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

Industrial Direct Heat Plant Resource & Heat Plant Modelling

Gregory Moore

P O Box 1055, Rotorua, New Zealand

greg@dobeng.co.nz

Keywords: Industrial direct heat use

ABSTRACT

A numerical model has been developed to assist the feasibility review of industrial direct heat use geothermal systems. The model allows all major components in the system to be simulated. Supply and reinjection well models and piping distribution systems can be evaluated to optimise sizing and maximize potential well outputs. With knowledge of the application's heat requirements, the plant temperature, pressures and energy flows can be matched with the geothermal resource.

Applications are possible for both heating of secondary fluids using two phase or separated geothermal flows as well as direct geothermal steam applications.

The model includes budget costing parameters and allows rapid analysis for feasibility purposes.

System flexibility allows sensitivity analysis for varying well performances and end use variations.

1. INTRODUCTION

Dobbie Engineers are a NZ based Mechanical Engineering consultancy that has worked in the fields of geothermal engineering for over 30 years. Projects have covered a number of areas from above ground steam field development, well performance testing plant, specialist geothermal fluid testing plant for inhibition of corrosion and fouling deposition and the extraction of minerals. Dobbie Engineers have also had a major involvement in direct heat use from small domestic use to commercial use (hotels, spa complexes and bathing) and in large scale industrial applications. Dobbie Engineers have been involved in most types large industrial direct heat use applications including glass house heating, heating of timber drying kilns through to the use of two phase geothermal fluids and separated steam to generate clean steam to supply large industrial paper making processes. Studies have been completed to provide heat to Medium Density Fibreboard (MDF) plants. Dobbie Engineers have received several awards for their direct heat industrial plants.

All applications are different and require careful evaluation of the options available to ensure a successful outcome. Above all the varying chemistry within the geothermal fluids must be treated with respect. To assist with the review of options available for the selection of operating conditions and equipment Dobbie Engineers have developed a flexible analytical software model based on excel spreadsheets to model proposed arrangements.

The model is used to provide initial plant and pipe sizing, evaluate operating conditions and assists in providing capital cost estimates to a reliability of +/- 30%. These parameters typically provide enough information for clients to develop business models and take initial steps (preliminary design) towards evaluating the feasibility of projects. This paper describes the process features that need to be considered when evaluating a direct heat use project and how this model is used and can be developed to provide a useful tool to support business cases.

2. MATCHING THE RESOURCE AND END USED

Once an industrial direct heat use application is identified it is important to rapidly identify if this matches the potential geothermal energy source available and that it can be economically serviced by that energy source. Several steps are required to confirm if there is a match between the direct heat use application and the available geothermal resource.

2.1 Identify the Process Energy Requirements

The first step is to accurately evaluate the temperature and energy flow requirements of the application's process plant. Accurate information, particularly temperatures are critical to achieving an acceptable outcome. These conditions then need to be matched to the resource. Plant and systems that require energy at temperatures ranging from 50-180°C are generally the most suitable for geothermal applications. In New Zealand the lower temperatures tend to match shallower resources (50-500m depth) while the higher temperature requirements are more likely to require deeper wells and resources (1000-2000m). Temperatures above 200°C require continuous well outputs at pressure in excess of 20 barg. While these temperatures and pressures are available in some geothermal reservoirs, the cost to generate continuously at this pressure may be prohibitive in both terms of drilling costs and the reduced well mass flow performance at these pressures.

Selecting a direct heat use that has a range of process temperatures is also an advantage. This may allow the geothermal energy use to be cascaded to make maximum use of the energy available.

The load profile needs to be identified. The plant may have short term high peak demands or it may have a constant load profile. This needs to be evaluated both in terms of daily use and throughout the year. Typically geothermal projects have high capital costs especially when well costs are considered. The plant needs to operate at or near it maximum capacity for most of its life to provide economic returns. Industrial plants that process or dry seasonal products are less likely to be viable unless the product can be stored or alternative uses of the energy are available in the off season.

2.2 Evaluation of the Resource

Evaluation of a geothermal resource starts with an analysis of the potential output from the geothermal field. The most accurate information comes from the testing data obtained by discharging existing wells for extended periods and accurate reservoir models. In some cases this may not be known at the initial project planning stages and calculated estimates may be required. Our model is ideal to evaluate a range of possible well performance data.

