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IDDP-2 Well Head Equipment and Test Setup

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ABSTRACT

The IDDP-2 drilling project at Reykjanes, Iceland is a continuation of the ongoing Iceland Deep Drilling Project (IDDP). It was launched in the year 2000 and the IDDP-1 well was drilled during 2008-2009 in Krafla, North Iceland. A 5 km deep well, IDDP-2, is proposed near the Reykjanes Power Plant in South-West Iceland.

Expected enthalpy of superheated steam from the well is 2800 to 3100 kJ/kg, resulting in shut-off pressure of up to 250 bar and temperature of up to 480°C at the well head. The well head branch, mounted on the well head, consists of redundant valves, pipes and fittings designed to withstand these conditions with low risk of failure of critical components. The inside of these valves and fittings are coated with corrosion and erosion resistant stainless steel alloys. The branch is connected to two full flow lines and two test flow lines, the former being used for maximum well discharge, the latter for further studies of thermodynamics, fluid flow and chemistry of the well fluid.

The full flow and test lines consist of a series of throttling orifices that reduce the high well pressure from over 200 bar down to atmospheric pressure. The steam, flowing at expected 10-35 kg/s is discharged through rock filled mufflers for silencing. Piping is designed to keep steam flow velocity within 50 m/s. The individual full flow and test lines are not designed as critical components and can be independently shut off from the redundant well head branch and repaired or replaced as needed.

1. INTRODUCTION

Three design groups are assigned to the IDDP-2 well project in Reykjanes, which will be drilled to an expected depth of around 5 kilometers. Group 1 handles drilling and well design, Group 2 well head equipment and test flow lines and Group 3 chemical aspects where three scenarios of expected fluid chemistry are considered. This article outlines the preliminary design from Group 2.

Steam at 300 bar and up to 450-500°C temperature is expected to be found at the target depth. These conditions are expected to create wellhead conditions that lie at the outer limits of standard pressure and temperature ratings of standard construction metals for pipes, fittings and valves. The selection of suitable equipment and design of a redundant system is therefore very important, in order to ensure that steam flow from the well can be maintained and damage to the well thus prevented, as happened in the IDDP-1 well in Krafla.

Lessons learned from the IDDP-1 well in Krafla (Markússon, 2013) are used as guidelines for this project. Among these lessons pertaining to this study are to operate the wellhead at a certain minimum pressure to avoid erosion from high flow velocities, to never shut off the wellhead and to minimize the number of piping components, as anything that can break down or break off will probably do so eventually. Other results from lessons learned are installing two master valves and two flow valves and to monitor all critical parameters in the flow lines.

The well head branch, containing corrosion/erosion resistant shut-off valves, pipes and fittings, is the most critical above-ground component. The test flow lines connected to these branches are designed to be shut off independently and repaired or replaced as necessary.

2. GEOTHERMAL FIELD AND WELL DESIGN

The maximum steam pressure and temperature in the geothermal field and the main aspects of the well design are described. Design temperature is based on information from production wells at Reykjanes Power Plant, obtained from HS Orka.

2.1 Thermodynamic Conditions

The well bottom pressure and temperature are assumed to be up to 300 bar and 450-500°C. This information is based on a diagram from HS Orka, showing extrapolated temperature and pressure from production well REYH-12 in Reykjanes, which is near the proposed IDDP-2 well (pers. com.). The temperature is especially important, as it dictates the enthalpy of the steam, which must be at least 2800 kJ/kg to be considered superheated. Well enthalpy ranges from 2821 to 3085 kJ/kg at 450 to 500 °C, respectively, at well bottom pressure of 300 bar.

The upper limit of temperature results in very high wellhead pressure and temperature. These conditions (250 bar and 480°C) match the highest temperature and pressure conditions that the ANSI Class 2500 will allow (ASME, 2004). Higher enthalpy than 3100 kJ/kg is not considered for this project.

