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# PIPING DESIGN FOR GEOTHERMAL PROJECTS

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## ABSTRACT

The best piping configuration is the least expensive over a long term basis. This requires the consideration of installation cost, pressure loss effect on production, stress level concern, fatigue failure, support and anchor effects, stability, easy maintenance, parallel expansion capacity and others. The expansion loops most commonly used in cross-country pipelines are L bends, Z bends, conventional 90° elbows and V bends.

The principal design codes used for piping design are the ANSI/ASME B31.1 (Code for Power Piping) and ANSI/ASME B31.3 (Code for Process Piping), ASTM A53 B, ASTM A106 B and API 5L carbon steel pipes are the ones used for geothermal fields. The allowable stress is $S_E$=88 MPa for ERW pipes and $S_E$=103 MPa for seamless pipes, $S_A$=155 MPa for operation loads, $kS_h$=124 MPa for earthquake loads and 258 MPa for combined sustained loads and stress range.

Pipe pressure design for the separation station and steam lines is 1.5 MPa, and for brine line ranges from 1.5 to 4 MPa. Pipe diameters are generally 250 to 1219 mm for nominal pipe sizes. The two-phase line can be in the range of 50 to 150 meters, the steam lines from 2000 to 3000 meters and for the brine up to 6000 meters long.

The total cost of pipe installation can be US$ 600 to US$ 1,200 per meter of pipe. Pipe configuration needs to be cost conscious; if the design can use under 10% of excess pipe to get from point to point in a straight line distance, then it is excellent from a piping material and pressure loss point of view.

## 1. INTRODUCTION

The basic concept of a geothermal piping design is to safely and economically transport steam, brine, or two-phase flow to the destination with acceptable pressure loss (Jung, 1997). The piping associated with geothermal power plants can be divided into the piping inside the power plant and the piping in the steam field.

Piping in the steam field consists of pipelines connecting the production wells to the separation station and those that run cross-country from the separation station to the power plant, and lastly to re-injection wells. The cross-country pipelines run on top of ridges, up and down steep hill slopes, cross roads, and across areas threatened by earthquakes, wind, rain and landslides. The geothermal piping system has to be flexible enough to allow thermal expansion but also stiff enough to withstand the seismic and operational load actions.

The steam field model used is a wet field as the piping encountered in this model covers most, if not all the possible types of fluids and piping that could be expected in any geothermal system.

The wet steam field system consists of:

1. Two-phase flow piping which collects the fluid from several wellheads and sends them to the separator;
2. The separator vessel;
3. The steam pipelines which take the steam from the separator to the power plant;
4. The brine pipelines which take the separated brine from the vessel to a wellpad where the fluid is reinjected into several wells; and
5. Miscellaneous cross-country piping includes the instrumental air lines, the water-supply line and also the condensate line.

Two aspects of the design process of geothermal piping systems that must be considered are the process of preparing the design and the deliverables.

The scope of this paper will be in the piping for the steam field and the process of preparing the design divided into the following main categories: design criteria, production process flow diagram, define control philosophy, separator location, route selection, dimension design, pressure design, load design, design codes and pipe stress analysis.

## 2. DESIGN CRITERIA AND DELIVERABLES

The design process consists of the establishment of the design criteria for the piping system. For a proper piping design, it is essential that the client and the contractor agree on a design basis, process, and mechanical, civil and electrical control and instrumentation.

Table 1 presents a design criteria guideline for an existing or a new piping system. The electrical control and instrumentation criteria have been considered in this paper as part of the power plant design. Appendix 1 presents the control and instrumentation philosophy for a separation station in the Berlín geothermal field.

Before proceeding with the design of the pipelines, some restrictions or assumptions about the characteristics of the production wells, reinjection wells, and power plant location need to be considered. The output characteristics, mass flow rates, well head pressure, temperature and chemistry of the wells enable the selection of optimum production values, which will be considered for the entire life of the project.

The transportation of the steam from the separation station to the power plant will take place with some heat loss, condensation and tapping due to pressure losses and the imperfect thermal insulation. To determine the size and diameter of pipe and the insulation thickness, the general working equation for an open and steady system is, (DiPippo, 2008):

$$\dot{Q} - \dot{W}_s = -\sum_{i=1}^{n} \dot{m}_i (h_i + 0.5V_i^2 + gz_i) \qquad (1)$$

where $\dot{Q}$ = Rate of heat transfer between the system and the surroundings (+ into the system);

$\dot{W}_s$ = Rate of work transfer (power) between the system and the surroundings (+ out of the system);

$i$ = Index that runs over all inlets and outlets of the system;
$n$ = Total number of inlets and outlets;
$\dot{m}_i$ = Mass flow rate crossing each inlet or outlet;
$h_i$ = Specific enthalpy of the fluid at each inlet or outlet;
$V_i$ = Velocity of the fluid at each inlet or outlet;
$z_i$ = Elevation of each inlet or outlet; and
$g$ = Local gravitational acceleration.

