PL} + \Delta_{PI}\right) \quad (19)$$

3.1.4. Pipe thickness

The thickness of pipe should be determined based on the pressure inside the pipe, which called design pressure. That is the maximum pressure along the pipe under all conditions. For example, in this project for brine water pipelines, static pressure plus the pressure after separator station, when the system does not work and there is not reinjection will be happened. In order to calculate thickness for brine water pipeline, it will be assumed that the friction head *(H_f)* is equal zero and pressure design *(P_D)* is equal *(-P)* from Equation 11, if there is pressure after separator this pressure should be add to the calculated pressure, for two-phase flow pipeline pressure design *(P_D)* is equal the wellhead pressure and for steam pipeline pressure design *(P_D)* is equal the separator pressure. According to ANSI B31.3 the nominal pipe thickness *(t_n)* is larger or equal to the requisite pipe thickness *(t_m)*, that shown in this Equation:

$$t_n \geq t_m = P_D D_o / (2(S_h E + Py)) + A \quad (20)$$

Where P_D = Pressure design (Pa);

D_o = Pipe outer diameter (m);

S_h = Allowable stresses (Pa);

E = Welding factor for butt-weld joint is equal 0.85;

y = Temperature dependent coefficient for steel and T<480°C is equal 0.4;

A = Additional thickness milling and corrosion (m) is equal 0.0015.

3.1.5. Distance between supports

When the pipe is installed above the ground, it should be hold by supports as shown in Figure 9. There are two kinds of support, the first one that allows the pipe to move vertically and horizontally as shown in Figure 10 and the second one allow the pipe just to move horizontally as shown in Figure 11. The second one used the part of pipeline that called arm of expansion loop. Horizontal means along of pipeline and vertical means perpendicular of pipeline.

Figure 9: Supports

Figure 10: Support with horizontal & vertical movement

Figure 11: Support with only horizontal movement

a. Allowable stresses

In order to calculate the distance between supports, we should know the basic allowable stresses of pipe (S). Based on the Yield limit ($R_{p/t}$) and Designates the ultimate strength at the calculated temperature. ($R_{m/t}$). Allowable stresses could be calculated from Equations Jónsson (2007):

$$S = \min\left(R_{m/T}/3, R_{m/h}/3, 2R_{p/c}/3, 2R_{p/h}/3\right) \quad (21)$$

$$S_h = \min\left(R_{m/h}/3, 2R_{p/h}/3\right) \quad (22)$$

$$S_c = \min\left(R_{m/c}/3, 2R_{p/c}/3\right) \quad (23)$$

Where

Steel	S_{235}	S_{275}	S_{335}
$R_{m/T} = R_{m/c\&h}$	340	410	490 MPa
$R_{p/50}$	235	275	355 MPa
$R_{p/200}$	185	115	245 MPa
$R_{p/300}$	140	165	195 MPa

In this project, steel is class (S_{235}), and for brine, steam and two phase flow T= 177.7°C, then $R_{m/T}= 340$, $R_{p/c}= 235$, $R_{p/h}= 192$ and *S=min (113.3,113.3,156.7,128.3=113.3 MPa*.

b. Distance between horizontal and vertical supports (L_s)

In order to calculate the distance between supports with only horizontal movement (L_s), the pipe assumed as a simple beam between two supports, the stress of sustain load and dynamic load plus the stress resulting from the pipe pressure is calculated, it should be less than allowable stress. As shown in the Equation 24 in Jónsson (2007):

$$P_D D_o/(4t_n) + (0.75i)(M_A/Z) + (0.75i)(M_B/Z) \le kS_h \qquad (24)$$

$$Z = \pi/\left(32\left(D_o^{\,4} - D_{in}^{\,4}\right)D_o\right) \qquad (25)$$

Where t_n = thickness (m);

i = Stress intensity factor (where $0.75i \ge 1.0$);

M_A = Sustained bending moment (Nm);

M_B = Dynamic bending moment (Nm);

Z = Section modulus (m^3);

k =1.15 if load is less than 10% operational time;

=1.20 if load is less than 1% operational time;

=1.00 else.

In order to calculate the bending moments *(M_A)* and *(M_B)*, first all vertical and horizontal loads should be calculated. Vertical sustained load *(q_{sv})* contains pipe weight and insulation weight, which can be calculated from Equation 26 to 28.

$$q_{sv} = q_p + q_e \qquad (26)$$

$$q_p = \pi g \rho_s \left(D_o^{\,2} - D_{in}^{\,2}\right)/4 \qquad (27)$$

$$q_e = \pi g \rho_e \left(D_e^{\,2} - D_o^{\,2}\right)/4 \qquad (28)$$

Where q_p = Pipe weight (N/m);

q_e = Insulation weight (N/m);

ρ_s = Steel density (kg/m^3) here $\rho_s = 7850$ (kg/m^3);

ρ_e = Insulation density (kg/m^3) here $\rho_e = 730$ (kg/m^3);

D_e = Insulation diameter (m).

The weight of insulation includes rock wool and aluminum plate. Vertical dynamic load *(q_{dv})* contains medium (steam, water or two-phase) weight, snow weight and seismic load, that can be calculated from Equation 29 to 33.

$$q_{dv} = q_v + q_s + q_{jv} \tag{29}$$

$$q_v = \pi g \rho_v D_{in}^{\ 2} / 4 \tag{30}$$

$$q_s = 0.2 S D_e \tag{31}$$

$$q_{jv} = 0.5 e q_0 \tag{32}$$

$$q_0 = q_p + q_e + q_v \tag{33}$$

Where q_v = Medium weight (N/m);

ρ_v = Medium density (kg/m^3) here for brine water $\rho_v = 889.5$ (kg/m^3);

For steam $\rho_v = 4.897$ (kg/m^3);

For two-phase $\rho_v = 22.99$ (kg/m^3);

q_s = Snow weight (N/m);

q_{jv} = Seismic vertical load (N/m);

e = Seismic coefficient here $e = 0.24$.

Horizontal dynamic load *(q_{dh})* is equal the maximum of wind load and horizontal seismic load, that can be calculated from Equation 25 to 27.

$$q_{dh} = \max(q_w, q_{jh}) \tag{34}$$

$$q_w = C p D_e \tag{35}$$

$$q_{jh} = e q_0 \tag{36}$$

Where q_w = Wind load (N/m);

C = Form factor for pipe $C = 0.6$

p = wind pressure $p = V_w^{\ 2} / 1.6$ and $V_w = 50$ is maximum wind speed (m/s);

q_{jh} = Seismic Horizontal load (N/m).

As mentioned before the pipe is assumed as a simple beam thus bending moment for sustained load and dynamic load is calculated from Equations 37 and 38.

$$M_A = q_{sv} L_s^{\ 2} / 8 \tag{37}$$

$$M_B = \left(q_{dv}^{\ 2} + q_{dh}^{\ 2}\right)^{1/2} L_s^{\ 2} / 8 \tag{38}$$

Based on the moments, that was calculated from Equation 37 and 38, and also using Equation 24 distance between support *(L_s)* should be less than or equal the resulting value from Equation 39.

$$L_s \le \left(\left[kS_h - PD_o/(4t_n) \right] \Big/ \left[\left((0.75i)/8Z \right) \left(q_{sv} + \left(q_{dv}^2 + q_{dh}^2 \right)^{1/2} \right) \right] \right)^{1/2} \quad (39)$$

c. Distance between vertical supports *(L_{sv})*

In order to calculate the distance between supports with horizontal and vertical movement *(L_{sv})*, the pipe is assumed as a simple beam between two supports, the stress of sustain load and dynamic load plus the stress resulting the pipe pressure is calculated, it should be less than allowable stress. In this case the span of pipe in horizontal direction and vertical direction are not the same. The vertical span is equal distance between supports *(L_{sv})* while the horizontal span is equal the arm of loop along the pipeline *(L_{sh})* as shown in Figure 12. Bending moment for sustained load and dynamic load can be calculated from Equations 40 and 41, which they are similar to Equations 37 and 38 in Jónsson (2007).

