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Comprehensive Comparison Between Transmission Two-Phase Flow in One Line Together and Two Line Separately for 50 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 levelised 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 that the new drilling was started since last spring. In this stage 3 deep wells were drilled.

In this paper, a power plant capacity of 50 MWe in site A is assumed, with steam from production wells on pads D and A, 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 to site A in one line together and in two lines separately, then a comprehensive compare will do between two methods for transmission, and 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 70 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.

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).

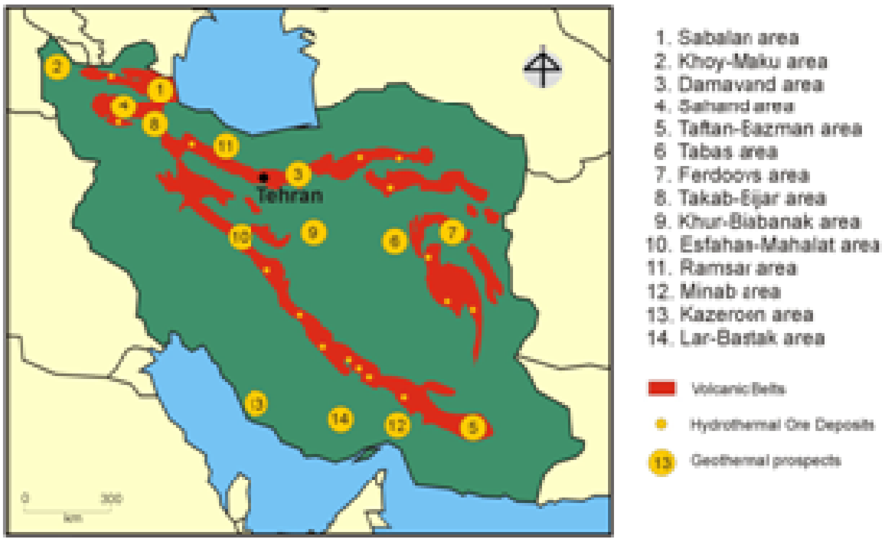

Figure 1: Map of IRAN (SKM, 2005)

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" North and 47° 38' 30" and 47° 48' 20" (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, 80 km (1 hour by car) to the east. Ardebil is serviced by daily flights from Tehran. The project can also be readily accessed through daily flights from Tehran to the large industrial city of Tabriz, 180 km NW of Meshkinshahr.

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. The lower terraces are intensively planted in wheat and lucerne by farmers from the villages of Moil and Illando. The upper terraces are occupied in the summer months only by nomadic people, herding sheep, goats and some cattle (SKM, 2005).

The area is identified as a seismically active location. The National Building Code (Standard 2800) published by the Building and Housing Research Centre for Iran, includes a seismic macrozonation hazard map for Iran. The site location around Mt. Sabalan is identified in the very high risk zone with a typical peak ground acceleration of 0.35g. Of greater significance will be seismically induced slope instability. The steep sided scree slopes of the deeply incised river gullies will experience large-scale translational slides, debris flows and lateral spreading. Any infrastructure or assets located on or adjacent to this slope will require specific design features to protect or reduce against the effects of earthquake induced slope instability. 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 stage, the project was divided into two-phases; the first phase (1998-2006) was aiming to build drilling pads at sites A, B, 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 exist road between Meshkinshahr and Moil village and to drill five exploratory wells. In the second phase, SUNA has decided to build a 5 MWe pilot power plant in site B for observing the actual viability of a geothermal power plant in Iran and simultaneously drill 13 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 these drilling processes, and well testing, SUNA is planning to build a 50 MWe power plant in order to reach 55 MWe capacities.

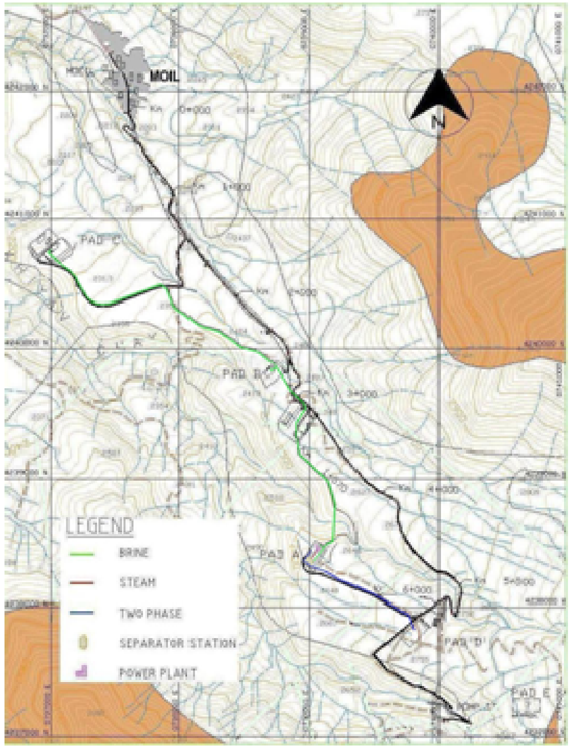

Figure 2: Plan of Sabalan area (SKM, 2005)

In this paper, the above 50 MWe power plant is assumed in site A, with steam from production wells on pads D and A.

The main objective of this study is compare between two methods for transmission two-phase flow from wellhead in site D to powerhouse in site A. The first we will design one pipeline that transmit the two-phase flow (mix) and also we will design two pipeline that transmit the steam and brine separately these two lines have two ways, in the first way the pipes could be separately and the pipes are side of each other in the second way one of the pipe is in inside of another pipe. Then we will calculate the cost and drop pressure and another related thing for each kind and compare these options together.

