Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Piping Design Considerations for Geothermal Steamfields

Cristo Umanzor, Alex Hall, Rory Buchanan, and Nicetos Rosaria

PO Box 9806, Newmarket 1149, Auckland, New Zealand

Cristo.Umanzor@jacobs.com, Alex.Hall@jacobs.com, Rory.Buchanan@jacobs.com, Nicetos.Rosaria@jacobs.com

Keywords: Geothermal, steamfield, piping design, separation stations, wellpads, reinjection pumping stations

ABSTRACT

The piping systems in a geothermal steamfield provide the means to transfer the geothermal fluids from the production wellpads to the power plant and to the points of disposal. They also have an integral role in the conditioning of fluids to optimize the efficiency of the energy conversion plant and to achieve high plant availability and flexibility to respond to resource change. While the piping system is typically lower cost than the wells and power plant, it is critical to maximizing the performance from these major capital investments. As such, these systems constitute a key component of any geothermal development, and design must integrate many factors to guarantee the project success. Hence, the project should include appropriate piping engineering from the concept design and feasibility studies to the commissioning and start-up of the steamfield.

Any geothermal steamfield project brings a series of inherent challenges to the designer that may include: well production uncertainty, fluid characteristics, injection well permeability, well and equipment O&M requirements, silica polymerization, future steamfield expansion options, unexpected changes in the reservoir, geotechnical issues, and environmental and community constraints. These field-specific variables drive customized configuration of every single steamfield design. Therefore, the challenge is to apply proven piping design methodologies and standardized practices to address these specific configuration issues in the most efficient but effective manner.

This paper discusses common steamfield piping design considerations, particularly for the design of production and injection wellpads, separation stations, and brine injection pumping stations. These standardized subsystem designs provide cost effective design elements that can be integrated into the customized cross country piping system and jointly meet the operational requirements of the fluid delivery and disposal system.

1. INTRODUCTION

The purpose of this paper is to provide some design considerations specifically for wet geothermal steamfield piping design; with the intention to inform mainly the geothermal developers who constantly need to take key design decisions, and deal with problems during the entire design phase. Some of these considerations may become critical for the project success.

The first section of the paper describes the typical piping design processes, some examples of the outcomes of each process, the impact of timely decisions, and the importance of proper field information gathering prior to kick-off for any design stage. Then the paper discusses some more specific design aspects for steamfield piping systems as follows:

- Production and injection well pads,
- Separation stations, and
- Hot brine injection pumping stations.

The last section provides some guidelines and tips to apply in the structural design (e.g. pipe supports) of a typical gathering system. For simplicity, we have limited the scope of this paper to a typical "wet" steamfield piping system, which is illustrated in Figure 11.

It is important to note that these considerations are only a "sample" of the wide list of aspects involved in the steamfield piping design, but they are sufficient to illustrate the complexities that this area of engineering may involve.

2. GENERAL CONSIDERATIONS

2.1 Piping Design Development Process

The successful delivery of any piping design in geothermal requires a number of well-structured processes which are customized to the geothermal developer and to the specific project requirements. These processes may vary among piping design companies; nevertheless the steps illustrated in Figure 1 appear to be very commonly used.

This group of processes belongs to the detailed piping engineering phase. The feasibility studies and concept designs are considered important design inputs at this stage.

It is not the intention of this paper to describe the details of these processes, but to illustrate their relevance and provide examples of typical pitfalls generated as a result of omitting steps or careless fast tracking.

Early involvement of stakeholders in establishing appropriate design criteria is essential for the piping design success (Step 1). The geothermal developer, drilling team, O&M team and piping designer discuss and agree a number of design criteria to be applied throughout the entire project. Relevant criteria such as pipe sizing, piping layout considerations, isolation methodology, applicable design codes and standards and seismic design considerations are typical components of these documents.

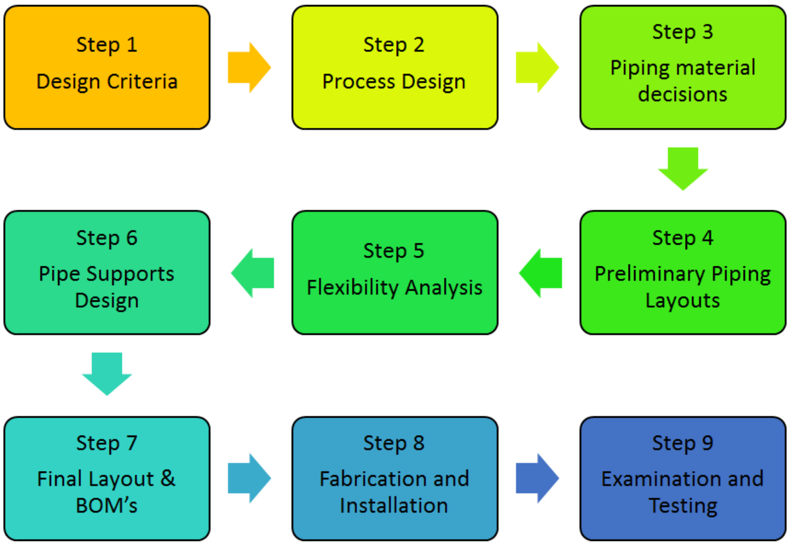

Figure 1: Piping Design processes

Make sure that the process design (Step 2) is well advanced before kicking off the procurement. Frequently, tight project execution schedules demand early procurement, especially for those process design items that require a relatively long procurement time (e.g. pressure vessels, large valves, pipe and fittings). Problems may appear when the process design is not properly supported by sufficient steamfield information or measurements; for example, premature data obtained from short term production well tests. This may generate procurement mistakes or costly design reprocessing.