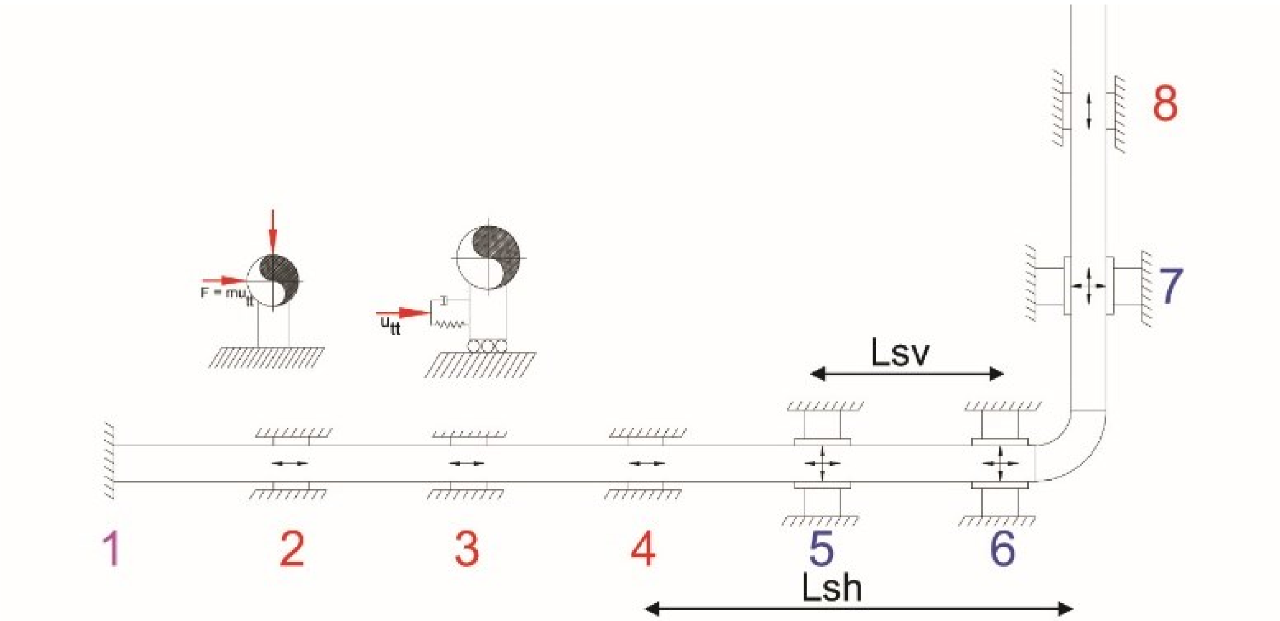


Figure 12: Supports

$$M_A = q_{sv} L_{sv}^2 / 8 \quad (40)$$

$$M_B = \left(\left(q_{dv} L_{sv}^2 \right)^2 + \left(q_{dh} L_{sh}^2 \right)^2 \right)^{1/2} / 8 \quad (41)$$

Based on the moments that were calculated from Equation 40 and 41 and also using Equation 24, Equation 42 will be calculated. Distance between support *(L_{sv})* and the arm of loop *(L_{sh})* are assumed, and then Equation 42 should be controlled.

$$q_{sv} L_{sv}^2 + \left(\left(q_{dv} L_{sv}^2 \right)^2 + \left(q_{dh} L_s^2 \right)^2 \right)^{1/2} \le \left(kS_h - PD_o/(4t_n) \right) / \left((0.75i)/8Z \right) \quad (42)$$

Deflection *(δ)* of pipe between two supports should be checked, which is often determined by allowable deflection Equation:

$$\delta = 2.07 q_0 L_s^3 / (384EI) \quad (43)$$

Where E = Young modulus (N/m²);

I = $\pi/64 \left(D_o^4 - d^4 \right)$.

3.1.6. Thermal expansion

All pipes will be installed at ambient temperature. Pipes carrying hot fluids such as water or steam operate at higher temperatures. It follows that they expand, especially in length, with an increase from ambient to working temperatures. This will create stress upon certain areas within the distribution system, such as pipe joints, which, in the extreme, could fracture. The amount of the expansion *(ΔL)* in a pipe with length *(L)* is readily calculated using Equation 35.

$$\Delta L = \alpha L \Delta T \tag{44}$$

Where α = Coefficient of thermal expansion ($1/^\circ\mathrm{C}$);

ΔT = Temperature difference ($^\circ\mathrm{C}$).

Then thermal strain *(ε_x)* is equal to:

$$\varepsilon_x = \Delta L / L = \alpha / \Delta T \tag{45}$$

If the pipe was fixed between two ends the thermal stresses *(Ω_x)* and Force *(F)* will be calculated from Equation 46 and 47.

$$\sigma_x = E \, \Delta L / L = E \alpha \Delta T \tag{46}$$

$$F = A \sigma_x = A E \alpha \Delta T \tag{47}$$

Where E = Young modulus (N/m^2).

a. Expansion loop

The expansion loop is a common way to absorb the temperature expansion in steel pipes. Expansion loops can be fabricated from standard pipes and elbows. As shown in Table 13 in Harvel (2007).

Piping supports should restrict lateral movement and should direct axial movement into the expansion loop. Do not restrain “change in direction” configurations by butting up against joists, studs, walls or other structures Figure 14

In this project the change of direction method will be used and piping system with only two anchors and no intermediate restraints. This expansion loop meets the following requirements with respect to thermal expansion in Jónsson (2007):

$$D_o Y / (L - L_A)^2 \leq 208.3 \tag{48}$$

$$Y = \alpha \Delta T \left(L_{T1}^{\ 2} + L_{T2}^{\ 2} \right)^{1/2} \tag{49}$$

$$L = L_1 + L_2 \tag{50}$$

$$L_A = \left(L_1^{\ 2} + L_2^{\ 2} \right)^{1/2} \tag{51}$$

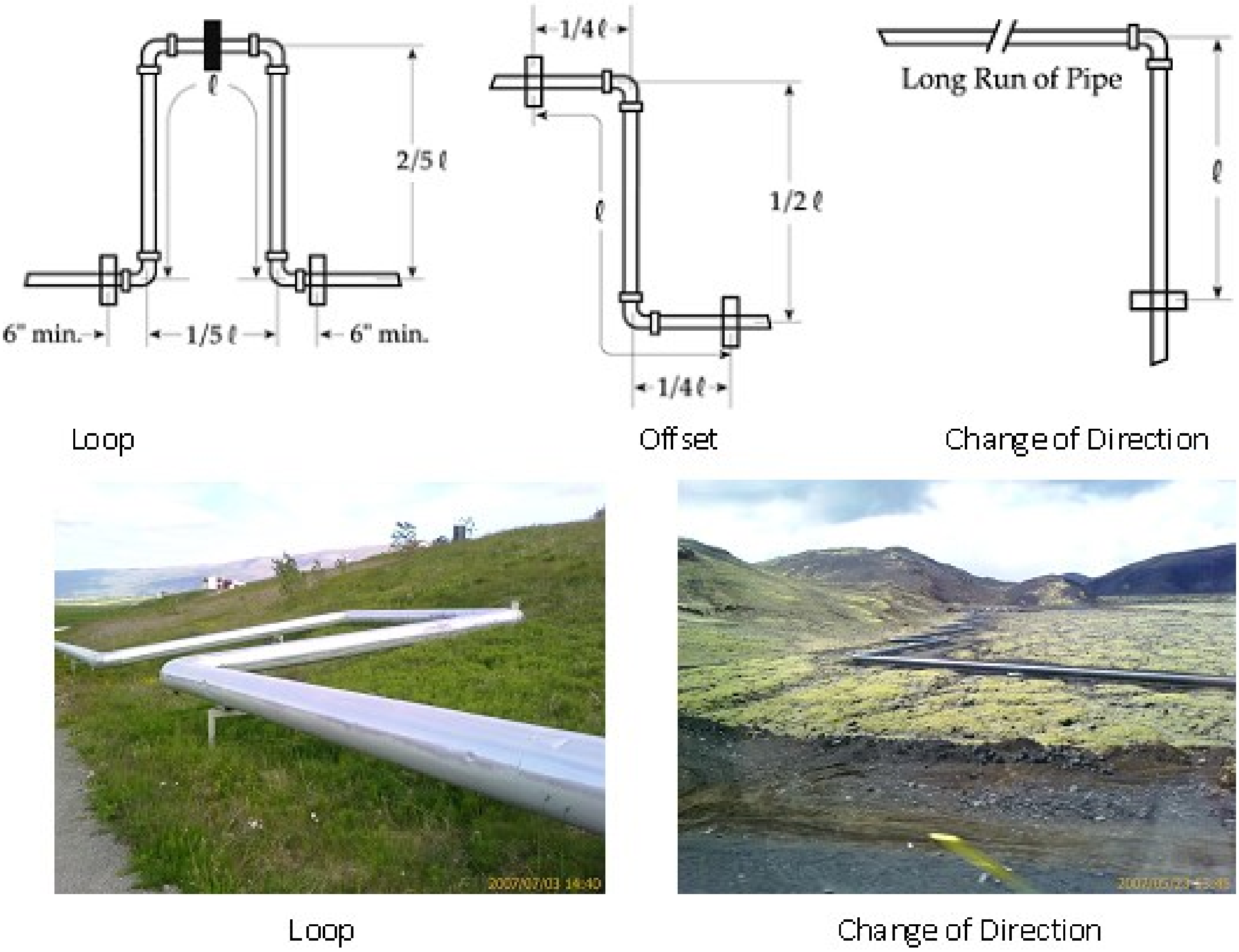


Figure 13: Expansion loops

Where Y = Resultant movement to be absorbed by the pipe loop (mm);

L = developed length of line axis (m);

L_1 & L_2 = length of arm (m);

L_{T1} & L_{T2} = Total of length in each direction (m);

L_A = Straight distance between two anchor (m);

α = Coefficient of thermal expansion ($1/{^\circ}\mathrm{C}$);

ΔT = Temperature difference (${^\circ}\mathrm{C}$).