For each line of these pipelines determining the diameter and other criteria such as thickness, distance between supports, expansion loops, expansion units, and the number of supports. The design is based on modeling technique using EES (Engineering Equation Solver) and Excel software. This paper is discussing the results of previous exploration studies in this area, the theory and method overview and finally comparing three options.

2. EXPLORATION OF SABALAN GEOTHERMAL AREA

2.1 Exploration Drilling Programme

The drilling and testing programme was carried out between November 2002 and December 2004.

The three deep exploration wells 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 deviated wells 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

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.

3. THEORY AND METHOD OVERVIEW OF 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 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 paper. 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.

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

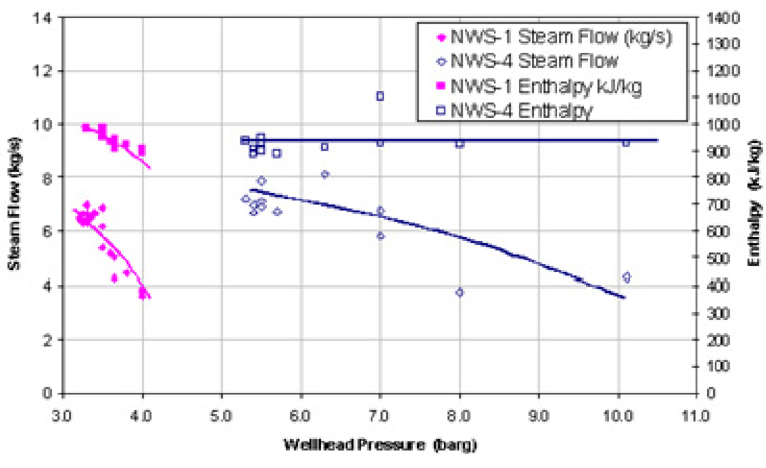

Figure 3: Output curve for wells NWS-1 & NWS-4 (SKM, 2004)

• 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.

3.2 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 C_t].

Total Update Cost (C_t) is:

$$C_t = C_c + C_e \left(1 - 1/(1+i)^T\right)/i \tag{1}$$

where C_c, C_e, T, i are capital cost, annual cost, life time, index rate, respectively.

The capital cost is equal to:

$$C_c = L_p k_p + n_b k_b + n_c k_c + n_u k_u + n_v k_v + n_d k_d + L_p k_e \tag{2}$$

where. L_p, k_p, n_b, , k_b, n_c, k_c, n_u, k_u, n_v, k_v, n_d, k_d, k_e, are pipe length (m), cost of pipe (Euro/m), number of bends, cost of bends (Euro), number of connections, cost of connections (Euro), number of expansion units, cost of expansion units (Euro), number of valves, cost of valves (Euro), number of pumps, cost of pumps (Euro), cost of insulation (Euro/m), respectively.

The annual cost is equal to:

$$C_e = k_e o_h P \tag{3}$$

where k_e, o_h, P, are cost of electrical energy (Euro/Wh), hours in one year is equal 365 times 24 (8760 hours), power of pump (W), respectively.

The power of pump was calculated using equation:

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

where g, ρ, H_f, Q, η .are gravity constant (m/s^2), density of fluid water or steam (kg/m^3), friction head (m), flow rate of fluid (m^3/s), efficiency of pump, respectively.

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

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

where V , D_{in} , are velocity of fluid (m/s), pipe inner diameter (m), respectively.

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 ,. h_b , h_c , h_u , h_v are pipe length (m), equivalent length of bends, equivalent length of connections, equivalent length of expansion units, equivalent length of valves, respectively.

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

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

where ν is 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:

$R_e \le 2100$

$$f = 64 / R_e \tag{8}$$

$R_e > 2100$

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

where R_e, k are Reynolds number, absolute roughness (m) , respectively.

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, f, L_e are friction head (meter of fluid), friction factor, equivalent length (m), respectively.

When the section is not cylindrical in order to calculate friction head, velocity of fluid (V) should be calculated using equation:

$$V = Q/(\pi (D_{inpo}^2 - D_{opin}^2)/4) \tag{11}$$

where D_{inpo}, D_{opin}, are outside pipe inner diameter (m), inside pipe outer diameter (m), respectively.

Hydraulic radius (R_h) define using equation:

$$R_h = A/P = (\pi(D_{inpo}^2 - D_{opin}^2)/4)/(\pi(D_{inpo} + D_{opin})) \quad (12)$$

where A, P, are area of pipe section (m^2), perimeter of pipe section that is wet (m), respectively.

If equation 12 use for cylindrical pipe line equal inner diameter (D_{ine}) could be calculated using equation 14 as follow:

$$R_h = (\pi D_{in}^2 / 4)/(\pi D_{in}) = D_{in}/4 \quad (13)$$

$$D_{ine} = 4R_h \quad (14)$$

In this case (section is not cylindrical) the first hydraulic radius calculate by equation 12 then equal inner diameter (D_{ine}) calculate by equation 14 based on the perimeter of section that is wet. This (D_{ine}) should be used instead of (D_{in}) in equations 7, 9 and 10 in order to calculate Reynolds number, friction factor and friction head.

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

$$P_P = (\Delta Z + H_f)\rho g \quad (15)$$

where P_P, ΔZ are pump pressure (Pa), elevation difference between end and start points of line $\Delta Z = H_s - H_e$ (m), respectively.

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

For each diameter 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 5 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 paper the brine water goes by gravity, and it is not necessary to pump, hence the annual cost is zero. The diameter will be selected by a proper velocity. In order to avoid corrosion and erosion in steam pipeline the velocity should be less than 40 m/s, and for brine pipeline the velocity should be less than 3 m/s.