Appropriate selection of piping materials is essential to guarantee the pressure integrity and expected lifetime of the geothermal piping systems (Step 3). However, the geothermal fluids do not have standard chemical properties; they may vary among steamfields and even among neighboring wells. Hence the piping materials selection should be confirmed after proper fluid chemistry analysis.

The preliminary layouts (Step 4) are essential tools to collect feedback and discuss expectations from relevant stakeholders such as the drilling team, O&M team, construction managers and many more. The success of the preliminary piping layouts is to avoid reprocessing of the detailed design at a very late stage and thereby avoid unnecessary project costs. Constructability and Safety in Design reviews are essential at this stage to confirm that the piping layout is properly thought out.

"The software does not design piping, engineers do". Once the layout has been approved, a pipe stress analysis is then executed to confirm flexibility and compliance with the design code requirements (Step 5). There are good computer packages for stress analysis modeling available commercially. They simplify the calculation process dramatically, but they need to be properly configured to obtain suitable results, and good engineering judgment and experience is essential to interpret and analyze the model results.

"In a design world, the pipe supports always go after the piping design, but in the construction world it is the other way around". Hence the structural engineer should be involved in the piping design at an early stage and before completion of the stress analysis to understand for example, the order of magnitude of the pipe loads, and any other physical constraint that may need to be assessed during the pipe support design (Step 6). Sometimes the pipe loads due to thermal or seismic loading conditions are extremely high simply due to insufficient flexibility or inappropriate piping layouts and restraints, which may produce expensive or impractical structural design solutions.

The design success is also the result of a good understanding of how the piping systems will be constructed, tested and commissioned (Steps 8 & 9). This includes construction sequences, accessibility, steam blowing, hydrostatic tests and start-ups. Constructability reviews run by senior practitioners in the middle of the design phase are always good practice.

2.2 Impact of Design Changes

Fast-track schedules are very common in geothermal development projects, and this may bring forward a number of decisions and assumptions that turn into relevant inputs for the steamfield design. For example, sometimes the steam pipeline sizes are based on estimated well two-phase flow rates or forecast maximum well shut-off pressures. These assumptions eventually need to be checked and potentially revised against new information gathered along the project execution (i.e. site measurements or test results). This is an important design reprocessing risk that requires proper management.

The first set of decisions and assumptions should be properly supported by sound engineering judgment, early stakeholder involvement and good practice. In addition, a sensible design strategy or methodology is required to address these unavoidable design input changes in a suitable and timely manner. The target is to control the project design cost and overall success. The cost of a design change increases as a project progresses; therefore any potential change in design variables should be properly addressed as soon as they become known. This approach is illustrated in the Figure 2.

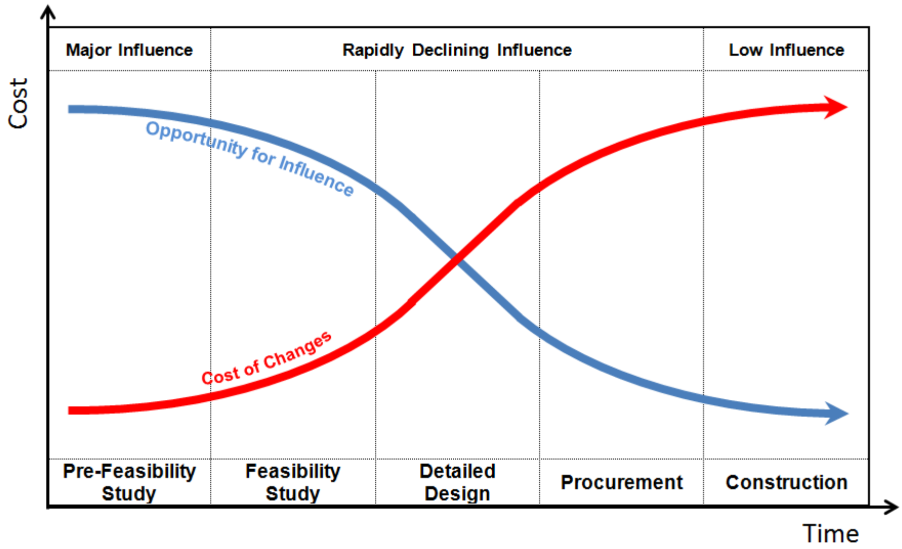

Figure 2: Impact of design changes at different project stages

2.3 Everything should be built twice

Every project starts with an idea, concept or plan before it is built physically and it is during its design stage that a project is being built first. The more time spent in ensuring that every aspect from all disciplines fits together, the less chance there is of having construction issues. However, spending too much time on this would also increase the design cost and at a time when competition drives the cost, this process has to be done as efficiently as possible.

Fortunately, technology now offers tools to build a virtual project model before any physical construction work is done. Potential construction issues such as accessibility, clashes and sequencing are identified and rectified early, rather than having to remedy these during actual construction.

The process involved is also very simple and straightforward, much like opening and combining the design CAD files in a universal viewer, which creates a 3D model of the project wherein a designer can inspect the model for any potential issues. Everyone involved in the design is able to see how the project is evolving, enabling them to adjust their design as necessary, minimizing rework.