Performance of wells needs to be evaluated in terms of temperatures, pressure, enthalpy and mass flow rate. Well performance curves need to be developed that identify how the pressure and enthalpy varies with the changing mass flow rate. Typically, the geothermal field's pressure drops and enthalpy rises as a geothermal field is developed. Ideally the temperature, pressure and enthalpy relationships should be extrapolated out to predict well performance over the life of the plant. These potential variations need to be considered when evaluating the field performance as they can have a significant effect on the design of both the steam field plant and the end users equipment. If unrealistically high generation pressures are assumed then the plant efficiency and viability may be significantly affected.

Knowledge of the geothermal fluid chemistry is also essential. It is necessary to understand the concentrations of dissolved solids and the mass flow of non-condensable gases (NCG) as these will have an impact on heat transfer, fluid fouling and corrosion issues. These parameters can the dictate the acceptable range of operating conditions for the fluids. In particular high levels of dissolved solids or NCG's may restrict the extent to which the fluids can be cooled due to potential fouling or changes in chemistry that may cause corrosion.

2.3 The Geothermal Fluid

When considering the best use of the geothermal energy it is necessary to consider in what form the fluid will be used. It may be used as two phase fluid, separated steam or separated geothermal water (brine). Each option has its advantages and disadvantages and these must be evaluated.

Using two phase fluid for a heat source ensures that the maximum quantity of heat is available and potentially allows the most efficient use of the energy available. It however complicates the design and selection of heat transfer plant. This option also requires the largest pipe line size from the production well to the point of end use and then a significant pipe line is required to pipe the condensate and cooled brine to the point of reinjection. If both the production well and point of reinjection are remote then this option may incur significant extra costs for the increased pipe sizes. Topography and hilly country may also make two phase piping less desirable.

The cooling of two phase fluid can also incur some undesirable consequences. It is often difficult to predict what minerals will be deposited. Some of these may be toxic and there are many mechanisms for creating corrosive environments. All these items need evaluation before materials are selected.

Separated water (brine) may be available as a by-product of other geothermal operations (i.e. electricity production). The specific energy levels available are generally low and large mass flows of fluid are required compared to two phase flows and separated steam options. In many instances the energy available is also limited by decreasing solubility of dissolved solids and the necessity to maintain these solids in suspension through to the disposal system. On the positive side these fluids are often of little economic value and there is little competition for their use. These systems are generally only viable when upstream processes do not cool the separated water to the saturation levels of the dissolved solids or if the disposal method is tolerant of the formation of heavy mineral deposits.

The use of separated geothermal steam in the process plant may provide some advantages. The heat exchanger plant design may be more conventional (though NCG's need to be considered) and the selected location of the separation plant may reduce the extent of piping between the production bore, reinjection site and point of use. On the negative side this type of system will incur the significant cost of a separation plant, the heat energy associated with the brine will not be available and the chemistry and risk of corrosion within the transfer plant must be considered with possible reactions between the condensing steam and NCG's present. Disposal of the condensate needs to be considered however due to its relatively benign state and small volume it may be able to be incorporated in the process or disposal to land or shallow reinjection. Some environmental authorities insist that it is reinjected with the separated water.

3. HEAT EXCHANGER PLANT SELECTION

Selecting the design of heat transfer plant with geothermal direct heat use applications is a balance of several parameters. Selecting the operating conditions (temperature and pressure), fluid compositions, heat transfer coefficients, materials and heat exchanger geometry all have a significant impact and will affect the overall performance and viability of the plant.

3.1 Operating Temperature and Pressures

Selecting the operating temperatures and associated pressure for geothermal heat transfer plant is a balance of multiple parameters. The secondary fluid conditions are based on the process being performed. The temperature of the secondary fluid leaving the heat exchanger is often fixed but should be selected as low as possible. The design however needs to consider any implications this may have for downstream plant i.e. lower temperatures will increase the size and cost of any downstream heat transfer equipment such as air heating coils.

The inlet geothermal conditions on the primary side of the heat exchanger need to consider the impact this temperature will have on the heat exchanger size and the production well capacity. Often geothermal heat exchangers are operating with small temperature differences (between primary and secondary fluids) where even small changes in approach temperatures results in significant increases in heat exchanger surface area and costs. These costs must be weighed up against the cost of supplying fluid from the bore field. If geothermal temperatures and the associated pressure are raised to increase temperature differences and reduce heat exchanger size then the separation and well production pressures must rise. This will decrease the mass and energy flow from the well and effectively increase the cost of supplying energy. Some of these costs may be offset by reduced pipe sizes for 2 phase or separated steam lines (due to higher pressures) however this would not offset the cost should an additional well be required.