3.3 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. A two-phase mixture can flow through a pipe in a variety of flow regime as shown in Figure 4. These regimes depend on various conditions.

• Transport properties of fluids.

• Mass and volume fraction in pipes.

• Velocity fraction between phases.

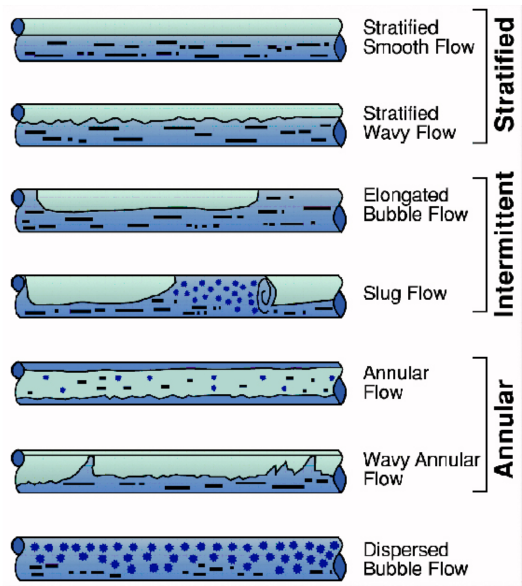

Figure 4: Flow regimes

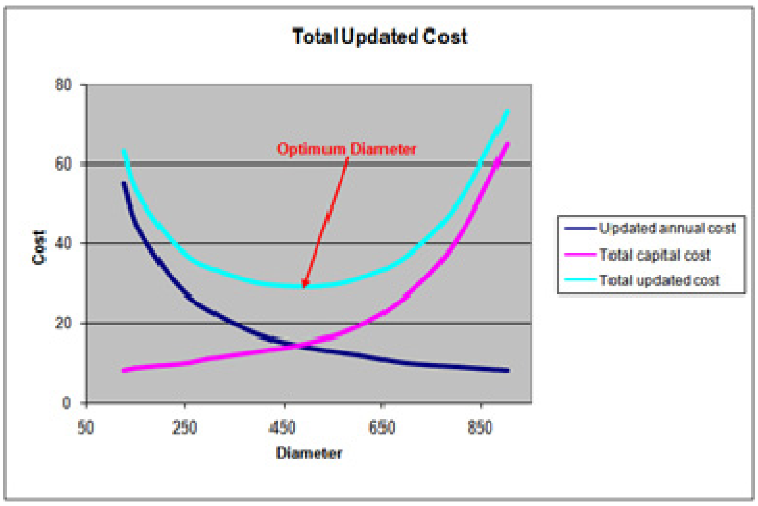

Figure 5: Total updated cost

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 two-phase flow from five wells in site D is shown in Figure 6.

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-section:

$$\alpha = A_g / A \tag{16}$$

where A_g, A are area of gas or steam, total area, respectively.

(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:

$$\frac{1-\alpha}{\alpha^{7/8}} = \left[\left(\frac{1}{x}-1\right)\left(\frac{\rho_g}{\rho_f}\right)\left(\frac{\mu_f}{\mu_g}\right)\right]^{7/8} \tag{17}$$

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:

$$\overline{V}_f = 1.1(1-x)\frac{W(1-x)}{\rho_f(1-\alpha)A} \tag{18}$$

where W, x, ρ_f, $1.1(1-x)$, are total mass flow rate (kg/s), steam quality, density of water (kg/m^3), correction factor mainly for entrainment, respectively.

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 (Zhao et al., 2000). The average velocity of the equivalent single-phase flow ($\overline{V}$) can be calculated using equation:

$$\frac{\overline{V}_f}{\overline{V}} = \frac{\left(1-\sqrt{\alpha}\right)^{(8/7)}\left(1+\frac{8}{7}\sqrt{\alpha}\right)}{(1-\alpha)} \tag{19}$$

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 20 (Zhao et al., 2000).

$$\Delta_{PL} = \frac{f\rho_f\overline{V}^2}{2D_{in}(1-AC)} \tag{20}$$

where Δ_{PL}, ρ_f, AC, m_g, p, A are drop pressure due to length (Pa), density of fluid (water) (kg/m^3), acceleration correction, $AC = m_g / \rho_g \left(pA^2\alpha\right)$, mass of gas (steam) (kg/m^3), pressure (Pa), inner area (m^2), respectively.

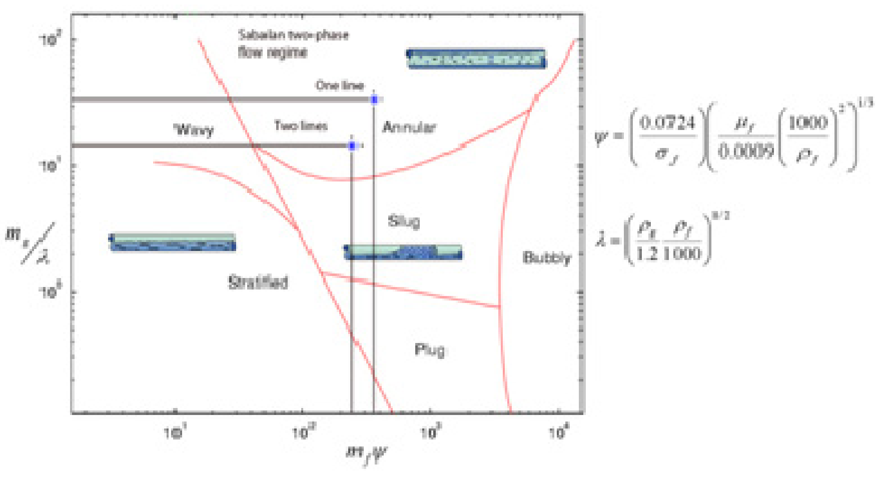

Figure 6: The Baker map

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).

$$\varphi^2{}_{BLO} = 1 + \left(\frac{\rho_f}{\rho_g} - 1\right)\left(Bx(1-x) + x^2\right) \quad (21)$$

where x, B, K_{BLO}, h, r, are quality of steam, $1 + 2.2/\left(K_{BLO}\left(2 + r/D_{in}\right)\right)$, $1.6fh$, equal length (m), bend radius (m), respectively.