This methodology is very valuable in the case of “brownfield” designs, where the challenge is to avoid clashes between the existing and new piping. See Figure 3 below.

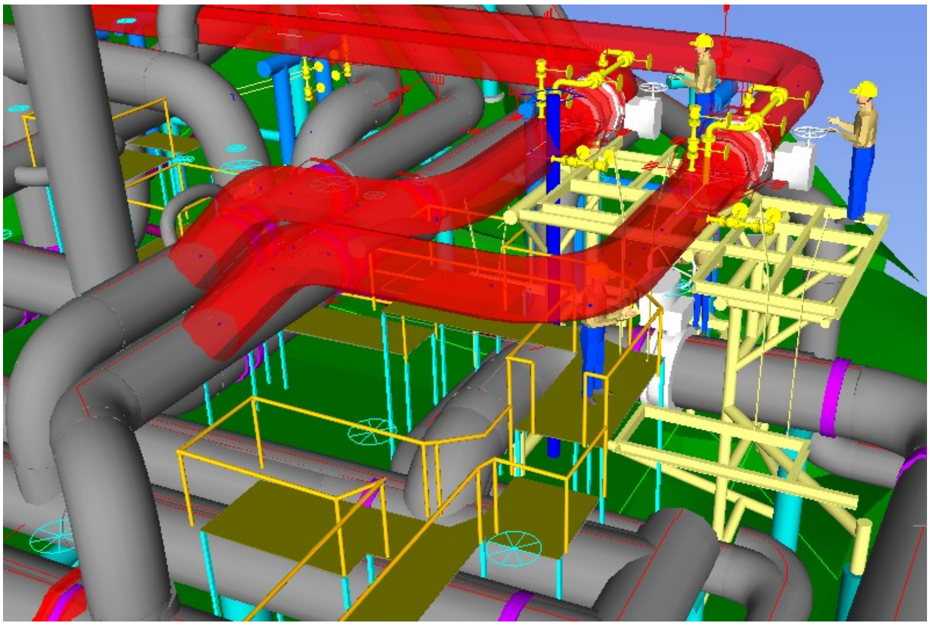

Figure 3: Virtual 3D model built first to minimize, if not eliminate, costly construction rework

3. PRODUCTION AND INJECTION WELLPADS

Nowadays, it is common practice to drill many wells in a single production or injection wellpad; this becomes a significant challenge for piping designers because they need to deal with several characteristic layout constraints and pipe flexibilty issues in the design of the geothermal wellpad. This section aims to illustrate some of these typical challenges.

3.1 Drilling Accessibilty

The wellpad piping design should provide suitable space to locate drilling equipment around the wellheads and piping to facilitate maintenance to the existing wells (i.e. work-overs) or sometimes to allow for future drilling on the same wellpad. The wellhead branch lines should be readily capable of disconnection from the rest of the wells without major production disruption and unnecessary cutting and re-welding of pipe. For example, branch lines should be provided with flanged connections to facilitate piping removal and reinstatement. Refer to Figure 4.

3.2 Thermal Wellhead Growth

The wellhead piping layout should be able to deal with the vertical wellhead displacements caused by the thermal expansion of the underground well casing. The objective is to properly support the pipe moving upwards and to control any excessive load on the wellhead. This is typically solved with the installation of counterweight supports near the wellhead. Refer to Figure 4.

3.3 Branches for atmospheric production well discharges

It is good practice to provide the production well piping design with permanent piping or connection for temporary piping to allow well discharges to the atmospheric separator. This is particularly important during the first discharges of the well, where a significant amount of material accumulated as a result of the well drilling is cleared by fully open well discharges. The accumulated dirt should not go to the production steam separator. In addition, the discharge piping is also useful to carry out cold start-ups after a long shutdown period and periodic production well tests.

3.4 Induced vibration problems

Excessive flexibility caused by too many changes in direction or vertical loops along the two-phase production lines may lead to unwanted vibration problems. These are typically caused by particular two-phase flow patterns. In general, the pipe should be designed to cope with that type of pulsating flow through suitable restraints and smooth direction changes. For example, angled reinforced branch connections like the one shown in Figure 4 help to reduce impulsive loadings.