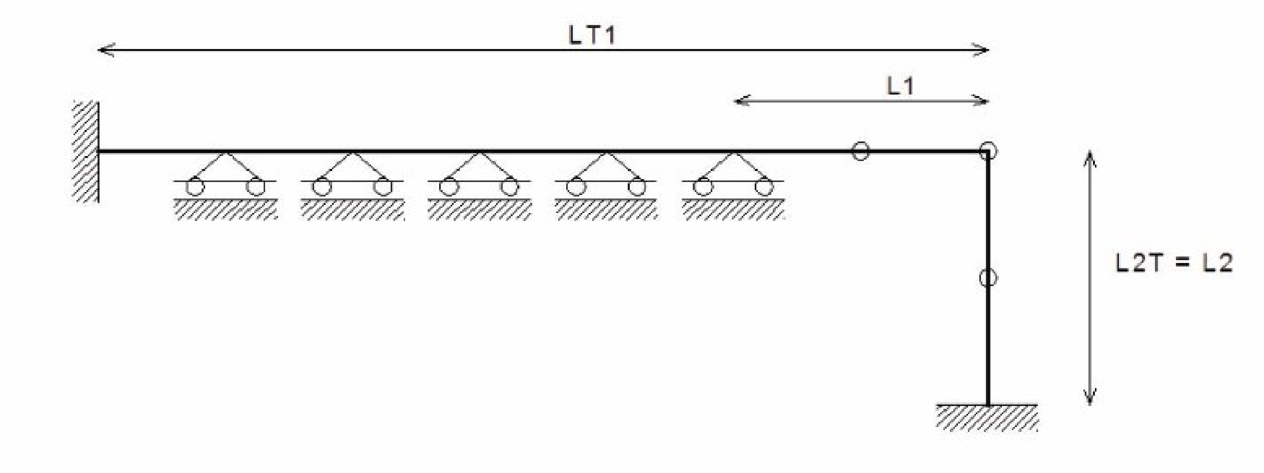


Figure 14: Expansion loop

Then will be assumed $L_a=L_1=L_2$ and use Equations 48 to 51, the length of arm will be calculated using equation:

$$L_a \geq \left(D_o \alpha \Delta T L_A / 71.477\right)^{1/2} \qquad (52)$$

b. Expansion units

There are three kinds of expansion units as shown in Figure 15. They are Axial, Angular and Lateral in Jónsson (2007).

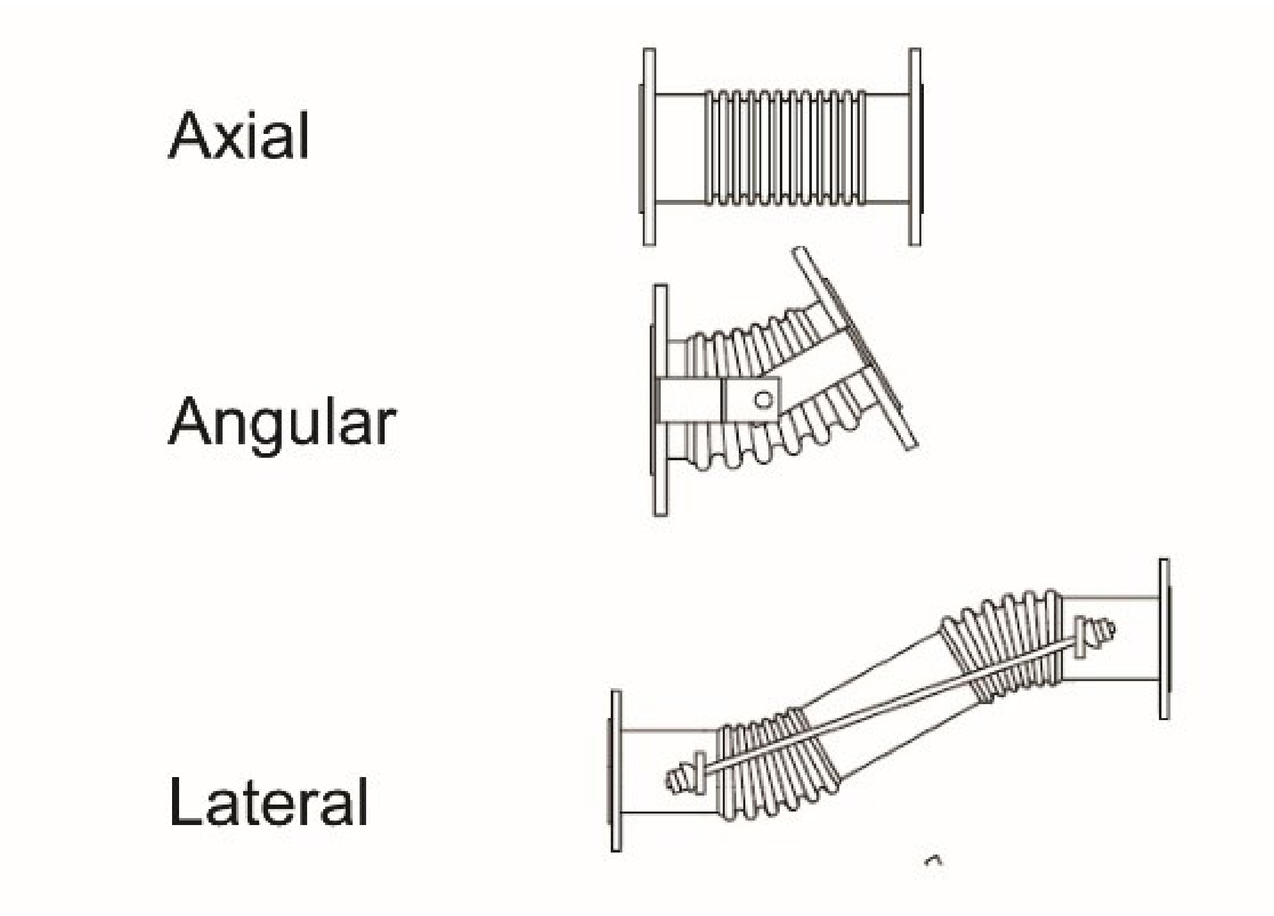


Figure 15: Expansion unit

• Axial unit can be used in the straight pipeline like an installation between to pipes. And also can be used in an expansion loop or direction change between two long pipelines that are perpendicular to each other.

• Angular unit can be used in direction change between two long pipelines with an angle less than 90° .

• Lateral unit can be used in an offset between two pipelines that are parallel to each other.

3.2. Separator design

Svrcek and Monnery (1993) divided the separation stages into three processes: primary separation, secondary separation, and mist elimination. In the primary separation, the largest water droplets enter the separator through an inlet diverter and are then separated by gravity forces. The secondary separation is a process where the smaller water droplets are separated in the disengagement area and then move downward by gravity. The last step is mist elimination using coalescing devices, which have a tortuous shape to form bigger droplets from smaller droplets and then drops downward by gravity. The first step is to determine the terminal velocity U_t in Zarrouk et al (2017).

$$U_t = K'(\frac{(\rho_l - \rho_v)}{\rho_v})^{1/2} \tag{53}$$

Where U_t = terminal velocity (m/s);

ρ_l = liquid density (kg/m^3);

ρ_v = steam density (kg/m^3);

The *K'* value is a function of pressure, where *K'* for most systems with mist eliminators is between 0.055 and 0.131 (m/s), whereas for common systems without mist eliminators, the *K'* should be *0.5* U_v is allowable vertical velocity and typically the value is between *0.75* Ut and U_t The hold-up time and surge time should be considered in the separator sizing.

Svrcek and Monnery (1993) suggested that the surge time is half the hold-up time for the first trial if there is not a specific requirement. The general hold-up and surge times are given in Table 3

Table 3: Hold up and surge times Svrcek et al (1993).