Then drop pressure can be calculated from this equation:

$$\Delta_{PI} = \frac{f\rho_m \overline{V}^2}{2}\left(\varphi^2{}_{BLO,b} n_b h_b + \varphi^2{}_{BLO,c} n_c h_c + \varphi^2{}_{BLO,u} n_u h_u + \varphi^2{}_{BLO,v} n_v h_v\right) \quad (22)$$

where Δ_{PI}, ρ_m, $\varphi^2{}_{BLO,b}$, $\varphi^2{}_{BLO,c}$, $\varphi^2{}_{BLO,u}$, $\varphi^2{}_{BLO,v}$ are drop pressure installation (Pa), density of mixture of fluid and gas (water and steam) (kg/m^3), two-phase multiplier for bends, two-phase multiplier for connections, two-phase multiplier for expansion units, two-phase multiplier for valves, respectively.

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

$$\Delta_{PT} = \rho_m g \Delta_Z - \left(\Delta_{PL} + \Delta_{PI}\right) \quad (23)$$

3.4 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. 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 ($-P_P$) from equation 15, 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:

$$t_n \geq t_m = P_D D_o / (2(S_h E + Py)) + A \quad (24)$$

where P_D, D_o, S_h, E, y, A are pressure design (Pa), pipe outer diameter (m), allowable stresses (Pa), welding factor for butt-weld joint is equal 0.85, temperature dependent coefficient for steel and t<480°c is equal 0.4, additional thickness milling and corrosion (m) is equal 0.0015, respectively.

3.5 Distance between Supports

When the pipe is installed above the ground, it should be hold by supports as shown in Figure 7.

Figure 7: Supports

Figure 8: Support with only horizontal

Figure 9: Support with horizontal & vertical

There are two kinds of support; the first one that allows the pipe just to move horizontally as shown in Figure 8 and the second one allow the pipe to move vertically and horizontally as shown in Figure 9. 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.

<u>3.5.1 Allowable Stresses</u>

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):

$$S = \min\left(R_{m/T}/3, R_{m/h}/3, 2R_{p/c}/3, 2R_{p/h}/3\right) \quad (25)$$

$$S_h = \min\left(R_{m/h}/3, 2R_{p/h}/3\right) \quad (26)$$

$$S_c = \min\left(R_{m/c}/3, 2R_{p/c}/3\right) \quad (27)$$

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

In this paper, steel is class (S_{235}), and for two-phase, steam and brine water flow T= 155.5 °C, then

$R_{m/T}=340$, $R_{p/c}=235$, $R_{p/h}=200$ and $S=\min$ (113.3,113.3,156.7,133.3)=113.3 MPa.

3.5.2 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 28 (Jónsson, 2007):

$$P_D D_o/(4t_n)+(0.75i)(M_A/Z)+(0.75i)(M_B/Z)\le kS_h \quad (28)$$

$$Z=\pi/\left(32\left(D_o^{\,4}-D_{in}^{\,4}\right)D_o\right) \quad (29)$$

where t_n, i, M_A, M_B, Z, k are thickness (m), stress intensity factor (where $0.75i\ge 1.0$), sustained bending moment (Nm), dynamic bending moment (Nm), section modulus (m^3),1.15 if load is less than 10% operational time, 1.20 if load is less than 1% operational time, 1.00 else, respectively.

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, that can be calculated from equation 30 to 32.

$$q_{sv}=q_p+q_e \quad (30)$$

$$q_p=\pi g\rho_s\left(D_o^{\,2}-D_{in}^{\,2}\right)/4 \quad (31)$$

$$q_e=\pi g\rho_e\left(D_e^{\,2}-D_o^{\,2}\right)/4 \quad (32)$$

where q_p, q_e, ρ_s, ρ_e, D_e are pipe weight (N/m), insulation weight (N/m), steel density (kg/m^3) here $\rho_s=7850$ (kg/m^3), insulation density (kg/m^3) here $\rho_e=730$ (kg/m^3), insulation diameter (m), respectively.

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 33 to 37.

$$q_{dv}=q_v+q_s+q_{jv} \quad (33)$$

$$q_v=\pi g\rho_v D_{in}^{\,2}/4 \quad (34)$$

$$q_s=0.2SD_e \quad (35)$$

$$q_{jv}=0.5eq_0 \quad (36)$$

$$q_0=q_p+q_e+q_v \quad (37)$$

Where q_v, ρ_v, q_s, q_{jv}, e are medium weight (N/m), medium density (kg/m^3) here for brine water $\rho_v=971.8$ (kg/m^3), for steam $\rho_v=2.9$ (kg/m^3), for two-phase $\rho_v=20.4$ (kg/m^3), snow weight (N/m), seismic vertical load (N/m), seismic coefficient here $e=0.24$, respectively.

Horizontal dynamic load (q_{dh}) is equal the maximum of wind load and horizontal seismic load, that can be calculated from equation 38 to 40.

$$q_{dh}=\max\left(q_w,q_{jh}\right) \quad (38)$$

$$q_w=CpD_e \quad (39)$$

$$q_{jh}=eq_0 \quad (40)$$

where q_w, C, p, q_{jh} are wind load (N/m), form factor for pipe $C=0.6$, wind pressure $p=V_w^{\,2}/1.6$ and $V_w=50$ is maximum wind speed (m/s), seismic horizontal load (N/m) , respectively.