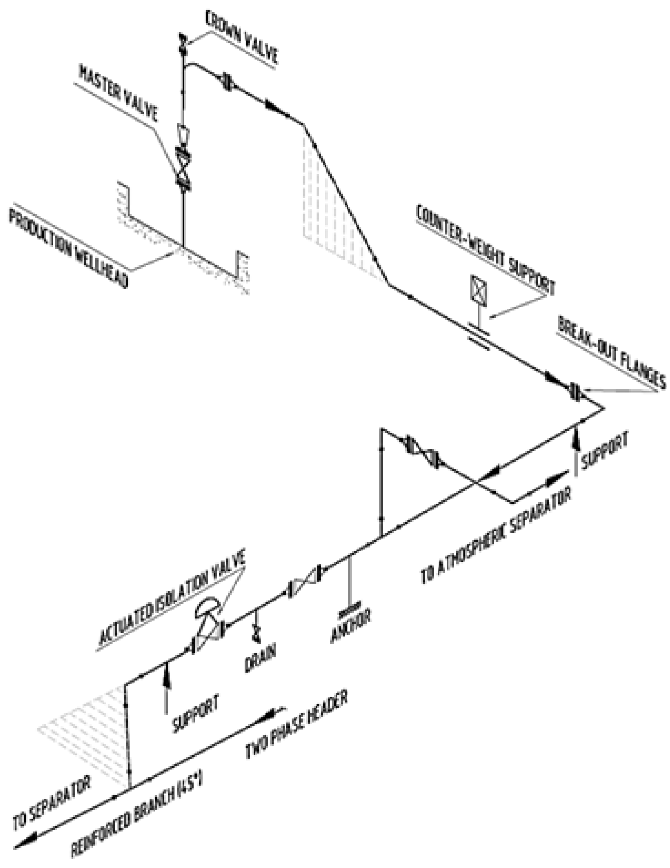

Figure 4: Typical production well branch line

3.5 Dirt traps at injection wellpads

It is good practice to install dirt/solids trapping systems at the injection wellpads to protect the injection wells against solids which may go down the well and cause a reduction in the well's injection capacity. These solids may be sand, debris, rocks and any silica scaling released during hot-cold expansion (thermal cycling) of the brine pipelines. The solid trapping systems should have the capability for servicing without interrupting the production (e.g. they require redundant elements or bypasses). Refer to Figure 5.

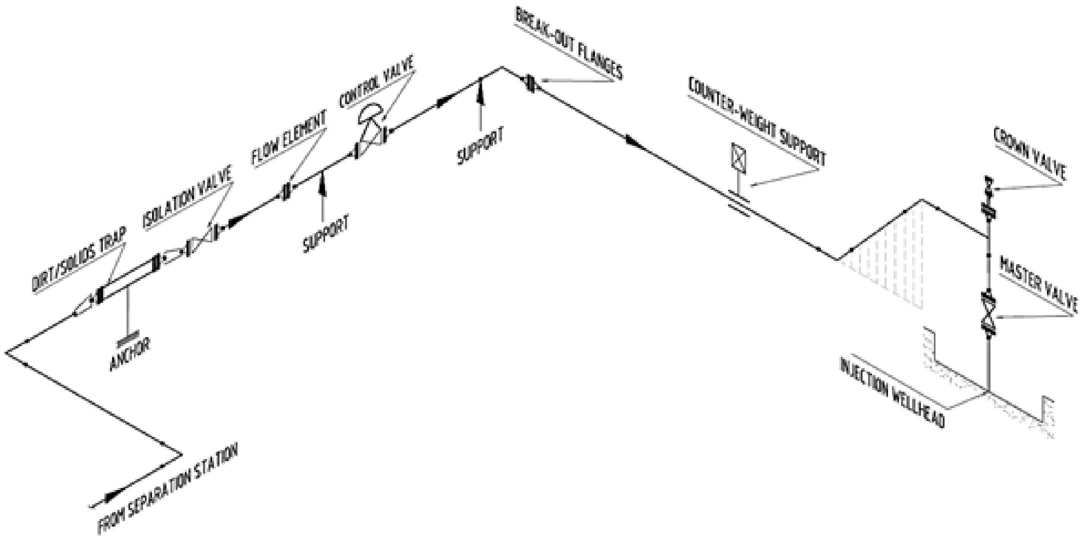

Figure 5: Typical injection well branch line

4. STEAM/WATER SEPARATOR STATIONS

In the early stages of a large fast-track steamfield project there is potential for uncertainty around the physical and geophysical data required for the design itself. In particular, there may be a lack of as-drilled well data for some of the areas of the planned steamfield. Actual well output, number of wells, or well locations can change between concept/tender design and final design. Jacobs has developed contracting strategies and planned and designed separator stations to account for this uncertainty.

4.1 Centralized Separator Stations

One approach to mitigate the risk has been to maximise the use of centralised separator stations so that the effects of resource uncertainties during Tender Design are reduced and shared by the wells connected to each separator station. This minimises the extent and likelihood of required design changes. The main benefit of this approach is the avoidance of small numbers of wells connected to smaller separator stations, and the avoidance of wholesale alterations in the numbers of planned separator stations or well pads caused by dramatically different well flow, pressure, and enthalpy data. In other words, the flexibility achieved by having a larger number of wells connected to a large separator station means that the knock-on effect of a significant change in the output of one well, even the abandonment of a planned well, can be more easily mitigated by changing separator station outputs or altering numbers of wells elsewhere in the system.

There are trade-offs to be made in the use of centralised separator stations and the degree of centralisation is dependent on the well characteristics and field topography. An example of this is that some of the benefits gained in the reductions of numbers of separator stations will result in longer lengths of production piping. If wellhead pressures are low this may trigger a departure from the centralised model for economic reasons. Another disadvantage is that it may not be possible to route production piping downhill to the separator station in all cases. It is important therefore to think holistically about wellpad and separator station location.

4.2 Modular Separator Station Design

Another mitigation measure in coping with well data uncertainty is to use a modular separator station design to further simplify any redesign required. If it is appropriate for the project, Jacobs will rationalise the separator station design to develop a standardised, modular approach in order to reduce design times for final construction-issue designs, and reduce changes within the contractual framework established through the tender process.

Modular separator station designs are achieved through the selection of a range of standard separators with fixed capacities that are then added or removed from individual separator stations as required when the updated well output data is received. Separator process interfaces and peripheral items of equipment can also be standardised to some extent to simplify design and provide the client with common equipment sizes and capacities across the field.