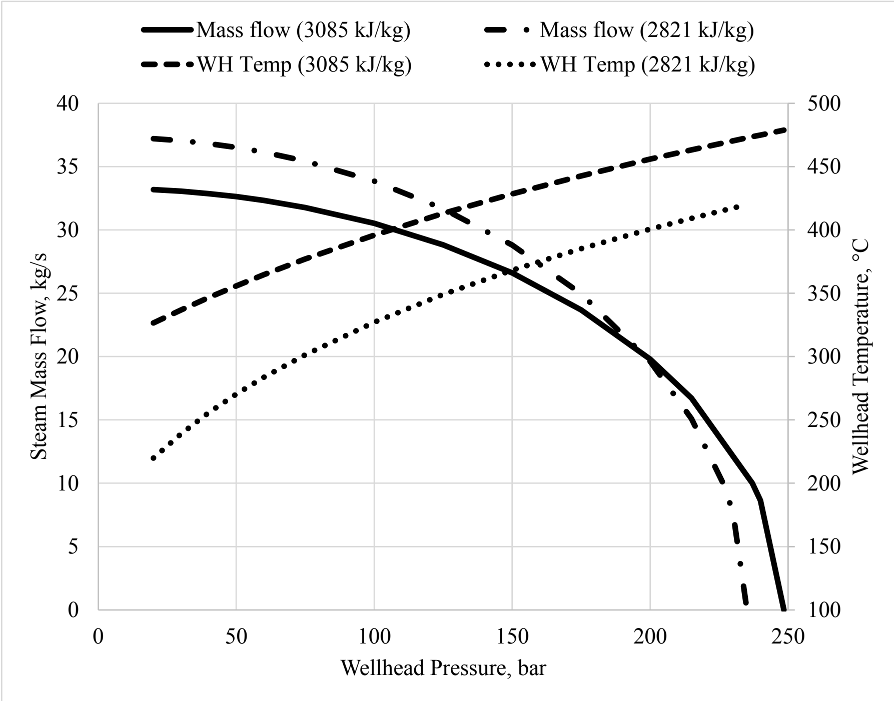

Figure 1: Well characteristic curve and wellhead temperature at maximum and minimum enthalpy.

The calculated well characteristic curve (steam mass flow) and wellhead temperature as a function of wellhead pressure is shown in Figure 1, for the maximum and minimum enthalpy considered for this project. Lower enthalpy results in higher mass flow and lower wellhead temperature.

The characteristic curve is calculated from assumed steam pressure and temperature at the bottom of the production well. Perforated liner and production casing diameters are used to calculate the pressure drop and expansion of steam from the bottom of the well to the surface, taking into account static pressure form the relatively dense steam column in the 5 km deep well (Einarsson, 2013, Appendix 2).

2.1 Well Design

The well is designed by Design Group 1. The following aspects are relevant when considering the conditions at the well head and flow lines. The proposed well has production casing from the surface down to 3.0 km and perforated liner between 3.0 and 5.0 km. Production casing and perforated liner diameters are 9 5/8" (244.5 mm) and 7" (177.8 mm), respectively, with inner diameters of 216.9 and 159.4 mm, respectively. Casing material is K55 BTC steel (Ingason et al, 2015).

The 1.2 km long anchor casing has 13 5/8" (ø346.1x15.9 mm) T95 Hydril 563 tubing on the upper 300 meter section but 13 3/8" (ø339.7x13.1 mm) K55 Hydril 563 tubing on the lower 900 meter section. The upper part is selected for extreme pressure and temperature conditions near the wellhead.

The top of the well has a 22 ½" surface casing and a 12" ANSI Class 2500 flange on top, to which the wellhead equipment will be fastened. The production casing is expected to change in length inside the expansion spool. This variation may reach up to 400 mm (up by 300 mm and down by 100 mm) due to temperature variations, as was experienced at the IDDP-1 well at Krafla (Mannvit, 2013). This has to be taken into account when designing thermal stress compensation counterweights and expansion loops.

3. VALVES AND WELL HEAD EQUIPMENT

The following is a description of the valves and connection piping/fittings placed on the top of the wellhead, designed for high pressures, temperatures, corrosion and erosion. Piping design is based on ASME B16.5 and B31.1 design standards for power piping and flanges.

3.1 Well Head Layout

A simplified schematic diagram of the entire well head and flow lines is shown in Figure 2.