And the conservation of mass requires that:

$$\sum_{i=1}^{n} \dot{m}_i = 0 \tag{2}$$

TABLE 1: Design criteria

| **General** | **Process** | **Mechanical** | **Civil/Structural** |
|---|---|---|---|
| Design life | Steamfield layout | Design Parameters – Process conditions – design Loads | Design codes and procedures |
| Meteorological & other local data | Economic analysis | Design codes and procedures | Project layout |
| Environmental requirements | Piping criteria<br>*pressure drop*<br>*line sizing*<br>*pipe routing*<br>*design pressure* | Piping systems design | Access |
| Operating and maintenance criteria | Draining & venting philosophy | Pipes | General Civil construction |
| Cost minimisation | Silica deposition | Valves | Thermal Ponds |
| Avoiding uphill two-phase flow | Insulation | Fittings | Retaining walls |
| | Control valve types | Vessels | Foundation design |
| | Pressure relief devices | Mechanical Equipment | Structural design loads |
| | Pumps | Other components | Pipe supports & anchors |
| | System isolation philosophy | Constructability and maintainability | Structures |
| | Instrument air - source & materials | | Concrete design |
| | Sampling & testing requirements | | Steel design |

For a given power capacity, the size of the steam pipe can be determined by calculating the pressure drop, heat loss and the electric power output, given by the equations in Table 2.

TABLE 2: Equations for calculating the pressure drop, heat loss and the electric power output of steam pipes

| Item | Description | Equation |
|---|---|---|
| 1 | Bernoulli Equation | $\frac{P_1}{\gamma}+\frac{V_1^2}{2g}+z_1=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+z_2+h_L$ (3) |
| 2 | Friction Losses in pipe and fittings | $h_L = h_{LPipe}+h_{LFittings}$ (4) |
| 3 | Darcy-Weisbach Equation (pipe friction) | $h_{LPipe}=\frac{\lambda L V^2}{D 2g}$ (5)<br>$h_{LFittings}=\frac{\sum K_{Fittings} V^2}{2g}$ (6) |
| 4 | Electric output | $MW=\overset{*}{m}(h_1-h_2)\eta_t\eta_g$ (7) |

where
$P$ = Pressure;
$V$ = Velocity of fluid;
$\gamma$ = Specific weight (ρg);
$\rho$ = Density;
$g$ = Gravity;
$z$ = Height;
$\lambda$ = Pipe friction coefficient;
$L$ = Length of pipe;
$D$ = Inner diameter of pipe;
$K$ = Resistance coefficient for fittings;
$h_L$ = Pressure drop;
$h_1$ = Enthalpy at inlet turbine conditions;
$h_2$ = Enthalpy at outlet turbine conditions; and
$\eta_{t,g}$ = Turbine and generator efficiency.

The deliverables that make up and document the design will consist of the conceptual design drawings, specifications, bill of materials, pad general arrangements, reports, piping layout, cross country drawings, etc.. For the process design, the deliverables consist of the Process Flow Diagram (PFD), Process & Instrumentation Diagram (P&ID) and the Line, Valve, Instrument and Equipment list. For the mechanical, civil and electrical design, the deliverables are Drawings, Specifications, Data sheets, Calculations, Reports and Bill of Quantities.

## 3. PIPING DESIGN

### 3.1 Design procedure

The problem of design procedure is to find a pipeline configuration and size within the constraints, which is both safe and economical.

The steps in pipeline design are as follows, (Geothermal Institute University of Auckland):

I. Determining the problem, which includes:
   a. The characteristics of the fluid to be carried, including the flow rate and the allowable headloss;
   b. The location of the pipelines: its source and destination, and the terrain over which it will pass, the location of separator station and the power plant;
   c. The design code to be followed; and
   d. The material to be used.

II. The determination of a preliminary pipe route, the line length and static head difference.

III. Pipe diameter based on allowable headloss.

IV. Structural analysis.
   a. Pipe wall thickness; and
   b. Stress analysis.

V. The stress analysis is performed in pipe configuration until compliance with the code is achieved.

VI. Support and anchor design based on reaction found in the structural analysis.

VII. Preparation of drawings, specifications and the design report.

**3.2 Fluid characteristics**

Important factors to be considered are the mass flow rate, pressure, temperature, saturation index and the allowable headloss over the pipeline length.

*Two phase piping*
The steam and water flow patterns in the pipe vary from annular, slug to open channel flow; depending on the velocity and wetness of the steam. Slug flow generates high dynamic load and vibration that can damage the piping system. The preferred flow regime in the pipes is usually the annular flow.

Pipes need to be sized correctly and run flat or on a downhill slope to achieve annular flow. The Baker or Mandhane maps combined with a simple understanding of the value of superficial velocity can be used in predicting the flow pattern inside a pipe. Uphill sloping pipes are not desirable as this encourages slugging in the pipe.

The pressure loss in a two-phase line is usually high and not easy to predict. Correlations for two-phase flow regimes and pressure drops in pipes and fittings are derived from Harrison, Mukherjee and Brill, Freeston, ESDU data Item 89012.