As mentioned before the pipe is assumed as a simple beam thus bending moment for sustained load and dynamic load is calculated from equations 41 and 42.

$$M_A=q_{sv}L_s^{\,2}/8 \quad (41)$$

$$M_B=\left(q_{dv}^{\,2}+q_{dh}^{\,2}\right)^{1/2}L_s^{\,2}/8 \quad (42)$$

Based on the moments, that was calculated from equation 41 and 42, and also using equation 28 distance between support (L_s) should be less than or equal the resulting value from equation 43.

$$L_s\le\left(\left[kS_h-PD_o/(4t_n)\right]\Big/\left[((0.75i)/8Z)\left(q_{sv}+\left(q_{dv}^{\,2}+q_{dh}^{\,2}\right)^{1/2}\right)\right]\right)^{1/2} \quad (43)$$

3.5.3 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 support (L_{sv}), while the horizontal span is equal the arm of loop along the pipeline (L_{sh}) as shown in Figure 10. Bending moment for sustained load and dynamic load can be calculated from equations 44 and 45, which they are similar to equations 41 and 42(Jónsson, 2007):

$$M_A = q_{sv} L_{sv}^2/8 \quad (44)$$

$$M_B = \left(\left(q_{dv} L_{sv}^2\right)^2 + \left(q_{dh} L_{sh}^2\right)^2\right)^{1/2}/8 \quad (45)$$

Based on the moments that were calculated from equation 41 and 42 and also using equation 28, equation 46 will be calculated. Distance between support (L_{sv}) and the arm of loop (L_{sh}) are assumed, and then equation 46 should be controlled.

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

$$\delta = 2.07 q_0 L_s^3/(384EI) \quad (47)$$

Where E, I are Young modulus (N/m^2), $\pi/64\left(D_o^4 - d^4\right)$, respectively.

3.6 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 39.

$$\Delta L = \alpha L \Delta T \quad (48)$$

where α, ΔT are coefficient of thermal expansion ($1/^\circ\mathrm{C}$),temperature difference ($^\circ\mathrm{C}$), respectively.

Then thermal strain (ε_x) is equal to:

$$\varepsilon_x = \Delta L/L = \alpha/\Delta T \quad (49)$$

If the pipe was fixed between two ends the thermal stresses (σ_x) and Force (F) will be calculated from equation 50 and 51.

$$\sigma_x = E\,\Delta L/L = E\alpha\Delta T \quad (50)$$

$$F = A\sigma_x = AE\alpha\Delta T \quad (51)$$

3.6.1 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. 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.

In this paper 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 (Figure 11) (Jónsson, 2007):

$$D_o Y/(L - L_A)^2 \le 208.3 \quad (52)$$

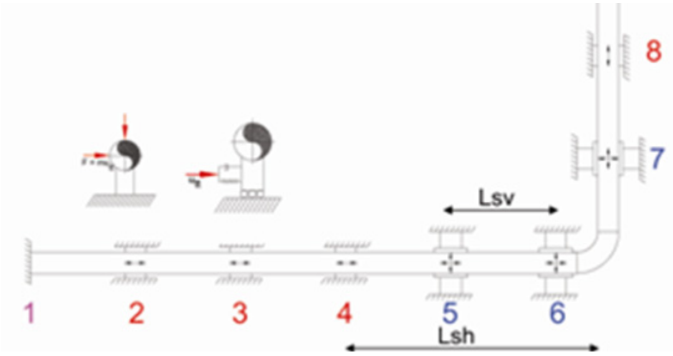

Figure 10: Supports

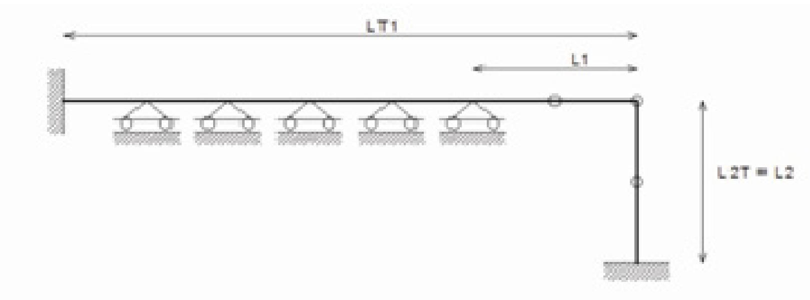

Figure 11: Expansion loop

$$Y = \alpha \Delta T \left(L_{T1}^{\ 2} + L_{T2}^{\ 2} \right)^{1/2} \quad (53)$$

$$L = L_1 + L_2 \quad (54)$$

$$L_A = \left(L_1^{\ 2} + L_2^{\ 2} \right)^{1/2} \quad (55)$$

Where Y, L, L_1 &, L_2, L_{T1} & L_{T2}, L_A, α, ΔT are Resultant movement to be absorbed by the pipe loop (mm), developed length of line axis (m), length of arm (m), Total of length in each direction (m), Straight distance between two anchor (m), Coefficient of thermal expansion ($1/{}^\circ C$), Temperature difference (${}^\circ C$), respectively.

Assuming $L_a = L_1 = L_2$ and use equations 52-55, the length of arm will be calculated by:

$$L_a \geq \left(D_o \alpha \Delta T L_A / 71.477 \right)^{1/2} \quad (56)$$

3.6.2 Expansion units

There are three kinds of expansion units as shown in Figure 12. They are Axial, Angular and Lateral. (Jónsson, 2007).