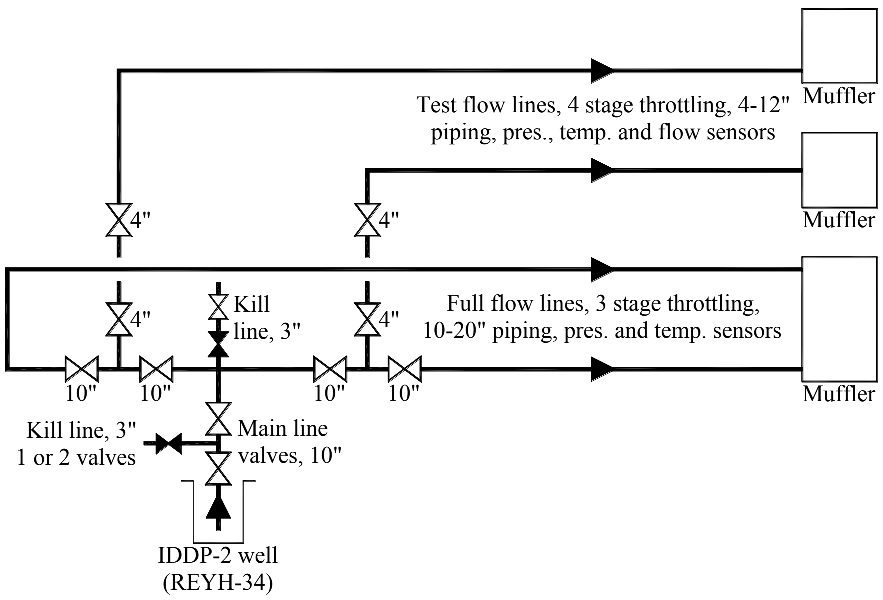

Figure 2: Well head and flow lines, simplified schematic diagram.

A layout drawing of the well head is shown in Figure 3, where the height and width of the well head branch are shown. The 4" test flow lines branch horizontally, perpendicular to the 10" full flow lines. More detailed schematic and layout drawings exist (Einarsson, 2013) but are not suitable for inclusion in this article.

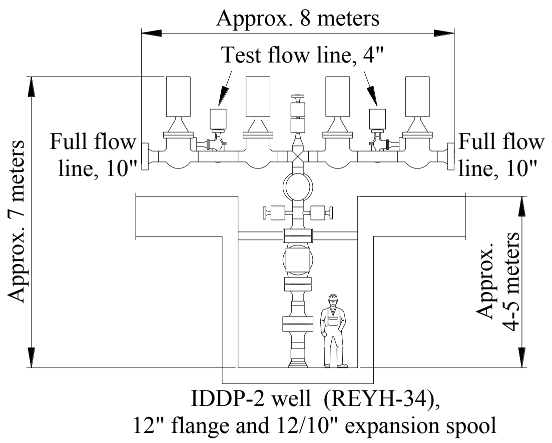

Figure 3: Well head layout, side view.

There are two valves placed directly on top of the well head. Both are 10" valves, the lower valve is flange connected, the upper valve is welded. The lower valve is placed on top of an expansion spool (12" to 10"), that is fastened directly on top of the 12" well head flange.

The lower main line valve on the well head is the most critical valve of the entire branch. If it fails and starts to leak steam, the only means to protect the well is to inject water through kill line connections.

There are two kill line connection set-ups: One kill line connection is at the top of the branch, consisting of two 3" valves in series. The other kill line connection is one or two 3" valves, mounted on separate branches between the main valves on the well head. 3" pressure sensor connection valves to each of the two test line connections may also be used as reserve kill lines, so there are, in effect, four points in the branch where a kill line water connection can be established. The upper main line valve serves as a reserve valve if the lower valve fails to shut off, without any significant leaks.

The upper valve is welded to the 2-way branch via a 4-way 10" tee. The two full flow lines have two 10" valves each. Counterweight hoisting points are located in between each valve pair on these two branches. The purpose of these counterweights is to eliminate torque on the branch and compressive vertical force on the two main line valves. The counterweights will be slightly oversized to maintain slight tension in the main line connection.

A 4" test line is connected between the two 10" valves on each full flow line. Each test line has two 4" valves in series and a 3" pressure connection valve.

All branch connections end in Class 2500 flanges. The full flow and test line flanges will be flange connected to steam throttling orifices (or any other pressure reduction nozzles) and the kill line/pressure sensor connections will be flange connected to pigtail piping/pressure sensors and high pressure water hoses/piping.

All piping and valve surfaces will be insulated with around 150 mm insulation. Thickness is to be finally decided during detailed design. This insulation is critical during operation. Uninsulated surfaces will experience severe thermal stresses if the temperature drop through 30-40 mm steel is up to 500 °C. This, combined with severe pressure loads, will most certainly cause the piping to fail.