Services	Hold Up Times (min)	Surge Times (min)
Unit feed drum	10	5
Separator		
-feed to column	5	3
-feed to other drum or tankage		
a) with pump or through separator	5	2
b) without pump	2	1
feed to fired heater 10 3	10	3

The ratio *L/D* for operation pressure 0 to 17.24 has been suggested to be 3 by Svrcek and Monnery Zarrouk Svrcek et al (2017). The steam volumetric flow rate Q_v and liquid volumetric flow rate Q_l could be calculation by following equations.

$$Q_v = \frac{\dot{m}_v}{\rho_v} \tag{54}$$

$$Q_l = \frac{\dot{m}_l}{\rho_l} \tag{55}$$

Where $\dot{m}_v$ = steam flow rate (kg/s);

Q_v = steam volumetric flow rate (m^3/s);

$\dot{m}_l$ = liquid flow rate (kg/s);

Q_l = liquid volumetric flow rate (m^3/s).

Then use the following equations to set the diameter of the vessel.

$$V_h = T_h Q_l \tag{56}$$

$$V_s = T_s Q_v \tag{57}$$

$$D = \left(\frac{4(V_h + V_s)}{0.6\pi(L/D)}\right)^{1/3} \tag{58}$$

Where T_h = Hold-up time (s);

T_s = Surge-up time (s);

D = vessel diameter (m).

In order to calculate shell thickness, the outer cylinder should be check under internal pressure. The required thickness of cylindrical shells shall be calculated from one of the following equations:

$$e = (PD_i)/(2fz - P) \tag{59}$$

Or

$$e = (PD_e)/(2f_z + P) \tag{60}$$

The equations are valid for *e/De ≤ 0.16*.

Where P = Calculation pressure P shall be based on the most severe condition of coincident differential pressure and temperature. The nominal design stress f is either the maximum;

f_z = Allowable values of normal design stress or exceptional load cases $f_{exp;}$

$$f_z = \max(3/2R_{p1},0/t;\min(5/6R_{p1},0/t;1/3Rm)$$

D_e = Outer diameter;

D_i = Inner diameter is.

Shell diameter for end plate calculated from following equations in Jónsson (2007)

$$e_{end} = \max((C_1 D_i (P/f_z), (C_2 D_i (P/f_{\min})) \tag{61}$$

4. DESIGN FOR TRANSMISSION FROM SITE D AND SITE E TO SITE A

In this paper, a 25 MWe power plant is assumed in site A, with steam from production wells NWS-6D, NWS-7D and NWS-10D in site D, plus NWS-8D and NWS-9D in site E.

For transmission and separator of two-phase flow from production wells from site D and site E to site A, two options will be assumed. This paper involves the design of two-phase flow, steam and brine water pipeline and separation system as follow:

• Option 1- Transmission of two-phase flow from site D and E to site A in one line and separate in Site A with a big separator.

• Option 2- Separate two-phase flow with two small separators in each site, D and E, then transmission steam and brine flow from Site D and Site E in two separate pipe lines to site A

As mentioned in the first part of this paper, Sabalan project 11 wells were drilled, that some of them were tested, the output curve for well NWS-6 EDC (2013) Figure 4 & 5. For all wells the result of the pressure, flow rate and temprature was assumed the same as NWS-4, as follow:

• Number of production wells in site D and E= 5 wells.

• Mass flow for each well = 55 (kg/s).

The assumptions are shown in Table 4.

Table 4: General Assumptions Information

Item	Amount	Unit
Two-phase flow rate from wellhead site D to site A (for 5 Wells)	275	kg/s
Brine flow rate from separator station in site D to site A (for 5 Wells)	207.5	kg/s
Steam flow rate from separator station in site D to site A (for 5 Wells)	67.5	kg/s
Two-phase flow rate from wellhead site E to site D (for 2 Wells)	110	kg/s
Brine flow rate from separator station in site E to site D (for 2 Wells)	83	kg/s
Steam flow rate from separator station in site E to site D (for 2 Wells)	27	kg/s
Quality of steam	0.2455	
Wellhead pressure	9.5	barg
Enthalpy two-phase fluid	1175	kJ/kg
Temperature of two-phase, steam and brine flow	177.7	°C
Steel grade	S235	
Thickness of insulation of brine flow	50	mm
Thickness of insulation of steam and two-phase flow	100	mm
Roughness	0.046	mm

Table 5: Data pipeline from wellhead site D to site A

Item	Amount	Unit
ΔH	117.9	m
Length	1142.85	m
Number of bends	15	
Number of expansion units	0	
Number of connections	0	
Number of valves	2	

Table 6: Data pipeline from wellhead site E to site D

Item	Amount	Unit
ΔH	142.65	m
Length	2149.5	m
Number of bends	28	
Number of expansion units	0	
Number of connections	0	
Number of valves	2	

As we assume brine water in two option will transmit to site C that in two options, there are the same cost and drop pressure. Thus in this paper, just separating system and transmission from site E and D to site A will be compared.

4.1. Option 1- Transmission of Two-Phase Flow from Site D and E to Site A in One Line and Separate in Site A with A Big Separator.

4.1.1. Pipeline design

These pipelines should be designed to transmit the two-phase flow from wellhead D to site A for 5 wells and from site E to site D for 2 wells.

a. Pipeline from site D to site A

Topography plan between Site D and site A is shown in Figure 16, the data for this pipeline is shown in Table 4 and Table 5.

There is a main access road between these two sites. The best route can be selected between these two sites which is next to this main road, the longitude profile with plan are shown in and Figure 17. Because this route does not need new excavation and buying some lands, and also this route is straight between these two sites.There are two assumptions for this pipeline using one line and two lines. For each option, drop pressure due to pipe, bends, expansion units, connections and valves was calculated from equation 16, and the total costs of each diameter was calculated.