3.2 Heat Transfer Co-efficient

Heat transfer coefficients are difficult to predict however a realistic estimate is required for a successful heat exchanger design. Generally a coefficient must be selected to allow the plant to operate at design capacity between scheduled maintenance periods. In most instances this is likely to include at least 12 months of operation. Being conservative however will result in significant over sizing the heat exchanger and unnecessary cost. Over sizing can also result in over cooling of the primary fluid and complication with geothermal fluid chemistry, excessive fouling and corrosion in the back end of the heat exchanger.

Review of the chemistry and estimation of fouling rates may provide a basis to select heat transfer co-efficients however the most reliable information can come from comparisons with other installations were parameters can be measured and heat transfer rates calculated. When applying this methodology it is important to ensure operating conditions are similar especially fluid properties and flow regimes.

3.3 Material Selections

Heat exchanger life and material selections are import to the reliable operation of the system. The risk of corrosion of the materials in contact with the geothermal fluids must be considered under all conditions. Often standby or stored plant may be at higher risk of corrosion than operational plant.

Materials must be evaluated on the known operating conditions and the chemistry of the fluids. Materials such as stainless steel and in particular duplex alloys come at significant extra cost (often adding 50-100% to the cost of heat transfer plant) however they seldom eliminate the risk of corrosion under all conditions and they may be at particular high risk when the plant is shut down. This is most likely when fouling occurs and concentration of chlorides can occur. The use of titanium materials will mitigate many risks, however poor availability and the high cost limit its use.

The use of high quality carbon steels along with regular inspection and planned maintenance (i.e. re-tubing) may prove to be the most economic first solution and may provide sufficient information under operating conditions to optimize its life. The controlled deposition of products such as iron sulphides may also provide a suitable barrier to further corrosion.

4. SEPARATION PLANT SIZING

The design of cyclone separation plants and the selection of the separation pressure are fundamental to two phase separation. Separation plants are typically sized by a series of parameters based on the inlet steam velocity and vertical steam velocity within the cyclone separator. The most commonly used parameters are those proposed by Lazalde and Crabtree (1984).

Selecting separation pressures, like heat exchanger selection, is a balance of choosing a pressure that is acceptable for the direct heat use application however this needs to be balanced against the effects on the well performance. The end use will have a minimum practical temperature. As the geothermal separation pressure determines the saturation temperature, the separation pressure dictates the temperature difference across the heat exchanger. Low temperature differences result in higher costs of the heat transfer equipment. This cost needs to be balanced against the decreased production from the well at high pressures and the true cost of this reduced energy production capacity.

The design of the separation plant also needs to take into consideration the location of the plant relative to the production well, point of end use and the re-injection well and its elevation relative to the re-injection system. There is usually an optimum position that results in the most efficient piping system.

Selection of a suitable separator elevation is also important to ensure that the separated geothermal water can be delivered to any heat exchange plant and to the re-injection system without flashing. This will require the review of possible sites, elevations, pipe sizes and pressure drops to achieve the desired outcome. Expensive pumps may be required if sufficient elevation is not available.

5. PIPELINE OPTIMISATION

Pipeline design is primarily affected by the location of relative equipment (wells, separation/heat transfer plant, the end user), the nature of the fluid (steam, separated geothermal water or two phase fluids), the volume flow rate and the available economic pressure drop. To optimise the pipeline cost requires review of all of these parameters. Smaller diameters and minimized pipe lengths typically minimize costs however excessive velocities and pressure drops may cause pipe erosion and will decrease the output from the production well. Pipe sizing and plant location needs to be optimised to achieve the correct balance between well output and piping cost.

6. DEVELOPING A COMPUTER MODEL

Due to the number of piping and heat plant permutations, the uncertainty of some parameters (for example well performance) and the need to optimise plant at many levels Dobbie Engineers have developed several mathematical models to allow the geothermal systems to be evaluated and tested. The models are based on Excel spreadsheets and need to be able to be manipulated to suit individual projects. Two examples are presented in figures 1 & 2.