Temperature sensors will be placed on each side branch from the 10" 4-way tee. These will be contact sensors, placed between the pipe surface and insulation.

The vertical main line pipe and two main line valves are installed in an approximately 4 m deep well. The well is rectangular, 5 x 3 meters on the inside. The well will be entered at the bottom through a stairwell, which surrounds the well shaft. The total base area of the well and stairwell is approximately 35-40 m². The walls in the concrete well will be very thick, as the vertical branch is supported with 4 horizontal steel supports, to eliminate vibration, earthquake loads, etc. The support will be fastened to the uppermost flange pair on the main line.

The branch, with all pipes, fittings and valve bodies will be roughly 8x3x2 meters in size when it has been welded together. This branch will have to be heat treated in one piece, once welded. Although the branch is rather bulky, it may be transported overseas to facilities with large enough heat treatment furnaces, which are not available in Iceland.

A step-by-step risk analysis of failure events, consequences, remedies and preventive measures for each valve in the well head has been carried out (Einarsson, 2013). If the lower main valve or the piping below the main valve should burst, the only way to kill the well is to pour gravel into the well and/or hoist a large concrete lid on top of the well (in the event that the wellhead branch is detached from the wellhead by a steam explosion). In any case, it will be difficult to connect kill line water to save the well but may not be impossible.

3.2 Valve Construction

Full bore gate valves will be used in all cases. Several valve manufacturers have been contacted in the last months and various mechanisms of the gate have been proposed. Ordinary gate valves cannot be used for the medium from the production well. The valves must be 100% metal-to-metal. Expanding gate valves have been considered, where force has to be applied both in the case of opening and closing the valve. Although slab gate valves require lower opening torque, they are not recommended because of delicate spring mechanisms that cannot withstand the aggressive medium.

The approach will be to select valves with as few moving parts as possible and rugged, robust design, to minimize the risk of erosion damage on fully opened valves. The valves must also be guarded against scaling deposits with one or more metallic seal rings. Installing a pressure relief conduit inside the valve may be a possibility, as long as there is no risk of debris/scaling blocking the conduit. These precautions prevent high pressure steam, debris and other impurities from entering the bonnet at the top of the valve, which must be kept free of impurities. All gate valves will also have a pressure sealed bonnet, to minimize the risk of leakage.

The valve spindle shall be designed to withstand forces several times that of normal valves. This means that the diameter of the spindle shall be larger than on standard valves and/or the steel used shall have higher yield strength. Hydraulic actuators will be mounted on each valve, maneuvering the gate back and forth through linear motion, not through a worm gear mechanism.

The implementation of a double spindle/double bonnet with two simultaneously operated hydraulic actuators has been considered. Such a construction would only work on a vertical pipe (where the two critical main line valves are mounted), not on valves installed horizontally above ground. Such a construction would probably double the chances of moving the gate against the extreme pressure forces and scaled valve surfaces. It would most likely require some sort of hydraulic control synchronization of actuators on each side, where one actuator is pulling and the other is pushing. This construction is not known to exist at this point so such a valve would have to be developed from scratch. This will most likely be a very costly and time-consuming process.

The valve body will in all but one cases be welded to the piping. The welded branch, including the valve bodies, will be heat treated after welding. The valve body must be designed so that the valve internal parts can be removed from the body. The valve body must be able to withstand heat treatment of the integral piping branch.

The valves are all Class 2500 valves and must be designed for severe variations in temperature. The connection piping will be designed to eliminate forces from thermal expansion and weights on the valves, so the main focus is on free thermal expansion of the valves themselves.

Hydraulic actuators are highly recommended instead of pneumatic actuators, as they produce more stable force, due to incompressibility of the oil. The product of 250 bar pressure and cross-section of 10" pipes may be as high as 800 kN, which is the expected force acting on the valve gate. Scaling and other mechanical issues furthermore result in high friction between the gate and the valve seat.

The required stem forces are thus very high, so adequate sizing and practical force-to-size ratio of the actuators is important. Assuming a friction factor of 3.0 (due to scaling and impurities), the opening force on 10" valves can be as high as 2400 kN. If hydraulic pressure is 100 barg, the membrane area will need to be around 550 mm. If opening speed is 1 mm/s, the hydraulic pumping capacity will be around 3.5 kW, assuming 70% hydraulic efficiency.