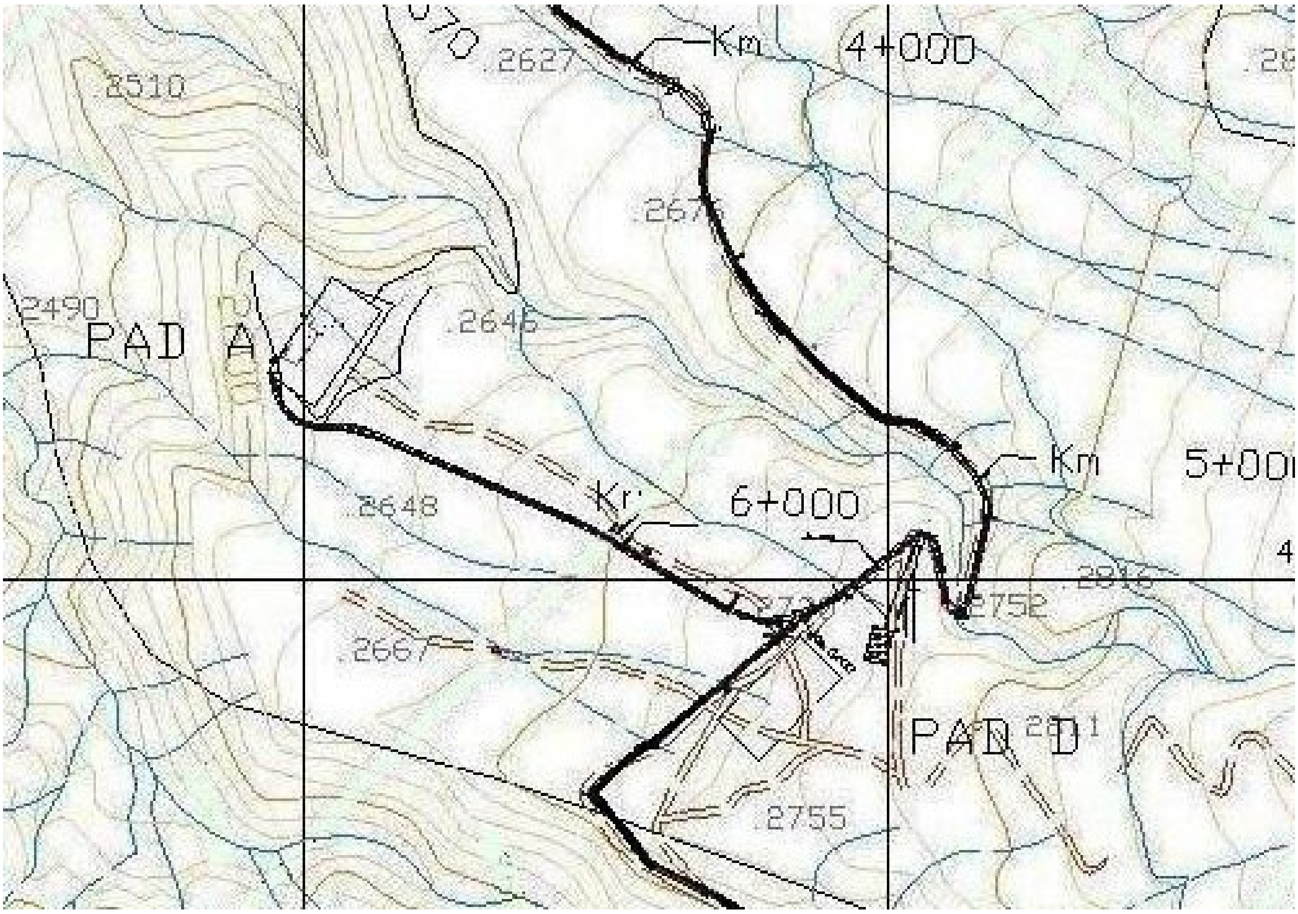


Figure 16: Topography plan between sites D and A

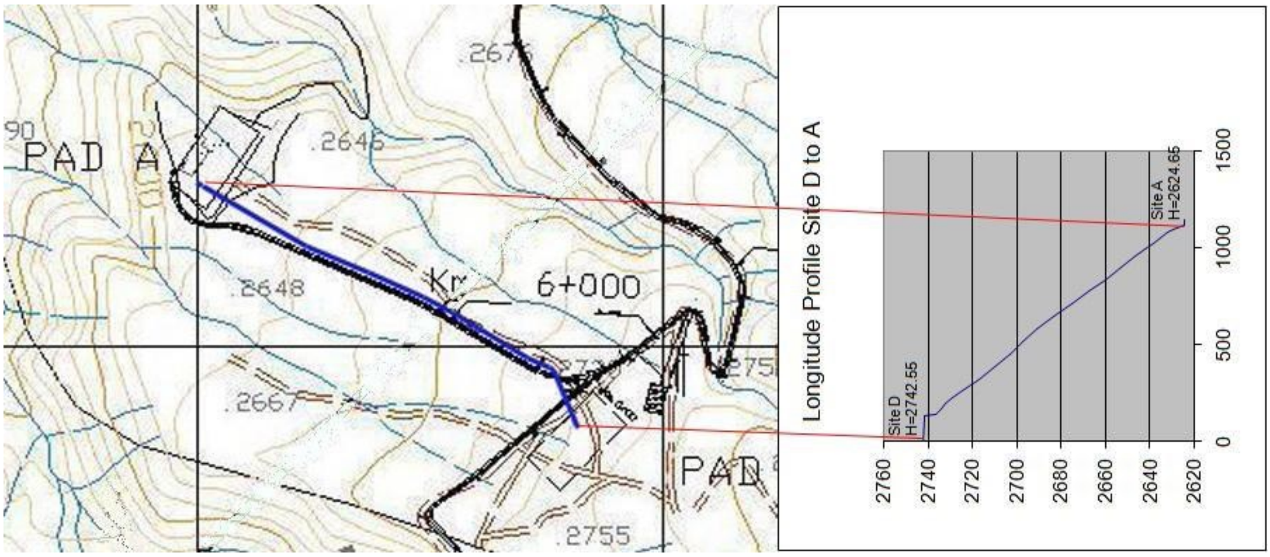


Figure 17: Longitude and plan between site D and A

In each option, the best diameter based on drop pressure and cost of pipeline will selected. The result of two options is shown in Table 7. The result shows that one line with 900 mm diameter is better with less total costs and drop pressure is a little more than 2 lines with 700 mm diameter. Another detailed result for these pipe lines is shown in Table 7 and Table 8.

Table 7: The result of cost of design of pipeline between site D and A

Option	D (mm)	Velocity (m/s)	Drop Pressure (barg)	Cost of Pipeline (Euro)
1.1	900	2.036	0.2544	267,109
1.2	2*700	1.696	0.2398	401,248

Table 8: Result of detail of two-phase pipeline between site D and A

Item	Amount	Unit
Nominal thickness (t_n)	6.3	mm
Distance between support (L_s)	18	m
Distance between two anchor (L_A)	70	m
Length of arm (L_{sh})	39	m
Distance between vertical support (L_{sv})	4	m

<u>b. Pipeline from site E to site D</u>

Topography plan between Site E and site D is shown in Figure 18.The data for this pipeline is shown in Table 4 and Table 6.

There is a main access road between these two sites. The best route can be selected between these two sites which is next to this main road, the longitude but in some part of route is better to select a straight path, profile with plan is shown in

Figure 19.

There are two assumptions for this pipeline using one line and two lines. For each option drop pressure due to pipe, bends, expansion units, connections and valves was calculated from equation 16, and the total costs of each diameter was calculated.