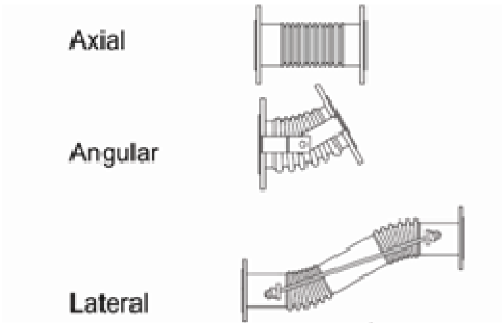

Figure 12: Expansion unit

• 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.

4. PIPELINES DESIGN FOR TRANSMISSION TWO-PHASE FLOW FROM SITE D TO SITE A IN SABALN PROJECT

In order to transmission two-phase flow from production wells from site D to site A, three options will be assumed. This paper involves the design of two-phase flow, steam and Brine water pipeline as follow:

• Option 1- One line with Two-phase flow (mix).

• Option 2-Two line one of them with steams fellow another with brine flow that they are separately.

• Option 3-Two line one of them with steams fellow another with brine flow that one of them is inside of another pipeline.

As mentioned in the first part of Sabalan project 5 wells were drilled, that two of them were tested, the output curve for well NWS-4 (SKM, 2004) Figure 3. For new wells based on the result of well NWS-4, the pressure, flow rate and temprature was assumed the same as NWS-4, as follow:

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

• Mass flow for each well = 56 (kg/s).

The assumption is shown in Table 2.

Table 2: General Assumption Information

Item	Amount	Unit
Two-phase flow rate from wellhead site D to site A	280	kg/s
Brine flow rate from separator station in site D to site A	240.74	kg/s
Steam flow rate from separator station in site D to site A	39.26	kg/s
Quality of steam	0.1402	
Wellhead pressure	5.5	barg
Enthalpy two-phase fluid	950	kJ/kg
Temperature of two-phase, steam and brine flow	155.5	°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

4.1 Option 1- Two-Phase Flow in one or in Two Line (mix)

This pipeline should be design to transmit the two-phase flow from wellhead site D to site A.

A topography plan is shown in (Figure 13). The data for this pipeline is shown Table 3

There is a main access road between these two sites. The best route can be selected between these two sites is next to this main road, the longitude profile with plan are shown in Figure 14. 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 23, and the total cost of each diameter was calculated.

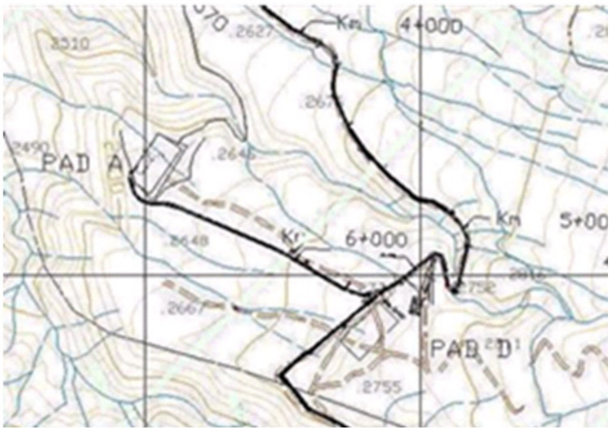

Figure 13: Topography plan between sites D and A

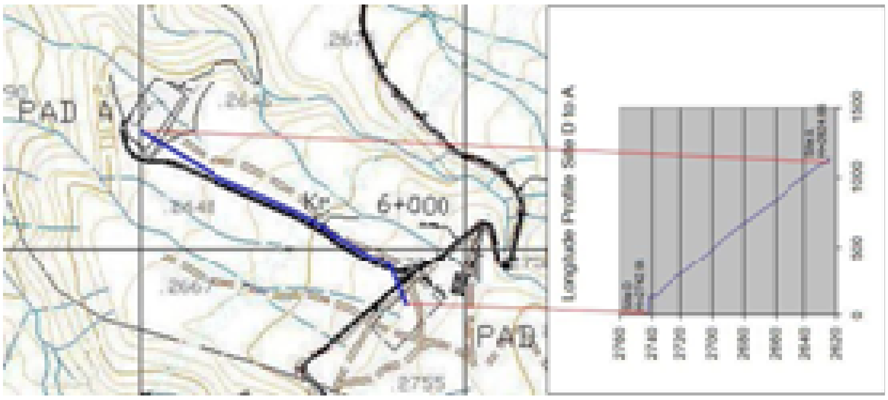

Figure 14: Longitude and plan between site D and A

Table 3: 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	

In each option the best diameter based on drop pressure and cost of pipeline was selected, and the result of two options is shown in Table 4.

The best option is option 1.2, because with 40000 Euro deference of cost between this option and option 1.1 the drop pressure is equal half of this option. The total cost is equal 234,000 Euro. And now the calculation will be continue in this option, the diameter of pipe is 800 (mm). Based on calculation in Excel file and using the equation from last section the calculated results are shown in Table 5.

4.2 Option 2-Two Line One of Them with Steams Fellow Another with Brine Flow That They Are Separately

Two pipeline should be design to transmit the steam flow and brine water from separator on site D to site A. As mention in previous part the route here is the same as last part and the best route is selected between these two sites is next to the main road between these two sites, the longitude profile with plan are shown in Figure 14. The data for these pipelines is the same as previous part that shown

Table 3. In each pipeline of steam and brine based on the maximum velocity as mentioned in section 3.2 for each case the diameter was selected as shown in Table 6.