A common hydraulic reservoir and pumping station may have to be installed for all valve actuators, of which there are 14 (6 pcs. for 10" valves, 4 pcs. for 4" valves and 4 pcs. for 3" valves). Actuators must have a high IP class rating and resistance to high ambient temperatures, so that they may be used to operate critical reserve valves in case of piping or valves rupturing at the well head.

Two main line valves (10") and two pressure connection valves (3") will be installed with the spindle and gate lying horizontally, with hydraulic actuators fastened to the spindle.

3.3 Material Selection

All valves, pipes and fittings that make up the well head branch must fulfil the ASME B16.5 Class 2500 pressure/temperature rating. The steel used must be able to withstand temperatures of at least 480°C. The thickness of pipes, fittings and reinforcements is then selected to withstand 250 bar pressure at said temperature, as well as stresses from thermal expansion and other mechanical forces.

A213-T2 alloy steel for seamless pipes (ASME, 2004) is rated for temperatures up to 1000°F (537°C). At 480°C (900°F), the maximum allowable stress is 13.7 ksi (94 MPa). The modulus of elasticity (stiffness) is reduced from 207 GPa to approximately 183 GPa (Metal Ravne, 2013) at this temperature. Whatever steel will be selected, it must be rated for temperatures up to at least 480°C, notwithstanding the mechanical stresses from pressure and piping forces (thermal, weight, wind, earthquake, etc.).

A213 Grade T91 and A335 Grade P91 have around 20% higher maximum tensile strength at temperatures around 500°C (ASME, 2004) and are rated for temperatures up to 1200°F (650°C). Another grade, A213 Grade T22 has lower tensile strength but is very commonly used in high temperature piping systems. These steels will also be considered for this project, as they are widely used in extreme conditions at power plants (Bright Hub Engineering, 2011).

The final selection of steel will be based on price, availability and weldability of pipes and fittings, as well as weldability of corrosion/erosion resistant metals on the inside of these pipes and fittings.

Steel softening at high temperatures may aid in reducing thermal stresses. This will become clearer when the piping will be designed in detail.

The inside of the valves, pipes and fittings must be lined with corrosion and erosion resistant material. Several materials were tested in the IDDP-1 project and none has shown absolute resistance to neither corrosion nor erosion.

The lining is to be welded onto all inner surfaces of pipes and fittings in the branch. Using loose inner tubes is not recommended. Explosion welding of the lining into the inner tube may be a possibility. This is the same material used in the welding joints and thus the liner material will fuse with the welding material at pipe/fitting/valve joints, providing a continuous layer through the piping cross section. This layer of suitable thickness will result in lower corrosion allowance in the piping.

Using AISI 309 (1.4833) steel lining of suitable thickness in the well head branch has been considered. Since AISI 309 has not been fully proven to be corrosion/erosion resistant at this point, the use of Inconel 625 liner on the internal surfaces of valves, pipes and fittings may still be an option. This material is very expensive but may be more reliable for the critical well head equipment. Further results from chemical analysis from IDDP-1 (Group 3) will be used to decide on the inner surface liner, as well as the necessary thickness of the surface liner, which will reduce the overall corrosion allowance of the piping. It should also be pointed out that the chemical composition of the medium from the production well is not fully known.

The well head and test line pipe diameters have been designed so that steam flow velocities do not exceed 50 m/s at the design conditions (well enthalpy of 3085 kJ/kg), to reduce the risk of erosion. The flow velocity will be drastically reduced for enthalpy lower than 3085 kJ/kg, so risk of erosion damage will be further reduced for lower pressures and temperatures.

Material selection of valves, pipes and fittings in the well head branch is summarized below:

Valve body: Forged or cast carbon steel (WC6, WC9), Class 2500 rating

Valve stem: Solid Inconel 625

Valve seat and gate: Stainless or carbon steel

Seat pocket: AISI 309 or Inconel 625

Valve surface coating in contact with steam: AISI 309 or Inconel 625

Pipes and fittings: A213 Grade T2 alloy steel (A219-T91, A335-P91 or A213-T22 also possible)

Flanges: Class 2500 Group 1.9 materials (ASME B16.5)

Inner surface coating, pipes and fittings: AISI 309 or Inconel 625

3.4 Counterweights, Pulleys and Supports

The counterweights are used to eliminate compressional forces and momenta from the total weight of the four full flow line valves on the two branches, the weight of the two main line valves and the weight of the piping and fittings connecting these valves. These weights include the hydraulic actuators on valves, as well as insulation and cladding on valves, pipes and fittings.