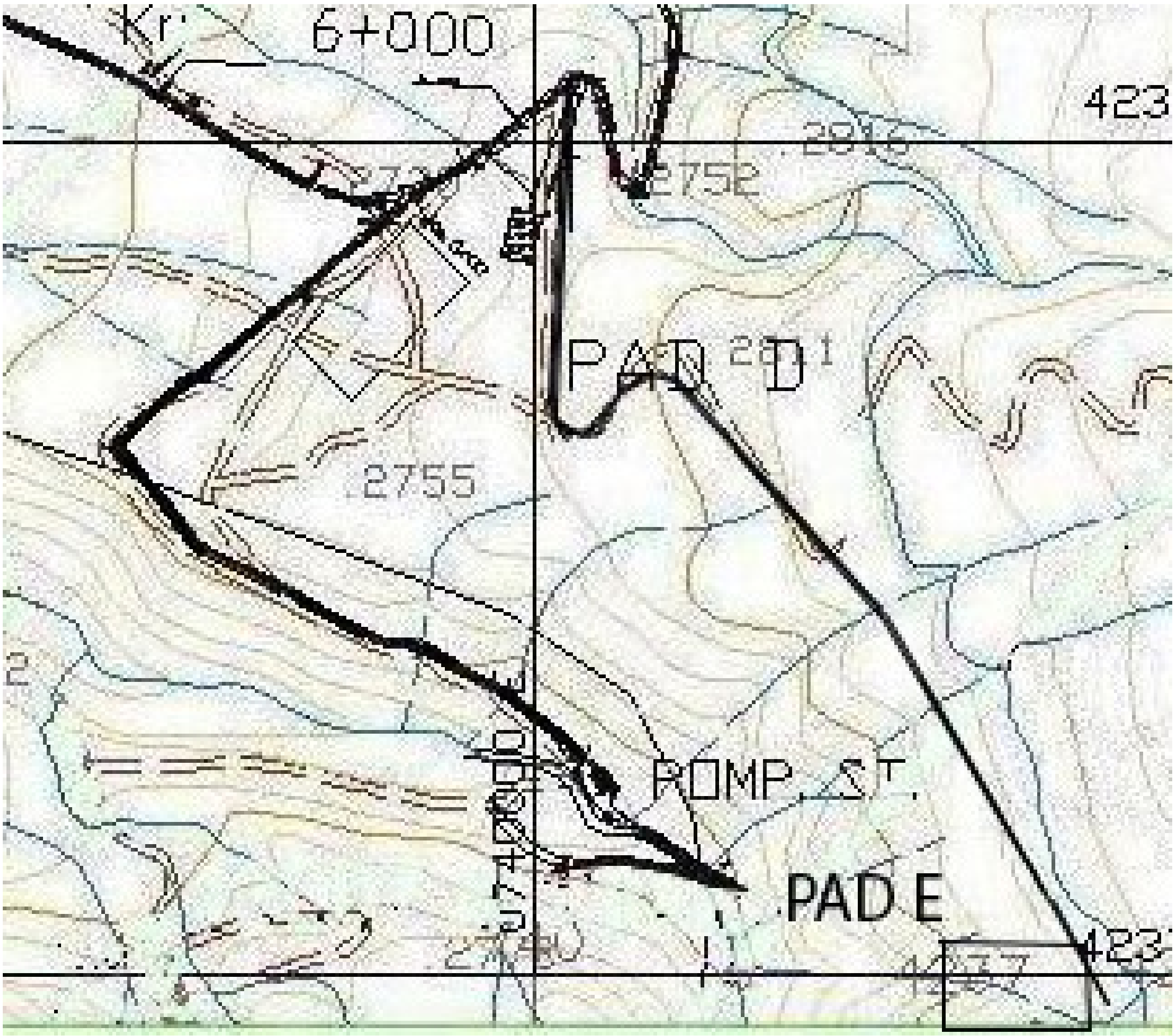


Figure 18: Topography plan between sites E and D

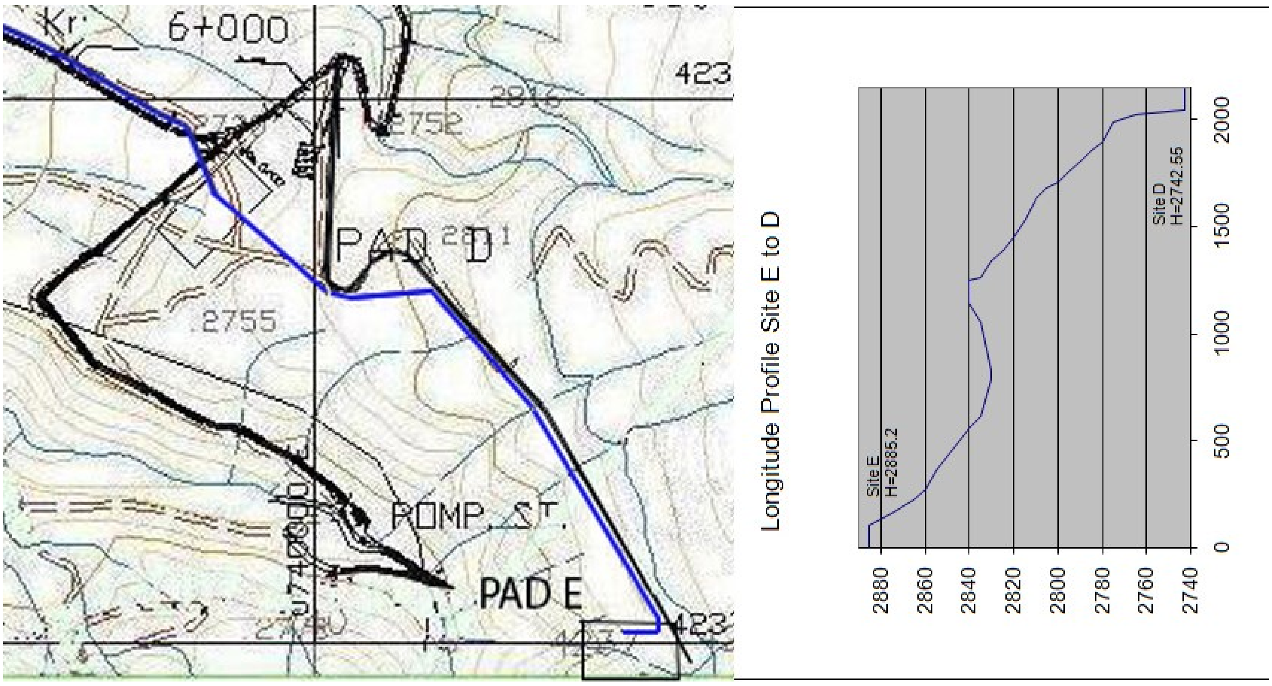


Figure 19: Longitude and plan between site E and D

In each option, the best diameter based on the drop pressure and cost of pipeline will selected. The result of two options are shown in Table 9. The result shows that one line with 700 mm diameter is better with less total costs and drop pressure is less than 2 lines with 500 mm diameter. Another detailed result for these pipe lines is shown in Table 9 and Table 10.

Table 9: Result of cost of design of pipeline between site E and D

Option	D (mm)	Velocity (m/s)	Drop Pressure (barg)	Cost of Pipeline (Euro)
1.1	700	1.357	0.2905	369,116
1.2	2*500	1.349	0.4319	539,596

Table 10 : Result of detail of two-phase pipeline between site E and D

Item	Amount	Unit
Nominal thickness (t_n)	6.3	mm
Distance between support (L_s)	14	m
Distance between two anchor (L_A)	65	m
Length of arm (L_{sh})	29	m
Distance between vertical support (L_{sv})	5	m

<u>c. Separation system</u>

In this option, a big separator in site A should be designed to separate two phase flow of 5 wells. The assumptions are shown in Table 11.

Table 11: General Assumptions Information for design separator in site A

Item	Amount	Unit
Two-phase flow rate	275	kg/s
Brine flow rate	207.5	kg/s
Steam flow rate	67.5	kg/s
Quality of steam	0.2455	
Wellhead pressure	9.5	barg
Enthalpy two-phase fluid	1175	kJ/kg
Temperature of two-phase, steam and brine flow	177.7	°C
Steel grade	S235	
Thickness of insulation of brine flow	50	mm
Thickness of insulation of steam and two-phase flow	100	mm
Roughness	0.046	mm
Level ABSL	2624.66	m

Based on calculation on an Excel file, the result of dimensions of separator is shown in Table 12.

Table 12: The result for separator in site A

Item	Amount	Unit
D_i	3.70	m
L	11.00	m
e	16	mm
e_{end}	35	mm
Weight	21884	kg

The cost of each kilo for construction separator assumes 4.0 Euro total costs for separator system that is shown in Table 13.

Table 13: Total costs of separator system

Site	Weight	Cost of each Kilo (Euro)	Total Cost (Euro)
A	21884	4.0	87,536

4.2. Option 2- Separate two-phase flow with two separators in each site, D and E, than transmission steam and brine flow from Site D and Site E in two separate lines to site A.

4.2.1. Pipeline design

These pipelines should be designed to transmit the steam and brine flow from wellhead D to site A for 5 wells and from site E to site D for 2 wells.

a. Pipelines from site D to site A

Two pipelines should be designed to transmit the steam and brine flow from separator from site D to site A. As mentioned in previous part, the route here is the same of two phase pipeline that is shown in Figure 16, and also, the longitude profile with plan are shown in and Figure 17. The data for these pipelines is the same as previous part that is shown in Table 4 and Table 5. In each pipeline of steam and brine based on the maximum velocity as mentioned in section 3.1.2, for each case the diameter was selected as shown in Table 14.

The calculation will be continued in these pipelines, the diameter of pipe is 800 (mm) and 2 lines with 600 (mm) for steam flow and 300 (mm) for brine flow. Based on calculation in an Excel file and using the equation from last section, the calculated results are shown in Table 14, Table 15, and Table 16.

Table 14: The result of Steam and brine pipeline between site D and A

Pipe line	D (mm)	Velocity (m/s)	Drop Pressure (barg)	Cost of Pipeline (Euro)	Total Costs of Pipelines (Euro)
Steam 1 line	800	27.422	0.3602	273,263	273,263+ 83,577=
Steam 2 line	2*600	24.633	0.3934	346,748	
Brine	300	2.964	-	83,577	356,840

Table 15: The result of steam pipeline from site D to A

Item	Amount	Unit
Nominal thickness (t_n)	6.3	mm
Distance between support (L_s)	25	m
Distance between two anchor (L_A)	80	m
Length of arm (L_{sh})	42	m
Distance between vertical support (L_{sv})	18	m

Table 16: Result of brine pipeline from site D to A

Item	Amount	Unit
Nominal thickness (t_n)	4.2	mm
Distance between support (L_s)	12	m
Distance between two anchor (L_A)	80	m
Length of arm (L_{sh})	21	m
Distance between vertical support (L_{sv})	12	m

b. Pipelines from site E to site D

Two pipelines should be designed to transmit the steam and brine flow from separator from site E to site D. As mentioned in previous part, the route here is the same of two phase pipeline that is shown in Figure 18, and also, the longitude profile with plan is shown in Figure 19. The data for these pipelines is the same as the previous part that is shownin Table 4 and Table 6. In each pipeline of steam and brine based on the maximum velocity as mentioned in section 3.1.2, for each case the diameter was selected as shown in Table 14.

The calculation will be continued in these pipelines, the diameter of pipe is 600 (mm) and 2 line 500 (mm) for steam flow and 300 (mm) for brine flow. Based on calculation in an Excel file and using the equation from last section, the calculated results are shown in Table 17, Table 18, and Table19.

Table 17: Result of steam and brine pipeline between site E and D

Pipe line	D (mm)	Velocity (m/s)	Drop Pressure (barg)	Cost of Pipeline (Euro)	Total Cost of Pipelines (Euro)
Steam 1 line	600	19.707	0.4750	322,799	322,799+ 112,589=
Steam 2 line	2*500	14.840	0.3334	536,162	
Brine	200	2.465	-	112,589	435,388

Table 18: Result of steam pipeline from site E to D

Item	Amount	Unit
Nominal thickness (t_n)	6.3	mm
Distance between support (L_s)	21	m
Distance between two anchor (L_A)	80	m
Length of arm (L_{sh})	36	m
Distance between vertical support (L_{sv})	15	m

Table 19: Result of brine pipeline from site E to D

Item	Amount	Unit
Nominal thickness (t_n)	4.2	mm
Distance between support (L_s)	10	m
Distance between two anchor (L_A)	80	m
Length of arm (L_{sh})	21	m
Distance between vertical support (L_{sv})	12	m

c. Separation system

In this option, two small separators should be designed to separate two phase flow of 2 wells in site D and 3 wells in site E. The assumptions are shown in Table20 and Table 21.