The normal evaluation process is to identify the end users requirements. This usually includes identifying the energy, temperature and fluid requirements (steam, Medium Temperature Hot Water (MTHW), Low Temperature Hot Water (LTHW)). To meet these requirements via a separator and/or heat exchanger plant it is necessary to select the upstream fluid conditions. This will determine the separation pressure and/or the primary heat exchanger fluid conditions. The selection of these conditions affect the size and cost of downstream heat transfer plant and the output performance of the upstream wells and the effective energy output of each well. The model allows a number of permutations to be tested and evaluated rapidly to optimise the design.

The model is broken down into three areas; the steam production equipment, the geothermal process equipment and the end users' process equipment.

6.1 End Use Requirements

Initially the model must be developed starting at the end use and working back towards the steam field equipment and production wells. The end use temperatures and energy flows need to be determined and the model customized. Typically, these conditions are known and fixed and the upstream equipment and systems need to be designed to meet these requirements. The model can evaluate changes in end use energy demands such as increasing application production rates.

The model may be as simple as identifying a single fluid steam, at a given temperature to supply the end use or it may include cascaded use of energy through a number of process applications at different temperatures and energy flows. The examples provided illustrate the diversity that can be incorporated.

If review of the up steam plant identifies that the geothermal source does not match the end use, it may become necessary to re-evaluate the end users' requirements.

6.2 Steam Field Equipment

The steam field equipment may include a two phase separation plant and/or a heat exchanger system, separated water and re-injection system and a steam/hot water distribution system to the end user.

When a separator is selected, the separator pressure is calculated based on the end users' required temperature/pressure and flow rate. The model then calculates pipe line pressure and temperature losses between the separator heat exchanger and the point of end use. This is used to calculate the separator pressure or heat exchanger conditions.

Where a separator is used the separator and separated geothermal water vessel dimensions are calculated using the Lazalde and Crabtree (1984) correlations. At present heat exchanger plant is modelled based on conservation of energy and the input of typical process temperatures and temperature approaches.

The conditions identified at this stage are used as inputs for the steam field equipment where the well output and two phase piping is evaluated.

The separated or sub-cooled geothermal water left over from the process needs to be re-injected. The re-injection systems are modelled to ensure the fluid can be disposed of. Pipeline system pressure drops are modelled evaluating both static and dynamic losses to determine the final pressure at the reinjection point. If available, the model can include reinjection well injectivity curves and identifies if the required volume can be reinjected as a single phase fluid given the supply conditions. This will identify if reinjection pumping is required.

6.3 Steam Field Supply Systems

The steam field supply systems include the production wells and two phase distribution piping. See figures 1 and 2 where the equipment is identified.

The production well output curves are modelled. This includes current predicted pressure, mass flow and enthalpies. The model can also be provided with future production curves that simulate the likely effects of field run down as the resource is developed. Often direct heat applications are installed on undeveloped fields and it is important to consider the effects of further development of the field.

The two phase production piping is modelled and parameter for mass flow, pipe diameter, equivalent length and insulation thickness are entered. This then calculates the predicted pressure drop and final delivery pressure based on the calculated well performance for a given mass flow.

The model allows the impact of well performance and future run down to be evaluated and the pipe sizing optimised through testing of multiple scenarios to achieve the required flows and pressures at the geothermal process plant (separators or heat exchanges).

7. EXAMPLES

Two examples of how the model can be used are shown in Figures 1 and 2. Figure 1 generated medium temperature hot water at 170^{o} and 150^{o} to be used in timber drying kilns. Figure 2 illustrates a proposal to separate steam and deliver this to a wood fibre process plant.

7.1 Example 1 High Temperature Hot Water to Timber Kilns

In this example, the model has been used to evaluate the use of a high temperature geothermal resource to heat high temperature hot water that is circulated to two timber drying kiln systems. The system uses two heat exchangers connected in series to provide two separate closed pressurized water systems operating at 180^{o}C and 150^{o}C respectively. The heat exchangers are sized to operate in cascade to extract the maximum energy available.

The model allows the initial geothermal flow rate to be selected. The geothermal flow is estimated based on the energy required by the kilns, this is entered into the model and the well performance and pipe line pressure drops are calculated to determine the fluid delivery conditions at the heat exchangers. Various options for two phase pipe sizes and well conditions can be tested to optimise the pipe diameter and evaluate well output scenarios.