The piping for two-phase fluids has to be designed for high pressure, dynamic load, possible slug flows, erosion, corrosion, minimum pressure loss (by running the pipe as short as possible), the desired flow regime (by selecting the correct fluid velocity and slope for the pipes), and vibration prevention.

*Brine piping*
The brine leaving the separator is at saturated conditions. If the pressure at any point in the line is less than the saturation pressure, brine will flash into steam. This will cause slug flow which can result to dynamic forces that can damage the pipes. Brine lines are designed to gain static head pressure. Reinjection wells should be located lower than the separator.

Brine pipes have the highest hydrostatic head pressure at the lowest elevation due to the water column. Some brines pipes that have been designed have an elevation shift of 400 to 500 meters.

The pressure at the lowest point is usually high, where in this case, the pipe has to be divided into several pressure class ratings.

Brine flow is a combination of open channel and full flows, depending on the geometry of the line. On a sloping line, the flow commonly starts as an open channel flow and develops to a full flow.

The minimum slope of the line required for an open channel flow is predicted by Chezy's or Manning's equations. Full flow velocity is in the order of 2 to 3 m/s and the pressure drop can be predicted by the Darcy Weisbach equation with the friction factor calculated from Colebrooke's equation.

Rock fragments carried by the fluid from the production well are removed from the steam by the separator. They eventually travel down the brine pipe to the reinjection well. Like in the two-phase flow, this will cause erosion of the pipes and can clog the wells.

When designing brine pipes, the following factors need to be considered: erosion, corrosion, scaling due to silica saturation, residence time of the brine, pressure to be maintained above saturation pressure (to prevent flashing and slugging), high hydrostatic pressure, dynamic load from potential slug flow and water hammer, open channel flow, pressure, temperature and provisions for drainage.

*Steam piping*
For a given mass flow rate, the high specific volume of steam makes the pipe diameter bigger. Steam from the separators contains non-condensable gases, chlorides and other chemical species that can cause corrosion along the pipes, turbines, and related equipment of the power plant. These chemical species can be dissolved in the condensate, which then are collected in drain pots and discharged by means of steam traps.

The steam velocity is typically 40 m/s. The pressure drop can be predicted using Darcy-Weisbach's equation and Colebrooke's friction factor.

Steam pipe sizing is based on velocity, pressure drop and capital cost. Low fluid velocity is usually correlated to a low pressure drop, however, this results in large diameter pipes which are generally expensive. High fluid velocity usually translates to small diameter pipes, which reduces capital cost but results in unacceptable high pressure losses. Within the limit of the acceptable velocity range for a given service, a compromise needs to be made between pressure drop and capital cost. This is often termed as "sizing the pipe by economic pressure drop".

Factors needed to be considered for a steam pipe design are scrubbing the steam, steam velocity, corrosion allowances, pressure drop, pressure and temperature.

### 3.3 Separator location

The separator location is controlled by site topography, process and control system requirements and the pipes.

One option is to locate the separator close to the production well, which can reduce the overall line pressure drop from the well to the turbine. The separator pressure will be similar to the wellhead pressure, which means a lower flash ratio, therefore we will obtain less steam and more brine to dispose.

The other option is to locate the separator close to the turbine. The advantage is a lower separator pressure, which produces a higher flash ratio, to obtain more steam and less brine to dispose. A long two-phase line usually has a high pressure drop from the well to the turbine.

When the resource pressure is relatively low (where every Kpa represents additional flow and generation), two-phase pipelines produce 3 to 5 times higher pressure loss than a single-phase steam line, and may not be the best method.

For a high pressure and high flow rate well resource, the reservoir engineers must provide estimates on the well deliverability and the projected decline rate. Initially, two-phase flow pipelines can be a viable option, however, in the future, conversion to a steam and birne pipeline may be required.

It is preferred to have the separator located as close as possible to the production well pads to minimize process risk due to unpredictable two-phase flow. Figures 1 and 2 show the separation station location in the Berlín geothermal field.

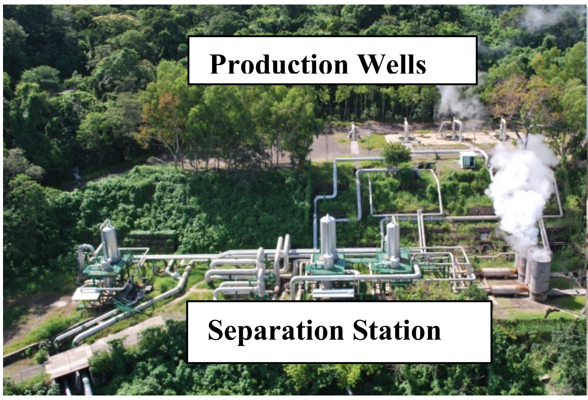


FIGURE 1: TR-5 Well Pad

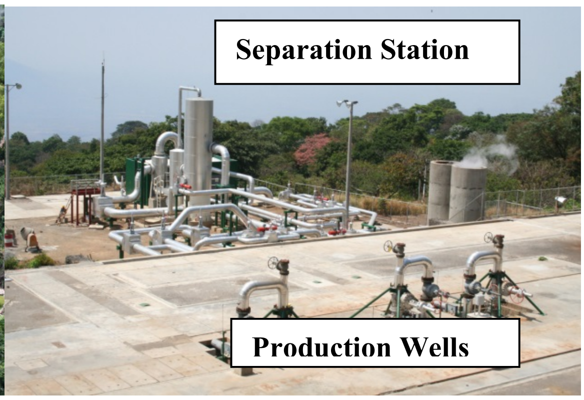


FIGURE 2: TR-17 Well Pad

### 3.4 Pipe types and application

Seamless Pipe (SMLS)
These pipes are extruded and have no longitudinal seam. There is no weld and they are the strongest of the three types of pipes mentioned.