A modular approach to separator station design reduces the levels of engineering that have to be done. In particular, the levels of mechanical engineering are minimised with similar vessel and inlet and outlet piping designs.

4.3 Key Factors in Separator Station Planning and Design

It is critical that the fundamental requirements of the separator station are not neglected when economising and rationalising the design. Steam purity and quality are paramount, and when input two-phase flows are changed the performance of the separator must be checked to ensure compliant steam quality.

Separator station design should be considered in the very early stages of steamfield development and drilling schedules, in particular, should be planned to provide complete data for whole areas of the steamfield in order to allow the design completion that is required to support construction completion.

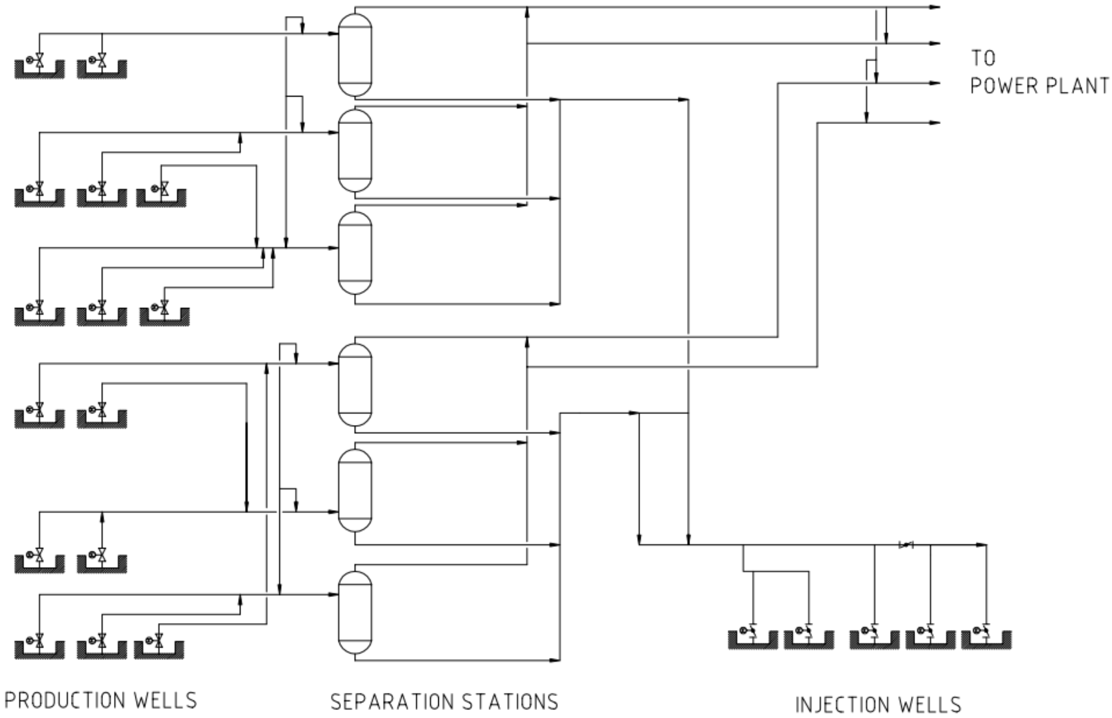

Figure 6: Centralized, Modular Separator Station Concept

5. HOT BRINE INJECTION PUMPING STATIONS

5.1 General

Hot brine injection pumping stations are used to transfer the brine from separation stations to the injection wellpads that cannot be reached by simple gravity flow pipelines or have relatively low permeability. The piping design of these pumping systems requires some special considerations such as the ones described as follows.

5.2 Piping Layout

Pumping stations should be laid out to provide adequate space for the installation, operation and maintenance of large and heavy equipment such as pumps, motors, valves and strainers. This means that the layout needs to provide sufficient space for the access of large vehicles and cranes to lift the equipment.

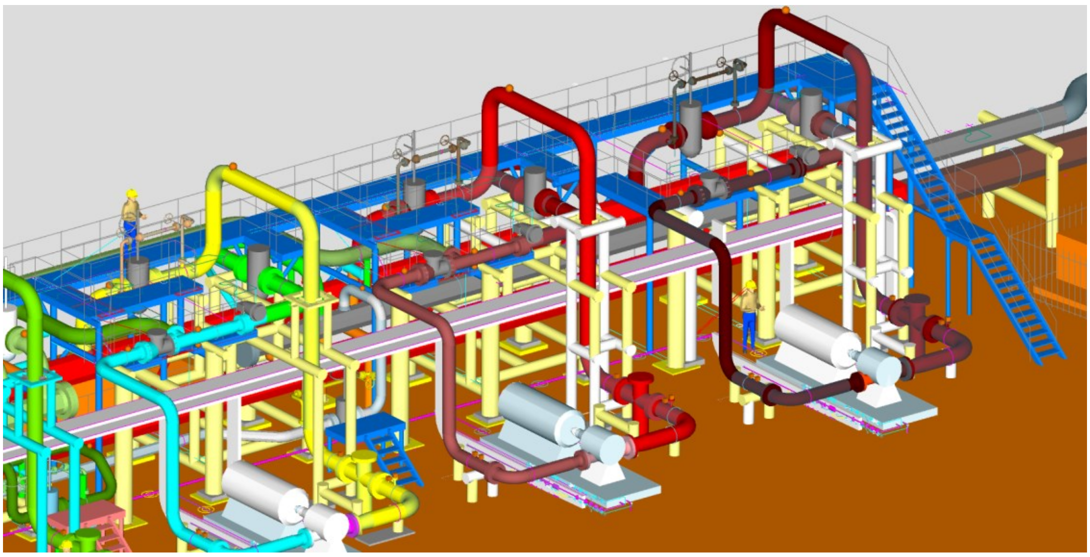

Figure 7: 3D computer model of a hot brine injection pumping station

The pumping station layout should also consider suitable space for other systems as follows:

- Drainage sump with adequate capacity to drain down and flush the piping near the pumps.
- Seal water system (pumps, filters and water storage).
- Flow measurement equipment, which requires relatively long straight pipe sections upstream and downstream to provide reliable measurements.
- Power supply and control & instrumentation cables and trays.
- Pumping station control room and switch boards.

Using 3D visualization tools like Autodesk Navisworks, the complete system can be modeled, including piping, equipment, structural supports, platforms, roadways, buildings and structures. This model can be used to check for clashes and access during the design stage before issues are encountered during construction. This saves time during design as all disciplines are involved in the design and rework is minimized.

5.3 Isolation Requirements

Maintenance of the pumps requires isolation and draining of the suction and discharge piping downstream of the isolation valves. However, sometimes the stagnant brine produces silica deposition in the valve seats, which may impact negatively on the valve isolation and hot brine leakage can become a safety issue.

There are different isolation methodologies to mitigate this risk. For example: double isolation valves, single isolation valve with an adjacent line blank and single isolation valve with a drop-out spool. The selection of the methodology will depend on the geothermal developer safety policies.

The most common method to provide isolation to the off duty pump is by way of drop-out spools plus the installation of blind flanges with small bore bleed valves at the pressurized pipe ends.

5.4 Filtration Requirements

Filtration is required to protect the pump impellers from damage due to rocks, debris or silica scaling released during the thermal cycling of the brine pipelines. Large brine flow rates require the installation of basket type strainers at the pump suction, and they require regular maintenance. Therefore, the strainers should be accessible from ground or from suitable access platforms to facilitate their operation and maintenance.

Seal water systems require filtration to prevent the hot brine pump seals from wearing due to suspended solids.

5.5 Low Point Drains

Low point drains in brine systems should be flanged to facilitate maintenance. Flanged connections allow for the drains to be rodded-out to clear silica deposits.

5.6 Non-Return Valves

The internal components of the non-return valves located at the pump discharge frequently get stuck with silica scaling. Hence, these valves should have provision for an external lever to allow the disc to be regularly stroked during operation and break up silica formation around the hinge pin.

There are some other valve non-return design options such as the “spring assisted” check valve that can also be considered.

5.7 Stress Analysis Considerations

Using anchor/fixed point locations at interface points between the pump station and cross country piping, the piping system can be split and kept isolated for modeling purposes.

Piping is designed using flexibility analysis tools like AutoPIPE. In pump station design the limiting design constraint is the pump nozzle loads. The low magnitude of allowable forces and moments on nozzles drives a layout solution with large amounts of flexibility and consequently the code stresses are not usually significant. The use of actual operating conditions (temperature and pressure) for the determination of the nozzle loads provides a more realistic approach to the loads on the pump nozzles. The design conditions are still used to check for system integrity.

A big consideration is how the system will respond when one or more pumps is on standby or out for maintenance. The differential thermal expansion between the hot lines and the cold lines can have a large effect on the pump nozzle loads. This comes back to the layout of the pump station, where standardisation of the pump branch can help ensure the piping behaves the same way and all pump branches have enough flexibility that the header piping does not adversely affect the nozzle loads.

6. STRUCTURAL DESIGN CONSIDERATIONS

6.1 General

Structural design, which comprises mainly of support design, is an equally important part of piping design. The design of supports usually comes last in the piping design work flow but usually comes first or second in the construction sequence. The structural engineer should therefore have an early understanding of the piping layout, topography and other physical constraints. The design considerations described in this paper are intended to facilitate this process.

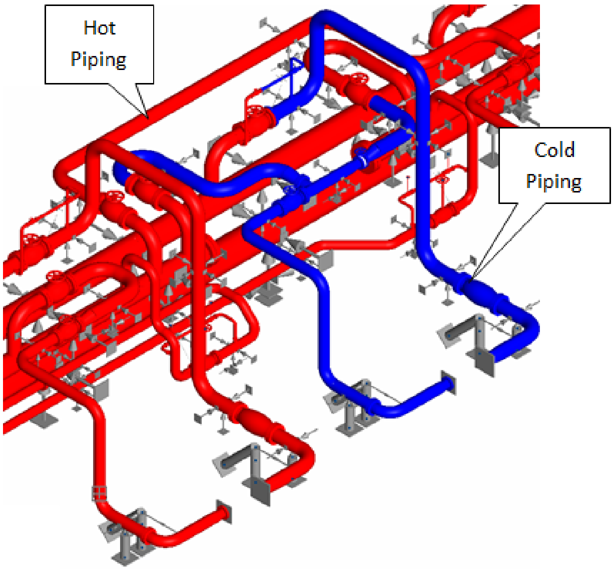

Figure 8: Stress Analysis Modeling – Hot & Cold Combinations

The use of special supports can be used to reduce the loads on the pump nozzles. Tie rod supports and low friction shoes can be used to reduce the role that friction plays in nozzle loading. This can be a significant portion of the loads due to the high thermal displacements from the hot piping.