The effect of varying the process design of the heat exchangers can be tested. With an iterative process the heat exchanger process can be finalized. The model also allows evaluation of the performance of the secondary hot water circuits, their operating temperatures and pumping requirements.

The reinjection system is modelled to calculate pipe pressure drops and ensure that the fluid remains sub-cooled and with sufficient pressure to enter the reinjection well. The effect of varying pipe sizes and the location of the heat exchangers was tested to determine the best outcome.

The model provided a useful tool to test the effects of varying well capacity, pipe sizing, the location of the heat exchangers and the heat exchanger performance.

7.2 Geothermal Steam Direct Heat Applications

The second example illustrates a simple geothermal steam supply for a wood process plant. The plant requires 13 barg steam to heat air which conveys and dries wood fiber. This pressure has been specified as the minimum practical for the process as lower pressures would significantly increase the heat transfer areas in the process plant. With a known energy requirement the steam flow rate is identified. The model then allows the pipe sizing and plant locations to be tested. The following variables can be reviewed to optimize the installation:

- The location of separation plant can be reviewed as this has an impact on both pipe sizing and the operation of the reinjection system. Choosing the correct location can eliminate the need for reinjection pumps if sufficient elevation is obtained and piping is sized correctly.
- The size of the piping for the two phase, steam and reinjection systems is reviewed to optimise the system performance and to minimise costs.
- The effects of varying the well performance allows the plant to be tested at both current and predicted future well outputs and enthalpies.

Again the model has allowed many options to be reviewed rapidly to ensure the most cost effective solution is put in place and that the plant is suitable for future operation when well performances may have altered.

8. FUTURE WORK

At present the model has been developed to allow the interactive design of the process conditions to select and size process the plant and to identify if there is a suitable match between the geothermal energy source and the proposed end use. The following items are identified as areas of improvement that would add value to the model. These will be developed and applied within future projects.

- **Heat Exchanger Design**
  At present heat exchange information is typically calculated outside the model and entered manually. This could be improved to allow preliminary determination of practical temperature approaches and preliminary sizing of the heat exchanger calculated by mean temperature differences and estimated heat exchanger surface area requirements based on a range of typical heat transfer co-efficients. These heat transfer co-efficients can be established from theory and existing examples currently in operation for both single and two phase fluids. After this initial design, more detailed specialist heat transfer designs can be performed.

- **Cost Estimates**
  The viability of all of these projects typically is measured in payback on the capital cost investment. The installation costs increases with the diameter and length of pipe lines and vessels sizes and these all have an impact on the system pressured drops. Reduced pipe sizes minimises cost however well output typically reduce at increased production pressures. Geothermal energy prices per gigajoule are based on recovering the capital cost of the wells and piping along with operating and maintenance costs. At increased production well pressure the energy flow reduces and the energy cost to recover the capital over the same period increases. If a value is placed on the cost to produce geothermal energy at the well for various pressures, this can be compared with the cost to install above ground piping and equipment of various sizes.

  It is proposed that the model will be developed to allow pipeline costs to be estimated (to ± 30%). With a known well output at a given pressure and the value of this output, then pipeline diameters can be selected to minimise the total project costs. This information will also assist with the development of the capital cost estimates required to show viability of the project.

- **Reinjection Systems**
  At present the model has only been developed to allow the review of gravity reinjection systems – when the model identifies that pumping is required then it could be an advantage to establish the pump head and power requirements. This would add additional information required to evaluate reinjection system options and costs.

Moore.

- **Annual Energy Use & Fluid Take**
  Ideally geothermal energy systems have a continuous 24 hour per day demand throughout the year. This high level of utilisation is generally necessary to justify the capital expenditure. Most processes require regular planned maintenance and down times, these may be weekly or annually and this will impact on total energy use. Other applications such as dairy processing, horticultural or aquaculture will have load variations dependent on weather or other seasonal factors. These are needed to be considered when evaluating the project viability. If shut periods and load profiles can be estimated and input to the model, these will provide further useful information to evaluate the overall system performance and the likely annual return on investment.

9. CONCLUSION

Optimizing a geothermal direct heat system requires the consideration of a large number of variables, some of which may not have accurate data. The models developed have allowed these variables to be evaluated rapidly ensuring that the process is suitable for the application and that the separators, heat exchangers, pipelines and control valves are selected to provide optimum performance. Further development of the model to include installation and operating costs will add to its value as a design tool.