Submerged Arc Welded Pipe (SAW)
These pipes are manufactured from plates, normally rolled and seam welded together. The welding has a joint efficiency of 0.95.

Electric Resistance Welded Pipe (ERW)
These pipes are manufactured from plates, where the seam weld is done by electric resistance welding. The welding efficiency is 0.8.

### 3.5 Design codes

The principal design codes used for piping design are the ANSI/ASME B31.1 (Code for Power Piping) and ANSI/ASME B31.3 (Code for Process Piping).

Complementing these codes are the ASME VIII (Code for Pressure Vessel) and British Standard BS5500 for an unfired fusion welded pressure vessel.

The basic consideration of the B31.1 Code is safety. It includes (ASME, 2007):

a. Material and component standards;
b. Designation of dimensional standards for elements of the piping system;
c. Requirements for design of components – including supports;
d. Requirements for evaluation and limitation of stresses, reactions and movements associated with pressure, temperatures and external forces;

e. Requirements for fabrication, assembly and erection; and
f. Requirements for testing and inspection before and after assembly.

*Pipes*
For pipes, the materials used in geothermal application are normally A53-B, A106-B and API 5L-B pipes, with mill tolerance. Commercial available pipes normally have a mill tolerance of 12.5% and pipe schedule numbers based on B36.10.

*Fittings*
For elbows, tees, and reducers, the material used in geothermal application is normally A234 WPB. All dimensions are in accordance with B16.9.

*Flanges and valves rating*
Flanges are rated to the ANSI B16.5 standard. For those up to 24" diameter, they are rated to ANSI 150, ANSI 300, ANSI 600 and ANSI 900.

For flanges 26" and bigger, ANSI B16.47 applies. The flanges are usually classified series A and series B. The material used for these flanges are A181 grade I and A105 grade I.

Valve rating is similar to the flange rating selected for the pipe.

### 3.6 Pipe routes

Aerial photographs and a contour plan of the area are sufficient information to identify a preliminary route for the pipes and suitable locations for the plant components. The preliminary route is then inspected on site to check land ownership, houses, swamps, soil condition for foundations, anchors and expansion loops, hot spots, slip risk, road crossings, watercourses, change in elevation, and access.

Using the preliminary pipe route, an estimate of equivalent line length can be made. The design flow and enthalpy are determined from the well data, and with this information, the optimum diameter for the pipes can be known. Figure 3 shows a contour plan of the Berlín geothermal field.

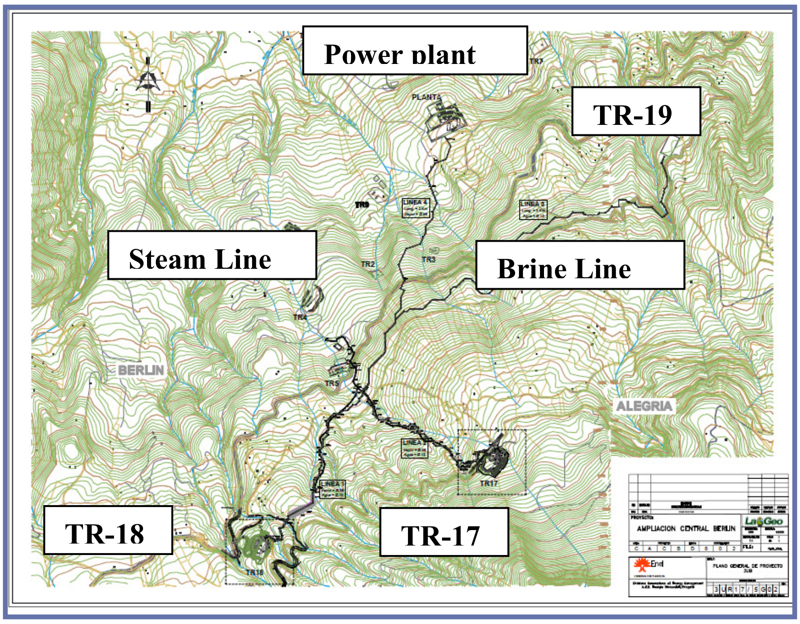

FIGURE 3: Contour plan of the Berlín geothermal field

### 3.7 Structural analysis

Circumferential stress or Hoop stress due to pressure and vacuum is considered for sizing and selecting the pipe with a suitable wall thickness.