The calculation will be continue in these pipelines, the diameter of pipe is 700 (mm) for steam flow and 300 (mm) for brine flow. Based on calculation in Excel file and using the equation from last section the calculated results are shown in Table 7 and Table 8:

Table 4: The result of pipeline between site D and A

Option	D (mm)	Drop pressure (barg)	Cost of Pipeline (Thousand Euro)
1.1	700	1.08	194
1.2	800	0.54	234
2.1	2*500	1.99	285
2.2	2*600	0.66	344

Table 5: The result of two-phase pipeline between site D and A

Item	Amount	Unit
Nominal thickness (t_n)	6.3	mm
Distance between support (L_s)	17	m
Distance between two anchor (L_A)	65	m
Length of arm (L_{sh})	34	m
Distance between vertical support (L_{sv})	12	m
Number of support (N_S)	108	

Table 6: The result of Steam and brine (separatly) pipeline between site D and A

Pipe line	D (mm)	Velocity (m/s)	Drop pressure (barg)	Cost of Pipeline (Thousand Euro)
Steam	700	35.13	0.41	195
Brine	300	3.44	32.35	84

Table 7: 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)	23	m
Distance between two anchor (L_A)	80	m
Length of arm (L_{sh})	39	m
Distance between vertical support (L_{sv})	17	m
Number of support (N_S)	75	

Table 8: The result of brine pipeline from site D to A

Item	Amount	Unit
Nominal thickness (t_n)	5.0	mm
Distance between support (L_s)	13	m
Distance between two anchor (L_A)	80	m
Length of arm (L_{sh})	25	m
Distance between vertical support (L_{sv})	8	m
Number of support (N_S)	105	

Table 9: The result of Steam and brine (one line is inside of another one) pipeline between site D and A

Line	D (mm)	Velocity (m/s)	Drop pressure (barg)	Cost of Pipeline (Thousand Euro)
Steam	700	44.75	1.37	195
Brine	300	3.44	32.35	69

Table 10: The result of Steam and brine (one line is inside of another one) pipeline between site D and A

Item	Amount	Unit
Nominal thickness (t_n)	6.3	mm
Distance between support (L_s)	23	m
Distance between two anchor (L_A)	80	m
Length of arm (L_{sh})	39	m
Distance between vertical support (L_{sv})	17	m
Number of support (N_S)	90	

4.3 Option 3-Two Line One of Them with Steams Fellow Another with Brine Flow That Brine Pipeline Is Inside Of Steam Pipeline

One pipeline should be design to transmit the steam flow with the area equal the area of outside's pipe minus the area of inside's pipe from separator on pad D to site A. Another pipeline should be design to transmit brine that it is inside of the steam pipeline. The design for brine pipeline is the same exactly as last part just without insulation. That means just the total cost will be changed.

As mention in previous part the route here is the same as last part and the best route is selected between these two sites is next to the main road between these two sites, the longitude profile with plan are shown in Figure 14. The data for these pipelines is the same as previous part that shown Table 3. In each pipeline of steam and brine based on the maximum velocity as mentioned in section 3.2 for each case the diameter was selected as shown in Table 9.

Because of the friction on the surface of brine pipeline that is inside of steam pipeline, the hydraulic radius and equal inner diameter (D_{ine}) calculated by using equation 13 and 14, then in order to calculate friction head in equations 7, 9 and 10 use (D_{ine}) instead of (D_{in}) and in this option velocity of fluid is calculated by using equation 11.

The calculation will be continue in these pipelines, the diameter of pipe is 700 (mm) for steam flow that there is a pipe with diameter equal 300 (mm) for brine water inside of it. Based on calculation in Excel file and using the equation from last section the calculated results are shown in Table 10.

5. CONCLUSIONS

In this paper three options of pipelines were designed in order to transmit the two-phase flow from well head in site D to power house in site A. The results are shown in Table 11.

This results show that the option 1 is the best option in order to transmit the two-phase flow, because the total cost is less than of another options and the drop pressure in not very bigger than the option 2 and also the area that need in this option is less than option 2 Figure 15.

When the length of pipeline is longer than the length of this pipeline (1143 m), maybe the option 2 will be better than option 1. Because the drop pressure depend on the length directly and the different between the drop pressure in two options will be bigger than this example.

Option three not recommended because of high drop pressure and there is some execution problem on the construction stage and repairing problem on the operation stage.

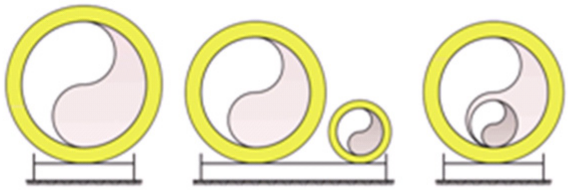

Figure 15: The view of three options

In appendix I Excel file calculation of steam for option 3 is shown.

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Table 11: The results of three options

Option	Length (m)	Diameter (mm)	Drop pressure (barg)	Cost of Steam Pipeline (Thousand Euro)	Cost of Brine Pipeline (Thousand Euro)	Cost of Supports (Thousand Euro)	Total Cost (Thousand Euro)
1	1143	800	0.54	234	0	27	261
2	1143	700 +300	0.41	195	84	35	313
3	1143	700 +300	1.37	195	69	23	287

APPENDIX I : An example of Excel file calculation of steam line for option 3

Steam from Seperatore station site D to Powerhouse site A - in ONE LINE outside of brine (D=300mm)

steam from Site A to A q_b=	39.26	kg/s	
T_v=	155.5	°C	
delta H=	-117.9	m	
Q=	13459.03	(l/s)	
Roughness=	0.046	mm	
Pressure saturation=Ps=	5.497	m	
Density=	2.917	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_u=	0	h_u=	18
Number of con.=n_c=	0	h_c=	20
Number of valve=n_v=	2	h_v=	10
D_{in300}=	312.7		
Do=	323.9		