REFERENCES

G. Moore & J. Dobbie.: Clean Steam for Tissue Products, NZGA Seminar, (12 October 2011)

G. Moore.: Direct Use of Geothermal Energy – Clean Steam Generation, NZGA/HERA Above Ground Geothermal Technologies Workshop, (25 July 2014)

G. Moore.: Ngati Tuwharetoa Geothermal Assets Clean Steam Supply to SCA Kawerau Tissue Mill, 33rd New Zealand Geothermal Workshop, (21 November 2011)

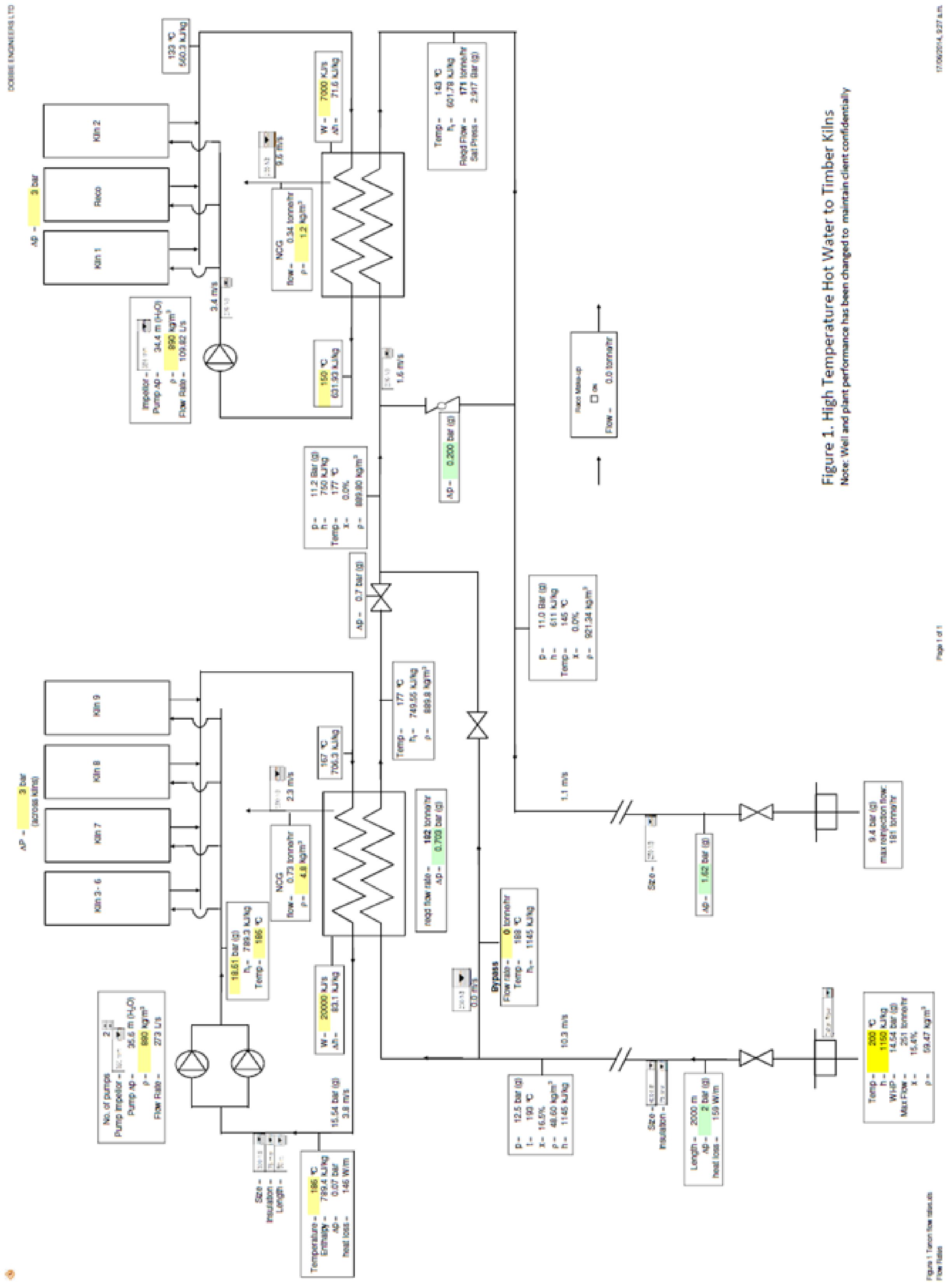

Figure 1. High Temperature Hot Water to Timber Kilns
Note: Well and plant performance has been changed to maintain client confidentiality