Equations for pipe stress analysis are given in the design code. The first step is the determination of wall thickness required by B31.1.

$$Tm = \frac{PD_o}{2(SE + Py)} + A \tag{8}$$

where $Tm$ = Wall thickness in millimeters;
$P$ = Design pressure in kilopascals;
$D_o$ = Pipe outside diameter in millimeters;
$SE$ = Allowable stress in kilopascals;
$Y$ = 0.4, for most geothermal application is a factor based on temperature range and steel type; and
$A$ = 3 mm corrosion and erosion allowance.

Stress analysis should be carried out for the following load cases for compliance with the code requirement and support load calculation. B31.1 requires that a pipeline shall be analyzed between anchors for the effects of:

1. Sustained loads, Gravity + Pressure;
2. Operation loads, thermal expansion stress alone or thermal expansion stress + sustained loads;
3. Occasional loads, sustained loads + seismic load or wind load perpendicular to the general alignment of the pipe;
4. Occasional loads, sustained loads + seismic loads along the general direction of the pipe;
5. Reverse the direction of seismic or wind loads; and
6. Modes of thermal operation need to be considered in the analysis.

In addition to this, an analysis should be carried out for zero friction to determine the maximum load on the anchors in the event of an earthquake. Other dynamic loads that can be considered are fluid hammer effects, thrusts from safety valves, and slugging flow. Figure 4 shows the well pad piping analysis using the PipePlus software.

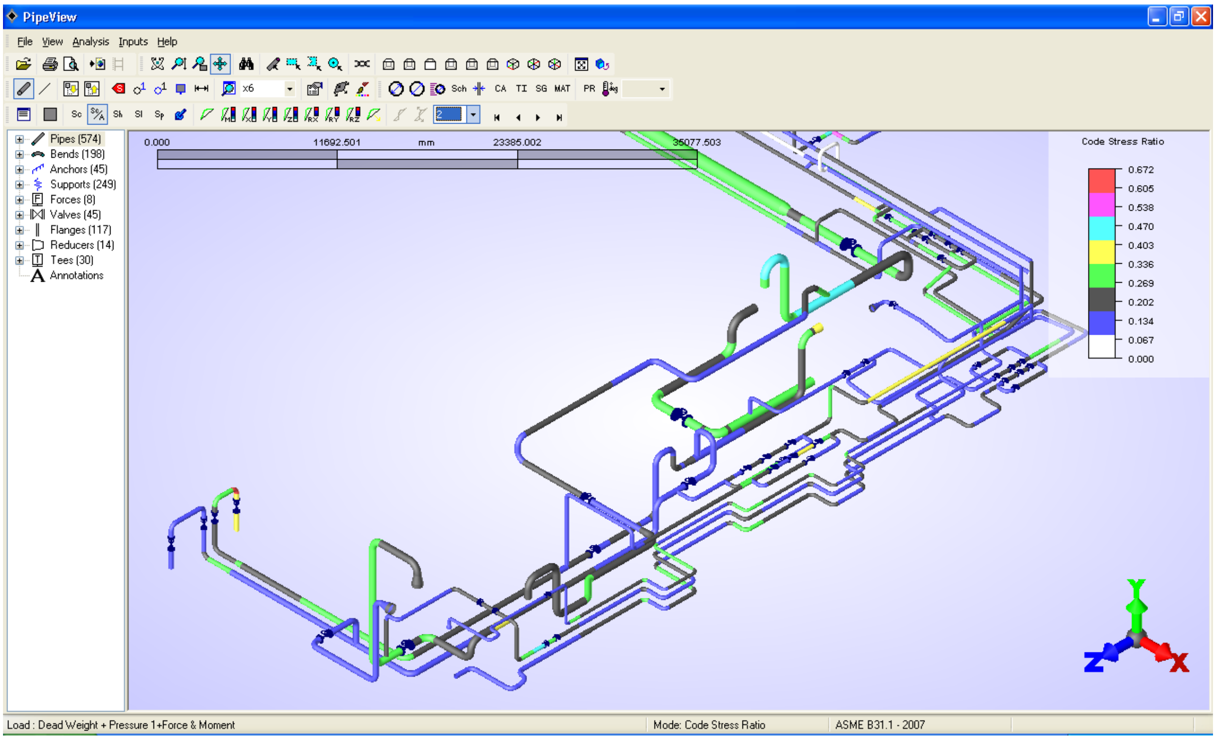


FIGURE 4: Pipe view in the Pipe plus software. Well pad design.

### 3.8 Expansion loops, pipe supports and anchors locations

Expansion loops are the most commonly used in cross-country pipelines to handle thermal expansion. On standard runs, L bends, Z bends, conventional 90 degree elbows and V bends are the most used pipe configurations for the design. Z bends can be very stable on downhill runs. Horizontal loops are very effective in congested areas. Custom designs based on following the natural configuration of the terrain can be very effective in cross-country designs.

Anchors shall be strategically located to reduce the magnitude of the resultant load. This reduces the size of the foundation. Typically, a cross-country pipe run without compensators will require an anchor every 150 to 200 meters.