The weight of each valve and actuator is at this stage estimated to be between 1-2 tons. Five of the six large valves are welded, which will significantly reduce the total weight compared to using only flanged valves. The total weight of the valves and actuators may be expected to be between 10-15 tons.

The weight of a 10” pipe with 35-40 mm thickness is approximately 200 kg/m. The Class 2500 flanges may be several hundred kilograms each. The total weight of piping (excluding valves) is thus no more than 1-2 tons.

The counterweights will be hung on a pulley, fastened to a support bracket. The bracket will be located on top of the branch well wall. By using levers or double pulleys, the counterweight mass may be reduced somewhat. The total weight of the counterweight equipment and branch should be around 20 tons, divided by each half of the branch. The hoisting points of the counterweight rope/chain will be between the valve pairs on the 10” full flow lines. Detailed pipe stress calculations may reveal that the counterweights need to be placed by the 4-way tee as well, resulting in up to 6 possible hoisting points on the branch.

The expected thermal expansion of the production casing is up to 400-500 mm, so the pulley, lever (or double pulley) and counterweight mechanism must allow for this vertical movement of the branch.

4. FLOW AND TEST LINE DESIGN

The process flow of the full flow (well blow-out) and test lines is described below, as well as the proposed layout. Key components – orifices, sensors, mufflers, etc. – are also described.

4.1 Process Description, Layout and Site

Two full flow lines and two test flow lines are proposed. Each of these two types of lines is designed for 100% operation of well blow-out (50 bar on well head, 32.6 kg/s steam flow) and well testing (237 bar on well head, 10 kg/s steam flow), while the second line is 100% reserve. The full flow line will be used for a short period, to clean out debris and dirt from the production well. The test lines will be used for further testing of the well (thermodynamics, chemical content of fluid, etc.).

The piping is laid in long straights and expansion loops to eliminate stresses from thermal expansion. A series of pressure reducing orifices will be placed on each of the four lines, with piping diameter expanding to keep steam flow velocity within 50 m/s when throttled steam expands.

No bends will be used anywhere in the piping. Instead, a tee with a flange/blind flange pair on the side facing the upstream pipe will be used. Any erosion from particles will be directed towards the blind flange, which may be coated with suitable materials and removed/replaced if damaged.

Pressure and temperature sensors are installed on every line between orifices. Pressure sensor nozzles will have shut-off gate valves, hand operated, size 2”-3”, depending on pressure conditions. Temperature sensors will be contact sensors, placed between the pipe steel surface and insulation. Temperature correction will be calculated in case of thick steel pipes. Temperature sensors will be placed at suitable locations in the mufflers as well.

Wet scrubbing and fluid sampling connections (2”) will be installed on each test line, as well as a flow measurement orifice. The latter will be placed on the last leg of the test line, before entering the mufflers at 11 bar pressure. A desuperheater connection will be placed upstream to each test flow line muffler.

The piping is connected to the well head main branch through orifices and ends in rock mufflers. The pressure in the pipes is between 11 and 120 bar during operation. Operating temperature in full flow and test lines and mufflers is highly dependent on the enthalpy from the production well – expected to be between 2800 and 3100 kJ/kg – and pressure. It may be anywhere between 170 and 410 °C.

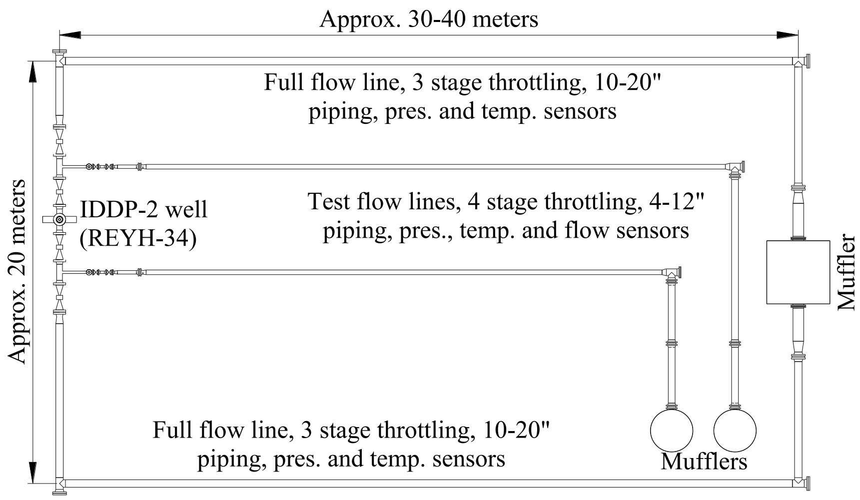

Figure 4: Typical flow and test line layout, plan view.