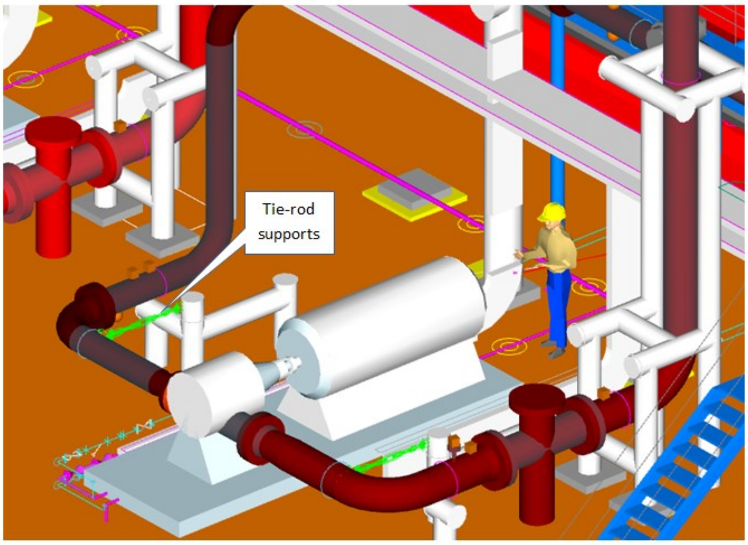

Figure 9: Tie rod supports used to reduce friction force on pump nozzles

6.2 Pipe and structure interaction

Traditionally, after the piping model has been made code compliant during stress analysis, the support loads are extracted, summarized and then forwarded to the structural engineer for support design. The pipe stress model would normally assume all the supports are rigid. However this is not always the case, especially when due to space constraints or right of way issues, pipe lines are stacked on top of existing pipelines. This results in relatively high supports which are prone to large deflections unless stocky member sizes are selected. Selecting larger member sizes will be more expensive but large deflections that may invalidate the assumptions on the pipe stress model will result if nominal member sizes are used.

A solution is to model the structural supports together with pipe on the pipe stress models. New structural analysis software tools now have the capability of exporting either support analysis results or the whole structural model back into the pipe stress analysis software. The piping engineer can then recheck the analysis for additional stresses resulting from the interaction between the pipeline and the structure. If the pipeline is still code compliant, the pipeline is actually allowed to deflect further which may result in reduced pipe support loads for the structural engineer, less robust pipe support frames and consequently an important project cost reduction. Refer to Figure 10 for illustration of this approach.

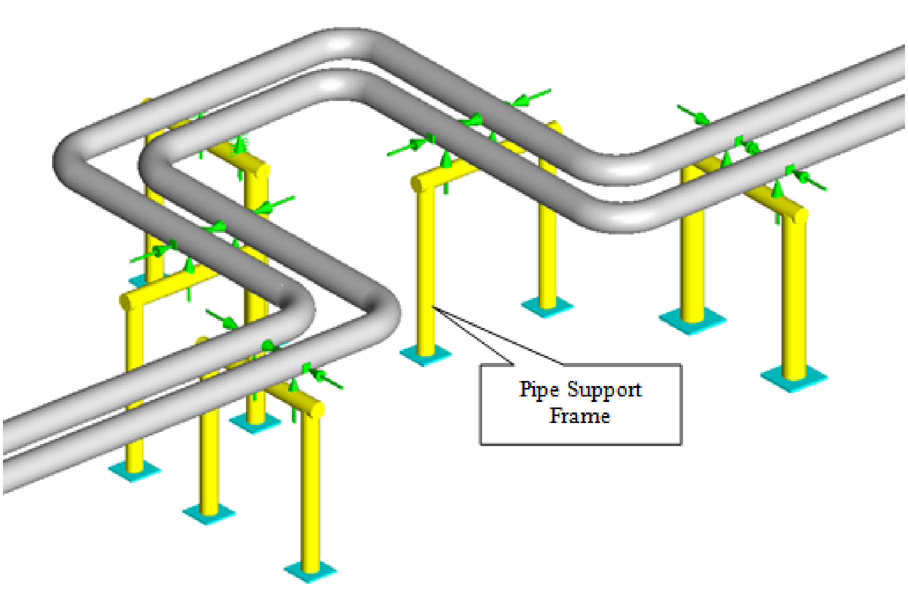

Figure 10: Support frame and piping modeled together

6.3 Simplify, minimise, standardise

A typical pipeline project will have several supports and each support location will have its own set of support design loads. Although a support design or member sizing has to be made for each location, the ease of implementing the design drawings has to be considered. It will be impractical to optimise member sizing for each location, more so to prepare a detail for each. A standard suite of support sizes, type or details is therefore recommended. Support selection should then be limited to the suite of standard support details as much as possible. Ideally only a small portion of the supports should be designed as special types.

Limiting the support selection to a number of standard types has the following advantages:

a. Fewer drawing details are needed for construction.

b. Ease of construction and fabrication.

c. Aesthetics, since support sizes are more uniform through the project.