The types of supports used are the Y stop, Guide, Line Stop, Constant Weight Support, and Shock absorbers. Reducing the number of pipe supports by spacing them as far apart as the maximum pipe span is allowed. There should be a pipe support located near every bend, as it reduces eccentric loading on the pipe and minimizes vertical vibration at bends, especially in two-phase lines.

Pipes are run close to the ground to reduce the overturning moment effect on the pipe support and anchors, which then reduce the foundation size and hence the cost. Figures 5 to 7 show expansion loops commonly used in Berlín and Figure 8 the types of support for the pipe lines.

FIGURE 5: V bend expansion loop

FIGURE 6: Omega bend expansion loop

FIGURE 7: Z bend connecting to the vessel

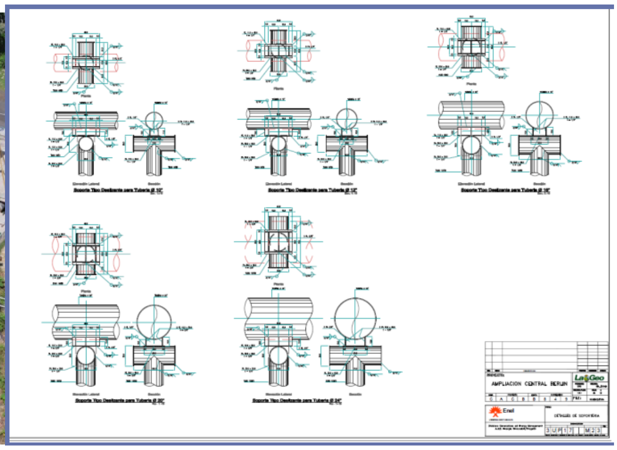

FIGURE 8: Support types

## 4. OTHER ASPECTS OF THE PIPING DESIGN

*Software*
In order to simplify the process for calculations and stress analysis, computer programs are available. Some are listed here: AutoCAD, PlantFow, EES, Autopipe, Caesar II, PipePlus, Finite Element Analysis-FEA.

*Nozzles connection–Pressure vessel, Pumps, Turbines, etc.*
Nozzle connection is beyond the scope of this paper. Generally, the piping designer works with the load limitation given by the manufacturer or a finite element specialist. As a general rule of thumb, loading on the nozzle should be less than 40 Mega Pascals. All care must be employed to protect the nozzle connect on vessel, equipment, well-heads and attachments.

*Pipe buckling*
Large diameter thin wall steam pipes supported by an anchor in a long steep slope is subjected to a high gravity load near the anchor. This could cause the pipe to fail by local buckling. The load required to cause this can be calculated using Euler's equation or by FEA.

*Cost of the pipe system*
The piping installation cost is made up of materials 30%, fittings 10%, installation labour 25%, installation equipment 10%, support 15% and P&G 10%. The total cost can vary from US$600 to US$1200 per meter, depending on pipe diameter, slope of the terrain, cross-country or well pad piping.

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## APPENDIX 1: Control system for steam separation station

## 1. PRODUCTION WELLPAD PROCESS DESCRIPTION

A geothermal production wellpad consists of the following main equipments: Steam separator, water tank, ball valve, instrumentation system, control system and electrical system.

The steam separator receives the two-phase fluids from the geothermal wells and separates the steam and the water. The steam is sent directly to the power plant for the generation process. The separated water is sent to the water tank and then to the reinjection wells.

The ball valve is located in the steam line after the steam separator and protects the steam line against the presence of humidity. In case of the operation of the ball valve, there is a motorized valve that isolates the steam line and permits the draining of the ball valve to normalize the operation of the steam line. Figure 1 shows the P&ID for a typical geothermal production pad in El Salvador.