Two types of piping layouts are proposed – Layout A and Layout B. In the former, the mufflers are placed in a hill approximately 35 meters east of the production well, some 4 meters higher in land, as shown in Figure 4. In the latter, the mufflers are located some 20 meters south of the production well, towards the edge of a lake at 11 m above sea level.

As can be seen in Figure 3 (well head layout), the piping will be located approximately 4 meters above the well head flange, which will be at the bottom of a 4 m deep well. Any difference in land height will have to be levelled with landfill, approximately 4 meters deep.

If the mufflers are placed in the hill (Layout A), less landfill may be needed but then any runoff from the mufflers will have to be diverted towards the lake through a duct, several dozen meters south-west from the mufflers. However, if the mufflers are located by the lake, no duct will be needed.

For now, Layout B appears to be more favorable, even though considerable landfill will be needed. It should be noted that pipe leg lengths indicated on the drawing depend on the results from thermal stress calculations of the piping and are subject to change.

4.2 Material Selection

The well head branch is designed to be highly reliable during operation via double valves, counter weights (stress removal) and minimal amount of connection nozzles that are likely to fail during operation at the extreme pressures and temperatures encountered. The test flow lines, on the other hand, can be shut off from the rest of the system and repaired or replaced individually, while the other identical reserve line is used in its stead.

The material selection is thus not as critical in this part of the piping. A short part of each test flow line – approximately 2-3 meters – is a 6” pipe with 120 bar pressure, requiring ANSI Class 1500 flanges and piping. The rest of the piping has pressure at 11-60 bar, so Class 900 piping and fittings will suffice. The material selection for this part of the piping will thus mostly be regular carbon steel. No coating of inner surfaces with corrosion/erosion resistant materials is proposed for this part of the piping, as it will be too costly and difficult to implement in long stretches of piping. Temperatures and pressures are not as severe as in the well head branch. Also, individual legs of piping are not critical and may be shut off from the rest of the system and repaired or replaced, if necessary.

Steels with higher manganese content than 0.8% will be avoided, to minimize risk of stress corrosion cracking. A106 Grade A carbon steel fulfils this requirement but may be unsuitable at certain pressures and temperatures. Another common steel 15Mo3 (16Mo3 according to EN 10028) is commonly used in well heads and may be needed where temperature and/or pressure surpass the limits of A 106 Grade A steel.

The mufflers will be built from carbon steel and/or concrete and will mostly be rock filled – at this stage no detailed design is available for these components, except for preliminary sizing. The final throttling of steam (from 10 barg to atmospheric pressure) will be carried out via perforated tubes of 10-20 mm thick stainless steel of any suitable grade that will withstand prolonged usage. This may not be necessary in the full flow line muffler, as it is to be used for a brief period.

Material selection of pipes, fittings and mufflers in the flow and test lines is summarized below:

Pipes and fittings, incl. orifices or venturi tubes, low temperature/pressure: A106 Grade A

Pipes and fittings, incl. orifices or venturi tubes, high temperature/pressure: 15 Mo3 carbon steel

Flanges: Class 900 or 1500 (ASME B16.5), Group 1.1 materials

Mufflers, cylindrical or rectangular: Carbon steel or concrete, rock filled

Perforated throttling tube in full flow muffler: Carbon steel, thickness 10-20 mm, Class 300 material

Perforated throttling tube in test flow mufflers: Stainless steel, thickness 10-20 mm, Class 300 material

4.3 Pressure Throttling

The steam pressure will be reduced in 3-4 steps through each line. The simplest device for throttling steam is an orifice plate. Such plates, as well as thick, perforated plates with multiple circular holes, were tested in the IDDP-1 flow line and failed rather quickly. The steam flow velocity in these orifices is very high – around 250 m/s, choked flow – and the resulting erosion on the edges of the orifice is severe.