D (mm)	400	500	600	700	800	900	1000
D_o (mm)	406.4	508	609.6	711.2	812.8	914.4	1016
t (mm)	6.3	6.3	6.3	6.3	6.3	6.3	6.3
D_{in} (mm)	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
Flow	13.4590	13.4590	13.4590	13.4590	13.4590	13.4590	13.4590
Velocity (m/s)=$Q/(\Pi*(d^2-d_{300}^2)/4)$	341.76	122.02	68.17	44.75	32.02	24.21	19.01
Density (kg/m3)	2.917	2.917	2.917	2.917	2.917	2.917	2.917
Length=L_p	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85	1142.85
Kinematic							
$R_h=(\Pi*(d^2-d_{300}^2)/4)/(\Pi(d+d_{300}))$	17.5	42.9	68.3	93.7	119.1	144.5	169.9
$d=4R_h$	69.9	171.5	273.1	374.7	476.3	577.9	679.5
Re=V*d/v that v=μ/Density	4914298	4304884	3829940	3449380	3137614	2877532	2657268
Friction factor (solved by EES)	0.01785	0.01477	0.01357	0.01289	0.01246	0.01217	0.01197
$1/\sqrt{f}=1.14-2\log_{10}[k/d+9.35/(Re\sqrt{f})]$							
$L_e=L_p+\Sigma h_i n_i D_i$	1268.87	1301.38	1333.89	1366.40	1398.91	1431.43	1463.94
$H_f=(f*V^2/2g)(L_e/d)$ m of water	1928972.24	85054.07	15699.98	4797.81	1912.70	900.17	475.01
$\Delta_p=(f*V^2/2g)(L_e/d)*Density*g/1E5$ bar	551.990	24.339	4.493	1.373	0.547	0.258	0.136
D (mm)	400	500	600	700	800	900	1000
Pipe Euro/m	72	95	115	132	160	180	210
Bend Euro	69	86	107	125	150	175	205
Expansion unit Euro	717	859	957	1,150	1,350	1,600	1,900
Valve Euro	1,434	1,717	1,913	2,250	2,650	3,100	3,600
Connection Euro	132	155	217	255	300	350	410
Insulation Euro	20	24	29	33	38	42	47
Cc=Cost of equipment	109,045	140,723	170,001	194,945	233,834	262,538	303,987
Cost of road	-	-	-	-	-	-	-
Total Cost	109,045	140,723	170,001	194,945	233,834	262,538	303,987

Pressure design bar				5.50

D (mm)				700
D_o (mm)				711.2
t (mm)				6.3
D_{in} (mm)				698.6

$T_n >= t_m = P D / (2(S E + Py) + A$

P (Pa) is the design pressure

D (m) is the outer diameter

S (Pa) is the allowable stresses=min((Rm/c)/3,(Rm/h)/3,2(Rp/c)/3,2(Rp/h)/3)=113.3 Mpa

(Rm/c)/3=	340/3	113.3
(Rm/h)/3=	340/4	113.3
2(Rp/c)/3=	2*235/3	156.7
2(Rp/h)/3=	2*200/3	133.3

E is the Welding factor= 0.85

y is the temperature dependent coefficient= 0.4

A (m) is additional thickness milling and corrosion= 0.0015

P (Pa)				550000
D_o (m)				0.7112
S (Pa)				113333333
E is the Welding factor				0.85
y is the temperature coefficient				0.4
A (m) is additional thickness				0.0015
t_m (m)=				0.00352562

t_m (mm)=				3.5

Nominal thickness t_n (mm)				6.3
Outer diameter D_o (mm)				711.2
Inner diameter D_{in} (mm)				698.6
Section modulus Z (m3)				0.00243577
Insulation thickness T_e (mm)				100
Insulation diameter D_e (mm)				911.2
Steel density (kg/m3)				7850
Insulation density (kg/m3)				730
Media density (kg/m3)				2.917
Wind speed (m/s)				50
Seismic factor (N/m2)				0.24
Snow factor (N/m2)				1200
Load Pipe weight q_p (N/m)				1073
Load Insulation weight q_e (N/m)				1822
Load Media weight q_v (N/m)				11
Load Snow weight q_s (N/m)				219
Load Seismic q_j (N/m)				697
Load Wind q_w (N/m)				854
Vertical sustained load $q_{sv}=q_p+q_e$ (N/M)				2895
Vertical occational load $q_{dv}=q_v+q_s+.5q_j$				578
Horizontal occational load $q_{dh}=\max(q_w,q_j)$				854
Load factor k				1
Allowable stress at operation temp S_h				113333333
Stress intensification facot i				1
0.75 i (if 0.75 i < 1 than =1)				1
Part 1 $k * S_h - P * D_o / (4 * t_n)$				111781111
Part 2 0.75 * i / (8 * Z)				51
Part 3 $(q_{sv} + (q_{dv}^2+q_{dh}^2)^{0.5})$				3927
L_s^2 =< part1/(part2*part3)				554.72
L_s				23.55
L_s				23

D_o (mm)				711.2
L_A (m)				80
α				1.20E-05
ΔT				155.5
$Y = \alpha * \Delta T * LA$				1.49E-01
$L_{am} = (D_o*Y/71.477)^{0.5}$				38.5401614
$L_{sh}>=L_{am}$ assumption				39
L_{sv}				17
$q_{sv}*L_{sv}^2+[(q_{dv}*L_{sv}^2)^2+(q_{dh}*L_{sh}^2)^2]^{0.5}$				2146670
$(k*S_h-P*d/(4*t_n))*8*z/(0.75*i))$=part1/part2				2178182
Ratio				0.99