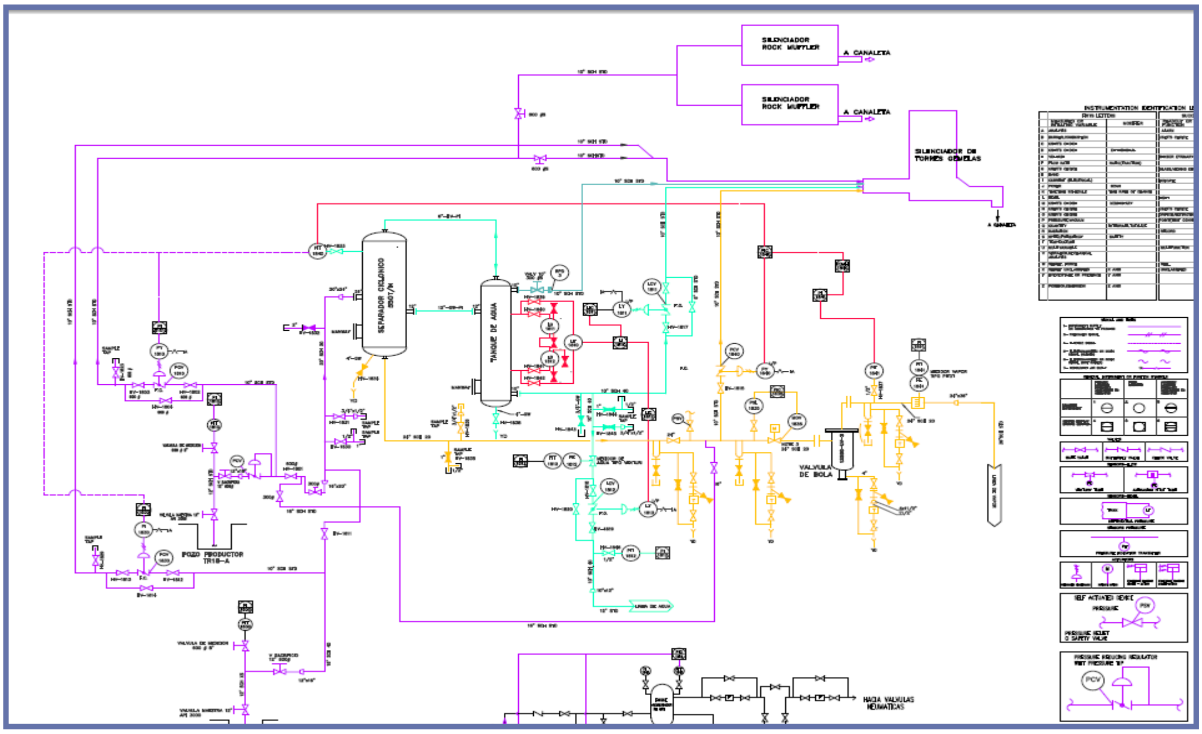


FIGURE 1: P&ID for a production pad

The instrumentation system is in charge of the measurement and control of the most important mechanical variables of the process. The measurement equipment includes different kinds of transmitters like pressure transmitter, level transmitter and flow transmitter that send their measurement to the control system as an electrical variable.

The control system processes the electrical signal and sends commands to the final control element that modifies the process conditions. The final control elements include control valves that are operated by electrical and pneumatic actuators.

The electrical system feeds all the electrical equipment required in the production wellpad like control system, instrumentation system, electrical actuators, compressors, lighting systems and auxiliary outlets for maintenance works, which is normally provided from the power plant. Because of the long distance between the power plant and the production wellpads, a medium voltage line (13.2 kV) is installed from the power plant to the production wellpad to minimize the electrical losses in the cable because of the distance. A substation is located in the wellpad that converts the voltage from 13.2 kV to 0.48 kV.

The control system is a Programmable Logic Controller, PLC, with different kinds of input and output cards like analog input (AI), analog output (AO), digital input (DI) or digital output (DO) that receive the electrical signals from the instrumentation system. The PLC has power source, CPU communication cards and communication network redundancy to ensure the safety and availability of the process. The wellpad control system is in communication with the main control system in the power plant and allows a remote monitoring of the process. For this separation station remote control is not allowed to ensure that the control system will not fail in case of communication lost. Figure 2 shows a control system architecture used for production pad.

The most important control loops in a geothermal production wellpad are the ones for the pressure in the steam separator and the level in the water tank. The pressure loop avoids pressure increases that can create disturbances in the steam supply and affect the power generation process. The level loop avoids the water to go into the steam line and trips the ball valve, or the steam to go into the water line and reduce the electrical generation.

The pressure loop is described as follows: if the pressure in the steam separator increases, the control system operates a pneumatic valve that sends the steam to the silencers and relieve the pressure on it. The type of valve used for this application is a butterfly valve with a spring opposed single acting cylinder actuator, because a high speed operation is required.

The level control is described as follows: there are two pneumatic valves in the water line, the main one is connected to the reinjection line and the other one to the silencer line.

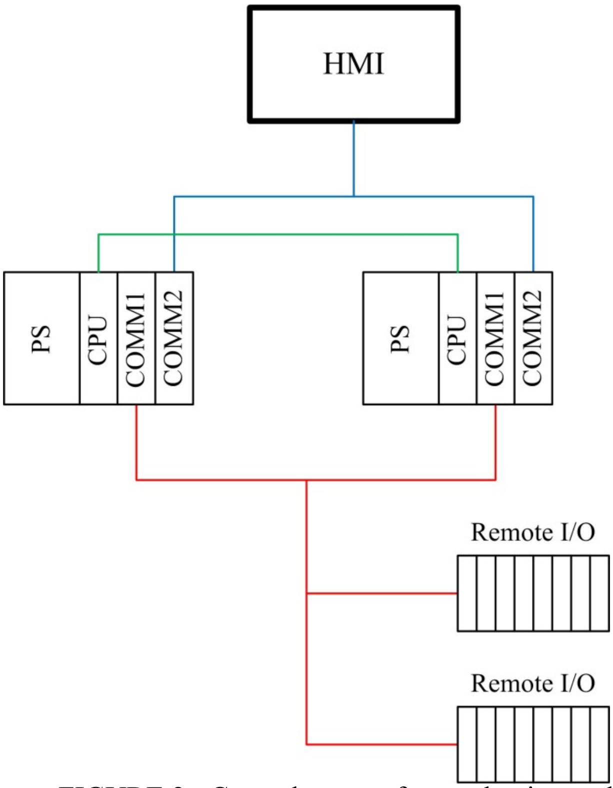

FIGURE 2: Control system for production pad

The reinjection valve is operated to control the level in the water tank under normal operation conditions. The silencer valve starts to work in case of an abnormal condition in the system where the high level in the water tank can't be controlled by the reinjection valve. Each control valve has a different level set point where the reinjection valve set point is lower than the silencer valve set point. If there is a level increase in the water tank, both valves open, according to their own set point, reducing the water level and if the level decreases, both valves start to close.