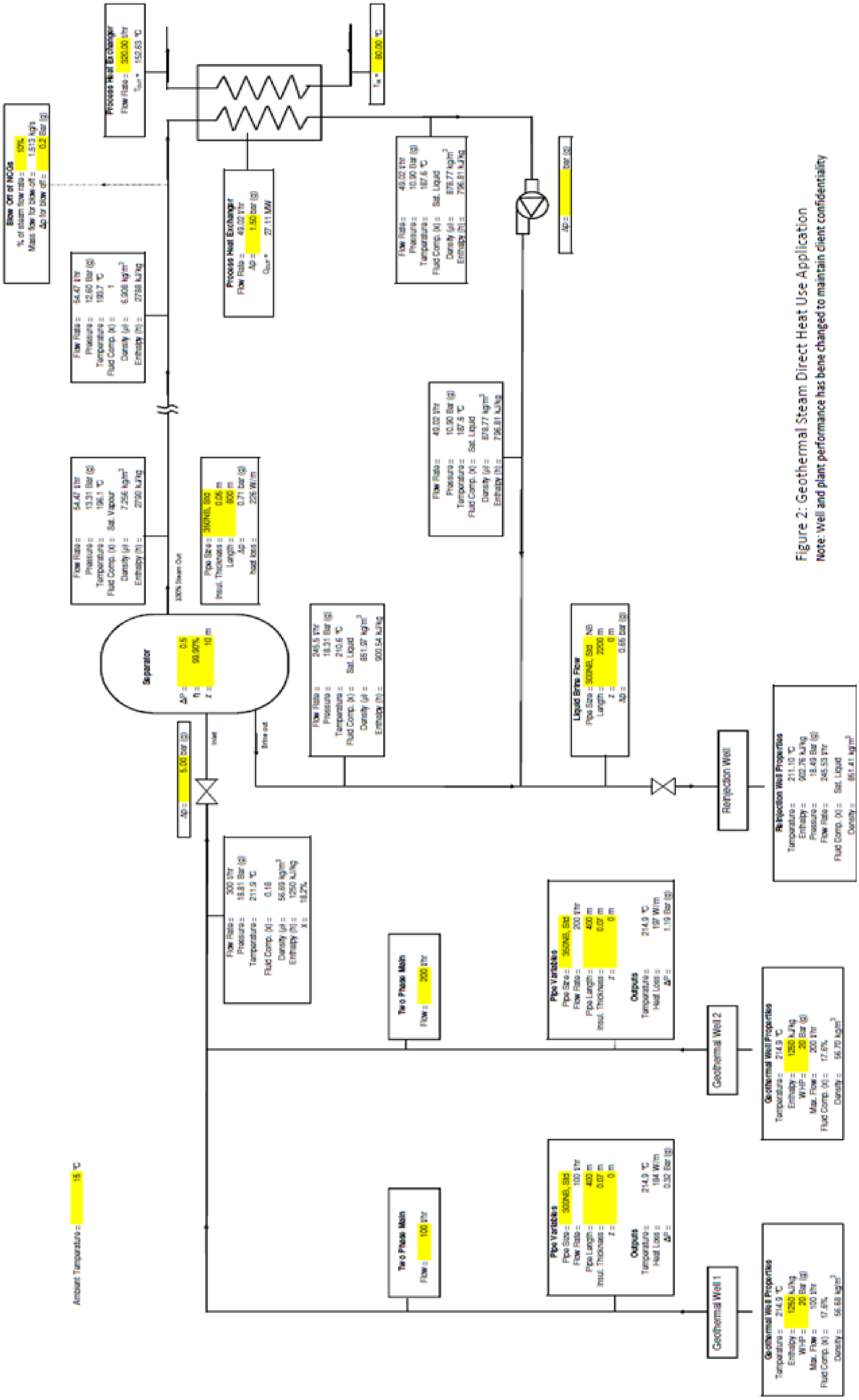

Figure 2: Geothermal Steam Direct Heat Use Application

Note: Well and plant performance has been changed to maintain client confidentiality