An alternative to orifice plates is to use venturi tubes, welded directly to the piping. These typically have inlet angles of approx. 20° and outlet angles of 7-8°, enabling very smooth flow passage and lowered risk of erosion. This will require very long tubes compared to flanged orifice plates. The narrow throat will be sensitive to pipe stresses and may require reinforcement of the tubes. Another issue is the possibility of a shock wave and supersonic flow in the diverging section of the venturi tube, which may have severe unforeseen consequences.

Whether orifice plates, venturi tubes or other means of steam throttling will be used will be further decided upon during detailed design of the flow/test lines.

The final pressure reduction will be carried out through perforated tubes, located at the bottom of the rock mufflers. The number, size and arrangement of the holes in the tubes will be designed for suitable steam flow velocity in each hole.

4.4 Desuperheater Connections

Steam may be anywhere between 170 °C and 320 °C when it has been throttled down to atmospheric pressure. In order to reduce noise and steam flow velocity and bring the steam down to saturation, a desuperheater connection is proposed on the line connected to the mufflers.

Desuperheater connections are proposed on the test line connected to each of the 2 test line mufflers (11 bar pressure), where steam can be brought from over 300°C down to approximately 180-190°C, which is the saturation temperature at this pressure. This may reduce noise during the test phase of the project and can be used to control/reduce the volumetric flow rate of the steam. Desuperheater connections are not proposed for the full flow lines, as the duration of well blowout will be significantly shorter than the test phase.

Desuperheater types (Spirax Sarko, 2013) range from spray nozzle type, through Venturi type to steam atomizing type, the latter requiring shorter downstream mixing lengths. Installation lengths are not foreseen to be a problem, as very long thermal expansion loops will be installed, in relation to pipe diameters.

The simplest type available – spray type, requiring a simple spray nozzle - will probably be selected, to minimize risk of erosion damage. Water pressure needs to be 0.5 bar over steam pressure (10.5 barg), which is not a problem. It is proposed to use water at around 100°C lower temperature than the steam, to prevent cavitation. Brine at a temperature of 100-200°C (which can easily be obtained at the Reykjanes Power Plant site) is an ideal medium for this application.

The desuperheater connections will thus be installed several pipe diameters upstream from the muffler connection on both test lines.

4.5 Mufflers

Mufflers are sized so that superheated steam at atmospheric pressure will exit through the top at approximately 10-20 m/s. Each of the two test lines has an independent muffler at the end. The two full flow lines are connected into one common muffler, which will be used for a relatively brief period during well blowout.

All mufflers will be filled with rocks of appropriate size, with sufficient void spacing through which steam flows before being discharged upwards from the mufflers. The mufflers will be built on a concrete foundation. Throttling of 10 barg steam entering the mufflers will be via perforated steel tubes, as described in section 4.3.

The indicated size of the mufflers (ø2 m cylinders on test flow lines, 3x3 rectangular structure on full flow lines) is indicative only, as these structures have not been designed yet. The height of the mufflers, for example, is unknown at this point. Other features, such as chimneys, may be added later on.

The pipeline from the wellhead to the mufflers lies some 4-5 meters above the current elevation of the REYH-34 well. The pipes will enter the mufflers 1 meter above land. This means that a considerable amount of land fill and foundation work will be required, especially if Layout B will be chosen (see end of section 4.1). Even if Layout A will be chosen (mufflers in hill east of well REYH-34), considerable foundation and earth works will have to be undertaken, as the soil in the hill is too soft to support these structures.

5. CONCLUSIONS

A preliminary design has been carried out for well head and flow test lines for the IDDP-2 well at Reykjanes, Iceland. All key components have been identified for the project. Cost is expected to be roughly 2 and 3 times higher than for well heads on ordinary geothermal wells and can be explained by the high number and unit cost of custom built gate valves and actuators, as well as high cost of high pressure and temperature piping, lined with corrosion and erosion resistant stainless steel alloys.

The detailed design of this installation consists mainly of mechanical design (thermal stresses, etc.) of piping, final selection of materials, based on findings of Design Group 3 (chemical analysis of geothermal fluid), tendering and selection of gate valves and actuators, design of steam throttling nozzles and design of civil structures, flow line piping and supports, mufflers, sensor placement, insulation, etc.

The aim of this installation is to demonstrate that superheated geothermal steam that contains aggressive chemicals can be processed through piping, measured and throttled down to atmospheric pressure, without substantial failure of surface piping components. This step is important when considering future harnessing of superheated geothermal steam for electricity production.

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