## 2. INSTRUMENTATION AND CONTROL SYSTEM SELECTION

### 2.1 Transmitter's main characteristic

For the pressure transmitter selection, the most important characteristics to be considered are the temperature rating, precision, NEMA classification, hart protocol available, electrical transient protection and LCD display.

The temperature rating for the transmitters is based on the geothermal fluid temperature, (190 °C in Berlin). In case the transmitter rating is not available for this temperature, an alternative installation method permits the transmitter to be used under this temperature condition.

The precision of the transmitter will depend on the application of any particular case. High precision is required for critical application like flow or pressure measurement at the turbine input or level in the condensers. A typical precision for geothermal application is 0.1% of the calibrated span.

NEMA classification refers to the grade of protection for outdoor use. Adequate protection for dust and water is necessary. Typical protection for geothermal application is NEMA 4X or IP66. Because of the presence of $H_2S$ in the atmosphere, all the equipment should be corrosion resistant. All the instrument parts that are in contact with geothermal fluid should be made of stainless steel.

Hart protocol permits the easy configuration of the transmitter. There are special tools to access to the transmitter and configure them, like portable hart communication tools or software. Hart protocol is used too to create special network that permits the communication of more than one transmitter to a Scada system for multiple transmitter configuration or monitoring.

Electrical transient protection protects the transmitter against electrical variation in the system, produced by external faults or atmospheric discharges. This protection can be integrated in the transmitter or be installed externally. LCD display permits the local monitoring of the different variables. Typical instrumentation brands used in geothermal power plants are listed in Table 1.

TABLE 1: Instrumentation and control valves common brands

| Description | Brand |
|---|---|
| Transmitters | Rosemount, Honeywell, Foxboro, Yokogawa |
| Control valves | Fisher, Vanessa, Masoneilan, Limitorque |

### 2.2 Pressure transmitter description

The pressure transmitter has two main elements: sensor and transmitter. The most common sensor used is a piezoelectric sensor that changes its vibration frequency with pressure changes. The transmitter takes the sensor signal and converts it into an industrial standard, typically a 4-20 mA that is proportional to the measurement range in the equipment.

### 2.3 Level transmitter description

The most common method used in the application in Berlin for level measurement is the differential pressure between the high and low sections of the containers. Differential pressure is proportional to the water level. The differential transmitter used for level measurement has the same principle as that of the pressure transmitter described below, but has two sensors where the transmitter receives both signals and gives the difference between them.

### 2.4 Flow transmitter description

The flow transmitter has three main elements: flow element, sensor and transmitter. The most common method used for flow measurement is the pressure drop caused by a flow element that is proportional to the flow in the pipe using the averaging Pitot tube for steam flow measurement and the Venturi tube for water measurement. The transmitter used for flow measurement is a differential pressure transmitter that has the same principle that the pressure transmitter described below.

### 2.5 Control valves main characteristic

For geothermal production wells, there are two types of control valves: pneumatic valves and electric valves. Pneumatic valves are used for steam pressure control and water reinjection control. Electrical valves are used in steam and two phase line to isolate the process in case of emergency or maintenance activities.

Pneumatic valves normally work as regulation valves operated by compressed air and have three main components( Fisher, 2010):

a) Mechanical valve - the part that is in contact with the fluid process, usually of three kinds: the Butterfly valve, ball valve and gate valve.

b) Actuator - a powered device that supplies force and motion to open or close a valve, usually of two types: cylinder spring-opposed single acting and diaphragm spring opposed.
c) Positioner - a controller that is mechanically connected to its actuator and automatically adjusts its output to the actuator to maintain a desired position in proportion to the input signal. It is electro-pneumatic type and receives an electrical signal (4-20 mA), which then converts it to a pneumatic signal (3-15 psi)

Electrical valves are normally gate valves type with an electrical actuator that supplies motion to the valve by an electrical motor and a gear box. The electrical actuator has an integral electronic control and protection functions. This valve are normally used as on/off valves.

Steam pressure control valve controls the separation pressure and in case of an overpressure, it opens to relieve the pressure through the silencer in the wellpad. This valve is normally butterfly type valve with eccentric disk to avoid shaft stuck because of silica deposition. The actuator used in these valves is a spring-opposed single acting as piston that provides high torque, characteristic for valve operation.

Water reinjection valves control the level in the water tank to avoid water to go into the steam line, or the steam going into the water line. These valves are normally segmented ball valves with a V-shape, which permit good seal characteristics and help against silica deposition in the valve body and entrained solids in the water.