Table 20: General Assumptions Information for design separator in site D

Item	Amount	Unit
Two-phase flow rate	165	kg/s
Brine flow rate	124.5	kg/s
Steam flow rate	40.5	kg/s
Quality of steam	0.2455	
Wellhead pressure	9.5	barg
Enthalpy two-phase fluid	1175	kJ/kg

Table 21: General Assumptions Information for design separator in site E

Item	Amount	Unit
Two-phase flow rate	110	kg/s
Brine flow rate	83	kg/s
Steam flow rate	27	kg/s
Quality of steam	0.2455	
Wellhead pressure	9.5	barg
Enthalpy two-phase fluid	1175	kJ/kg
Temperature of two-phase, steam and brine flow	177.7	°C
Steel grade	S235	
Thickness of insulation of brine flow	50	mm
Thickness of insulation of steam and two-phase flow	100	mm
Roughness	0.046	mm
Level ABSL	2885.2	m

Based on the calculation by an Excel file, the result of dimensions of separator is shown in Table22.

Table 22: Result for separator in site D

Item	Amount	Unit
D_i	3.10	m
L	9.30	m
e	14	mm
e_{end}	28	mm
Weight	13324	kg

Based on the calculation on an Excel file, the result of dimensions of separator is shown in Table 23.

Table 23: Result for separator in site E

Item	Amount	Unit
D_i	2.70	m
L	8.20	m
e	12	mm
e_{end}	25	mm
Weight	8834	kg

The total costs for separator system are shown in Table 24.

Table 24: Total costs of separator system

Site	Weight	Cost of each Kilo (Euro)	Total Cost (Euro)
D	13324	4.0	53,296
E	8834	4.0	35,336
SUM			88,632

5. CONCLUSION

In this paper, two options of pipelines were designed in order to transmit the two-phase flow or steam and brine flow from well head in site E and D to site A, and also two separator systems for these two options were designed. The results are shown in Table 25.

Table 25: The results of two options

Option	Drop Prusser (barg)	Cost of Site D to A Pipelines (Euro)	Cost of Site E to D Pipelines (Euro)	Cost of Separation System (Euro)	Total Cost of Transmission and Separation system (Euro)
1	0.5449	267,109	369,116	87,536	723,761
2	0.8350	356,840	435,388	88,632	880,860

These results show that the option 1 is the best option for transmission and separation, because the total costs is less than the other option and also the drop pressure is less than option 2. This shows that the cost of pipe and separator system both in option 2 is larger than those in option 1. Also, the result shows that if we don't need the brine and could inject them in site D and E, the option 2 is better than option 1.

Some of results of Excel files are shown as APPENDIX I.

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REFERENCES

Chisholm, D, Two-phase flow in pipelines and heat exchangers. The Institution of Chemical Engineers, NY. (1983), 154-166.

Efotg,: Pipeline, route selection and surveys. Efotg, website: http://efotg.nrcs.usda.gov/ references/public/NE/MSPM-4wNE.pdf (2007).

Harvel: Thermal expansion. Harvel, website: http://www.harvel.com/piping-cts-thermal.asp (2007).

Jónsson, M.Th.: Mechanical design of geothermal power plants. UNU-GTP, Iceland, unpublished lecture notes (2007).

SKM,: Well NWS-4, discharge evaluation report. SUNA and Sinclair Knight Merz, draft report, (2004), 43 pp.

SKM, NW-Sabalan geothermal feasibility study. SUNA and Sinclair Knight Merz, draft report, (2005), 92 pp.

Yousefi, H.: Application of GIS in the environmental impact assessment of Sabalan geothermal field, NW-Iran. Report 19 in: Geothermal Training in Iceland 2004. UNU-GTP, Iceland, (2004), 439-474.

Zhao, H.D., Lee, K.C., and Freeston, D.H.: Geothermal two-phase flow in horizontal pipes. New Zealand. Proceedings of the World Geothermal Congress 2000, Kyushu – Tohoku, Japan, (2000), 3349-3352.

Zarrouk S. and Santoso Y.: Geothermal Steam Water Separator Sizing for Optimizing Power Plant Cost Department of Engineering Science, The University of Auckland, (2017).

Svrcek, W.Y. & Monnery, W.D.: Design Two-Phase Separators Within the Right Limits: Fluids/Solids Handling, 1993, 53-60.

APPENDIX I: SOME EXAMPLE OF EXCEL FILE CALCULATION

Two Phase from Site D to A - ONE LINE

Two Phase from Site D to A q_{tp}=	275.0	kg/s
T_v=	177.7	°C
delta H=	-117.9	m
Q=	309.16	(l/s)
Roughness=	0.046	mm
Density mix=	22.99	kg/m3
(from EES)Density=	4.897	kg/m3
(from EES)Density water=	889.5	kg/m3
Length=	1142.85	m
dynamic Viscosity water=μ=	0.0001756	kg/m-s

Length that need expansion loop=1142.85   1142.85/80+1= 15.3

Length that need expansion joint=0   0/80= 0

Number of bend=n_b=	15	h_b=	20
Number of expansion unit=n_u=	0	h_u=	18
Number of con.=n_c=	0	h_c=	20
Number of valve=n_v=	2	h_v=	10

D (mm)	200	250	300	400	500	600	700	800	900	1000
D_o (mm)	219.1	273	323.9	406.4	508	609.6	711.2	812.8	914.4	1016
t (mm)	4.5	5	5.6	6.3	6.3	6.3	6.3	6.3	6.3	6.3
D_{in} (mm)	210.1	263	312.7	393.8	495.4	597	698.6	800.2	901.8	1003.4
Roughness k(mm)	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
Flow	0.3092	0.3092	0.3092	0.3092	0.3092	0.3092	0.3092	0.3092	0.3092	0.3092
Velocity from EES file	37.510	23.940	16.930	10.680	6.746	4.645	3.392	2.586	2.036	1.64
Density (kg/m3)	889.5	889.5	889.5	889.5	889.5	889.5	889.5	889.5	889.5	889.5
Length=L_p	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85
Kinematic										
Re=V*d/v that v=μ/Density	39920370	31893438	26816758	21304356	16928707	14046932	12003444	10482105	9300567	8355979
Friction factor (solved by EES)	0.014	0.01338	0.01295	0.0124	0.01191	0.01154	0.01126	0.01104	0.01087	0.01073
$1/\sqrt{f}=1.14-2\log_{10}[k/d+9.35/(Re\sqrt{f})]$										
Δ_p bar from EES file	1869.0000	212.8000	71.1200	19.4100	5.6970	2.1450	0.9488	0.4706	0.2544	0.1471
D (mm)	200	250	300	400	500	600	700	800	900	1000
Pipe Euro/m	42	45	57	72	95	115	132	160	180	210
Bend Euro	39	55	59	69	86	107	125	150	175	205
Expansion unit Euro	468	556	673	717	859	957	1,150	1,350	1,600	1,900
Valve Euro	936	1,112	1,346	1,434	1,717	1,913	2,250	2,650	3,100	3,600
Connection Euro	53	70	114	132	155	217	255	300	350	410
Insulation Euro 10 cm	12	15	17	22	27	32	36	41	46	51
Cc=Cost of equipment	64,171	71,620	88,148	111,331	144,152	173,430	198,374	237,263	267,109	308,559
Cost of land	-	-	-	-	-	-	-	-	-	-
Total Cost	64,171	71,620	88,148	111,331	144,152	173,430	198,374	237,263	267,109	308,559

Pipe pressure =WHP bar	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50

Steam from site D to site A - In ONE LINE

steam from Site D to A q_D=	67.50	kg/s		
T_v=	177.7	°C		
delta H=	-117.9	m		
Q=	13783.95	(l/s)		
Roughness=	0.046	mm		
Pressure saturation=Ps=	5.497	m		
(from EES)Density=	4.897	kg/m3		
Length=	1142.85	m		
dynamic Viscosity=μ=	0.00001418	kg/m-s		
H=	-117.9			
Length that need expansion loop=	1142.85		1142.85/80+1=	15.3
Length that need expansion joint=	0		0/80=	0
Number of bend=n_b=	15		h_b=	20
Number of expansion unit=n_e=	0		h_e=	18
Number of con.=n_c=	0		h_c=	20
Number of valve=n_v=	2		h_v=	10