6.4 Design tolerance

Actual site condition may differ from the information used during design. Site development involving earthworks could actually result in slightly different ground levels as specified on the drawings. Survey information may be incomplete or the geotechnical data may be inaccurate. All of these small variations could affect the original design. A practical design tolerance should therefore be part of the design process.

The design tolerance should be indicated on the drawings and the contractor should be encouraged to report to the engineer when these tolerances are exceeded.

The design tolerance should also be set to provide the contractor with a reasonable amount of latitude during the support installation, which will reduce the number of design queries during the construction phase.

7. CONCLUSIONS

This paper presents some considerations for the piping design of different subsystems in a wet geothermal steamfield. These considerations are a small illustration of the large number of experiences and lessons gathered by Jacobs as a result of the design and commissioning of several steamfields around the world.

It is important to emphasize that an effective communication between the designer and stakeholders, adequate steamfield information, and an early establishment of the design criteria are key aspects to assure the design project success.

Timely decisions in the steamfield design may represent significant cost savings to the project. In contrast, late design changes may drastically impact in the project schedule and budget.

ACKNOWLEDGEMENTS

We would like to acknowledge the input of Ross Sinclair in his review of this paper.

REFERENCES

Brookes, B., Chong, W. & De Kretser, S: Olkaria Geothermal Project: Fast Track Geothermal Steamfield Development Using Modular Steam Separator Stations, Proceedings, Renewable Energy World Conference & Expo, KL, 2011

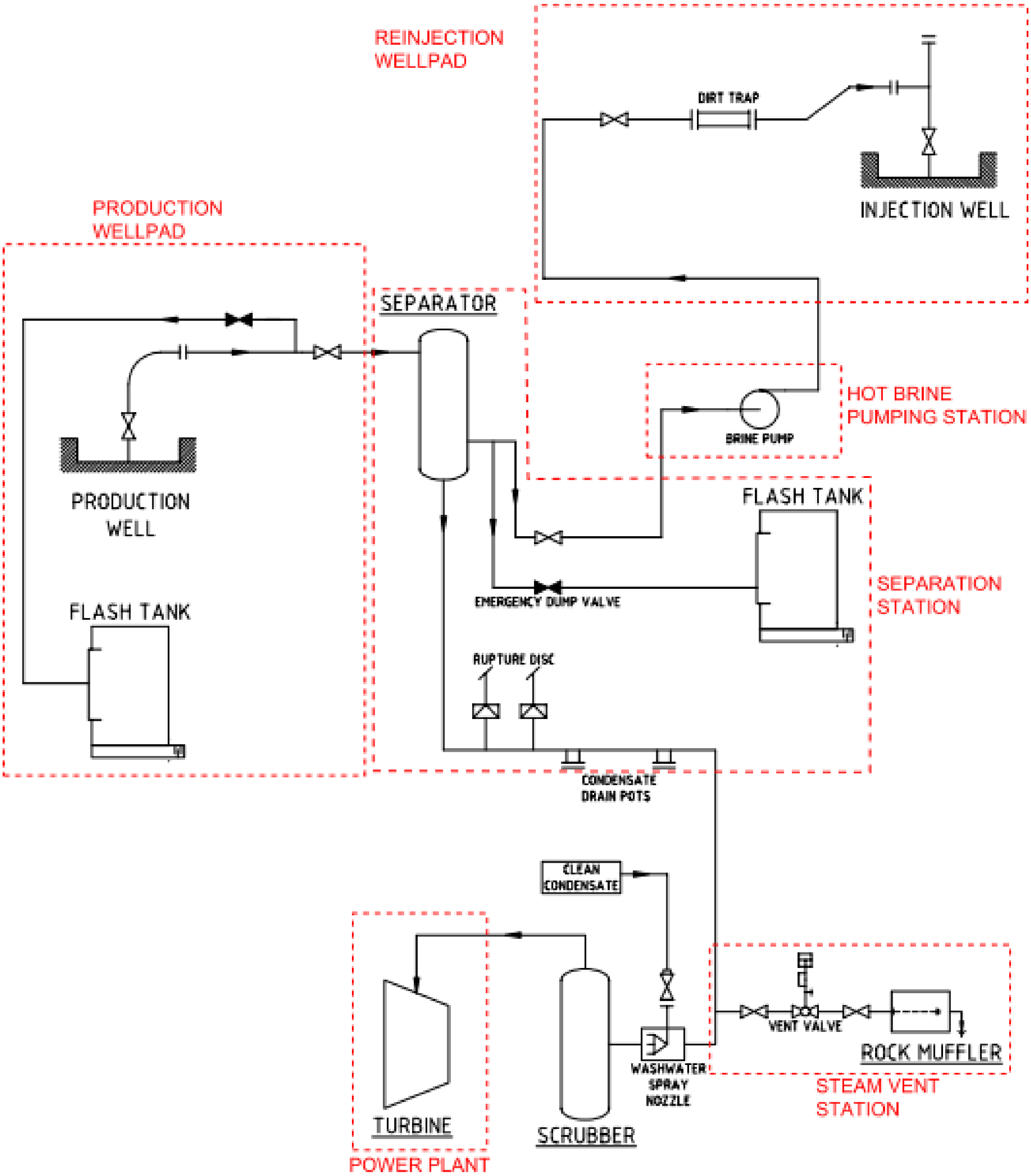

Figure 11: General Process Diagram for a "Wet" Steamfield Gathering System