D (mm)	200	250	300	400	500	600	700	800	900	1000
D_o (mm)	219.1	273	323.9	406.4	508	609.6	711.2	812.8	914.4	1016
t (mm)	4.5	5	5.6	6.3	6.3	6.3	6.3	6.3	6.3	6.3
D_{in} (mm)	210.1	263	312.7	393.8	495.4	597	698.6	800.2	901.8	1003.4
Roughness k(mm)	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
Flow	13.7839	13.7839	13.7839	13.7839	13.7839	13.7839	13.7839	13.7839	13.7839	13.7839
Velocity (m/s)=$Q/(\Pi*d^2/4)$	397.788	253.859	179.576	113.228	71.547	49.267	35.979	27.422	21.592	17.440
Density (kg/m3)	4.897	4.897	4.897	4.897	4.897	4.897	4.897	4.897	4.897	4.897
Length=L_p	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85
Kinematic										
Re=V*d/v that v=μ/Density	28862360	23056965	19392330	15398633	12240577	10157423	8680191	7578083	6724309	6043434
Friction factor (solved by EES)	0.01401	0.01341	0.01298	0.01245	0.01198	0.01164	0.01138	0.01119	0.01105	0.01093
$1/\sqrt{f}=1.14-2\log_{10}[k/d+9.35/(Re\sqrt{f})]$										
$L_e=L_p+\Sigma h_i n_i D_i$	1210.082	1227.01	1242.914	1268.866	1301.378	1333.89	1366.402	1398.914	1431.426	1463.938
$H_f=(f*V^2/2g)(L_e/D_{in})$ m of water	650776.25	205497.79	84797.96	26212.93	8210.87	3217.44	1468.54	749.79	416.76	247.22
$\Delta_p=(f*V^2/2g)(L_e/D_{in})$*Density*g/1E5 bar	312.6301	98.7203	40.7366	12.5926	3.9445	1.5456	0.7055	0.3602	0.2002	0.1188
D (mm)	200	250	300	400	500	600	700	800	900	1000
Pipe Euro/m	42	45	57	72	95	115	132	160	180	210
Bend Euro	39	55	59	69	86	107	125	150	175	205
Expansion unit Euro	468	556	673	717	859	957	1,150	1,350	1,600	1,900
Valve Euro	936	1,112	1,346	1,434	1,717	1,913	2,250	2,650	3,100	3,600
Connection Euro	53	70	114	132	155	217	255	300	350	410
Insulation Euro	12	15	17	22	27	32	36	41	46	51
Cc=Cost of equipment	64,171	71,620	88,148	111,331	144,152	173,430	198,374	237,263	267,109	308,559
Cost of road	-	-	-	-	-	-	-	-	-	-
Total Cost	64,171	71,620	88,148	111,331	144,152	173,430	198,374	237,263	267,109	308,559

Brine from site D to site A - ONE LINE

Brine from Site A to B q_B= 207.50 kg/s

T_v= 177.7 °C

delta H= -117.9 m

Q= 213.52 (l/s)

Roughness= 0.046 mm

Pressure saturation=Ps= 5.497 m

(from EES T=80)Density water= 971.8 kg/m3

Length= 1142.85 m

dynamic Viscosity=μ= 0.0001756 kg/m-s

H= -117.9

Length that need expansion loop= 1142.85 1142.85/80+1= 15.3

Length that need expansion unit= 0 0/80= 0

Number of bend=n_b= 15 h_b= 20

Number of expansion unit=n_u= 0 h_u= 18

Number of con.=n_c= 0 h_c= 20

Number of valve=n_v= 2 h_v= 10

D (mm)	125	150	200	250	300	400	500	600
D_o (mm)	139.7	168.3	219.1	273	323.9	406.4	508	609.6
t (mm)	3.6	4	4.5	5	5.6	6.3	6.3	6.3
D_{in} (mm)	132.5	160.3	210.1	263	312.7	393.8	495.4	597
Roughness k(mm)	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
Flow	0.2135	0.2135	0.2135	0.2135	0.2135	0.2135	0.2135	0.2135
Velocity (m/s)=$Q/(\Pi*d^2/4)$	15.493	10.585	6.162	3.932	2.782	1.754	1.108	0.763
Density (kg/m3)	971.8	971.8	971.8	971.8	971.8	971.8	971.8	971.8
Length=L_p	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85
Kinematic								
Re=V*d/v that v=μ/Density	11360778	9390537	7164698	5723586	4813889	3822506	3038561	2521446
Friction factor (solved by EES)	0.01552	0.01496	0.01425	0.01376	0.01344	0.01311	0.01291	0.01283
$1/\sqrt{f}=1.14-2\log_{10}[k/d+9.35/(Re\sqrt{f})]$								
$L_e=L_p+\Sigma h_i n_i D_i$	1185.25	1194.15	1210.08	1227.01	1242.91	1268.87	1301.38	1333.89
$H_f=(f*V^2/2g)(L_e/D_{in})$ (m)	1698.50	636.45	158.83	50.60	21.07	6.62	2.12	0.85
D (mm)	125	150	200	250	300	400	500	600
Pipe Euro/m	25	32	42	45	57	72	95	115
Bend Euro	26	42	39	55	59	69	86	107
Expansion unit Euro	290	351	468	556	673	717	859	957
Valve Euro	579	702	936	1,112	1,346	1,434	1,717	1,913
Connection Euro	39	44	53	70	114	132	155	217
Insulation Euro	6	7	9	11	13	17	21	24
Cc=Cost of equipment	36,976	46,605	60,742	67,049	83,577	105,617	137,295	164,287
Cost of road	-	-	-	-	-	-	-	-
Total Cost	36,976	46,605	60,742	67,049	83,577	105,617	137,295	164,287

Calculating pressure in site A

L(between site D and A)= 1142.85 m

D (mm)	125	150	200	250	300	400	500	600
D_o (mm)	139.7	168.3	219.1	273	323.9	406.4	508	609.6
t (mm)	3.6	4	4.5	5	5.6	6.3	6.3	6.3
D_{in} (mm)	132.5	160.3	210.1	263	312.7	393.8	495.4	597
Le (Total path)	1185.25	1194.146	1210.082	1227.01	1242.914	1268.866	1301.378	1333.89
Velocity (m/s)	15.49	10.59	6.16	3.93	2.78	1.75	1.11	0.76
Friction factor	0.01552	0.01496	0.01425	0.01376	0.01344	0.01311	0.01291	0.01283
H_f for in this part	1698.50	636.45	158.83	50.60	21.07	6.62	2.12	0.85
Hh-total	-117.9	-117.9	-117.9	-117.9	-117.9	-117.9	-117.9	-117.9
Pipe pressure (site A) P_p(site A)=	-1580.60	-518.55	-40.93	67.30	96.83	111.28	115.78	117.05

Separator for 5 Wells

$\dot{m}_v$= 67.5	kg/s	ρ_v= 4.897	kg/m3	
		ρ_l= 889.5	kg/m3	
$\dot{m}_l$= 207.5	kg/s	K'= 0.131	m/s	
P= 9.5	Barg	T_h= 200	s	Hold-up time
R_{p1}= 235	Mpa	T_s= 100	s	Surge time
R_m= 340	Mpa	L/D= 3		

$U_t=K'((\rho_l-\rho_v)/\rho_v)$^0.5= 1.761 m/s

$U_v=0.75U_t$= 1.321 m/s

$Q_v=\dot{m}_v/\rho_v$= 13.784 m^3/s

$Q_l=\dot{m}_l/\rho_l$= 0.233 m^3/s

$V_h=T_hQ_l$= 46.6 m^3

$V_s=T_sQ_l$= 23.3 m^3

$D=(4(V_h+V_s)/0.6\pi(L/D))$^(1/3)

D= 3.67 m

L=(l/D)D= 11.01 m

V= 116.469 m^3

S (Pa) is the allowable stresses=min [3/2 R_{p1},0/t ; min(5/6 R_{p1},0/t ; 1/3 R_m/20)]

$3/2R_{p1}$=	3/2*235=	352.5		
$5/6R_{p1}$=	5/6*235=	195.8	113.3	113
$1/3R_m$=	1/3*340=	113.3		

fz= 1133 Bar

e_1= $(P\ D_i)/(2\ f_z - P)$= 0.01545 m

$D_e=D_i+2e$= 3.701

e_2= $(P\ D_e)/(2\ f_z + P)$= 0.01545 m

e=max(e_1,e_2)= 0.01545 m

e/D_e= 0.004175 OK e/De=<0.16

e_{end} = max [(C_1 D_i sqrt(P/f)) ; (C_2 D_i sqrt(P/f_{min}))]

e_{end}= 0.033606

D_i= 3.67	→	D_i= 3.7		
L= 11.01		L= 11		
e= 0.01545		e= 0.016	W= 21884	kg
e_{end}= 0.033606		e_{end}= 0.034	Cost= 4	Euro/kg
		D_e= 3.716	Total Cost= 87536	Euro
		D_m= 3.708		