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SIMULATION OF A GEOTHERMAL SUPPLY AND REINJECTION PIPE NETWORK

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ABSTRACT

Geothermal supply and reinjection pipe networks are a necessary part of a geothermal utilisation system. The operation and control of such a system depend on the characteristics of production rate, reinjection rate, reinjection pump characteristics, turbine inlet pressure, etc. This paper presents a computer simulator which can be used to simulate the flow characteristic at any point of such a network system. Optimized operational parameters for the system is then given. The simulator can also be used to choose the size of reinjection pumps for a specific system. Computer-plotted diagrams as well as the printout of calculated results give a direct view of the characteristics of the pipe network. The simulator could be an important tool for the management of a geothermal supply and reinjection pipe network.

1.0 INTRODUCTION

The prediction or design of system operational characteristics, mass flow rate versus pressure, are of great importance for the running of a geothermal supply and reinjection pipe network. In most cases this knowledge is required well before the network is built. This is made easy and accurate when a numerical method is used for the calculation routine on a computer. Some of the contributions in this field are the computer simulators which are based on different situations. A numerical simulation of a steam pipeline network in Larderello geothermal field, Italy, was made using simulator VAPSAT1 (Marconcini and Neri, 1976). This work was based on the calculation of superheated steam flowing along a network of nonadiabatic steam pipelines. The objectives are to establish the characteristics of the production well and calculate the parameters of the pressure-mass flow rate curve at the manifold. A later simulator, ACT (Vaca, 1987), gives a wider range of application. It can be used for two-phase steam-water flow, steam and water in a geothemial supply system.

This paper is based on Vaca's work. The reinjection process of the pipe network system is specially treated and considered in this simulator. It can be expected that by use of a proper pipe network simulator combined with those designed for well bore simulation (Teklu, 1989) and reservoir simulation, an extensive simulator could be developed to give a complete systematic simulation for a geothermal production and reinjection system.

2.0 OUTLINE OF ANALYSIS

2.1 General

The model system of the simulator is shown in Figure 1, which consists of most of the main elements existing in a typical geothermal supply and reinjection pipe network. Two-phase pipelines are designed for the model system from production wells to separator 1, as seen in some developed geothermal supply systems. Alternatively, these two-phase lines can be either dry steam lines or water lines, as necessary. The two-stage flashing/separator system is modelled here though a single stage system can be run with minimum changes to the computer code. In fact, the high pressure separated water coming out from separator 1 flashes and produces the steam at intermediate

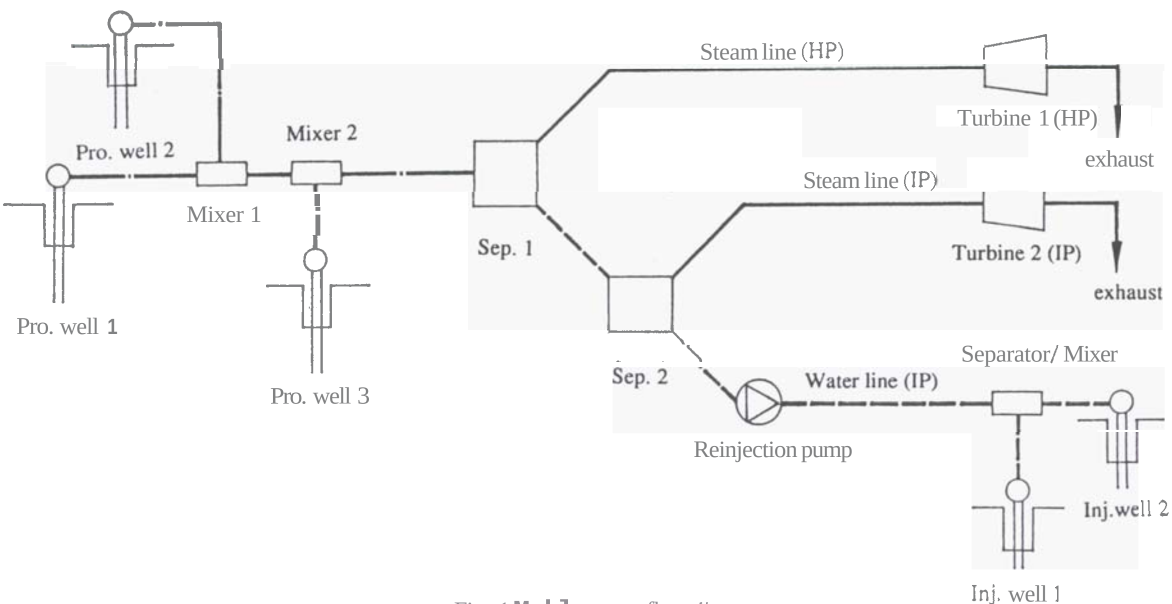

Fig. 1 Model system flow diagrarn.

pressure in separator 2 which then supplies the separated water at intermediate pressure for reinjection. Since the reinjection pump is connected to the supply system at the downstream end and is also connected with reinjection system at the upstream end, the operational parameters of reinjection pumps are affected by both of the systems simultaneously.

2.2 Production and reinjection wells

The well characteristic curves (pressure vs. mass flow rate and enthalpy) for production and reinjection wells are required as the input data for the simulator. It is often given as injectivity for a reinjection well. All the pressures referred to are well head pressures. The output mass flow of the production well is designed as two-phase flow which is connected to a length of two-phase pipe. For a particular case, the two-phase line could be changed into a dry steam line or unsaturated water line when the dryness of the produced fluid is 1 or 0.

2.3 Pipe lines

2.3.1 Two phase lines

Several methods have been developed for the calculation of two-phase flow. Among them, the Lockhart-Martinelli Method is the most frequently used. Since it is found to predict higher values than observations, another method - the Harrison and Freeston method - has been used instead, which showed good accuracy in an experimental two-phase line in Wairakei, NZ (Freeston et al., 1983). Some of the assumptions of the method are:

1) Annular flow;
2) Horizontal or small angle inclined transmission pipes.

The method is described by the following equation:

$$\alpha=\frac{1}{1+\left(\frac{1-x}{x}\right)^{0.8}\left(\frac{\rho_g}{\rho_f}\right)^{0.515}} \quad (1)$$

where α is the void fraction number of two-phase flow, x is the quality of steam, and ρ_g and ρ_f are the density of steam and water.

$$Re=\frac{m_t(1-x)D}{A_t(1-\alpha)\mu_f} \quad (2)$$

where Re is Reynolds number, m_t is total mass flow rate, D is inside pipe diameter, A_t is pipe cross sectional area, and μ_f is dynamic viscosity of saturated water.

The mean density of two phase flow is given by:

$$\rho_m=\alpha\rho_g+(1-\alpha)\rho_f \quad (3)$$

Introduce calculation factor K_1 and K_2:

$$K_1=\left(\frac{m_t(1-x)}{A_t(1-\alpha)}\right)^2$$

$$K_2=\frac{\left(\frac{m_t x}{A_t}\right)^2}{\frac{10^5\cdot P\alpha}{\rho_g}}$$

where P is local pressure of the pipe line.

The pressure drop on a length of pipe AL is given by:

$$\Delta P=\left(\frac{\lambda\Delta l}{D}\frac{K_1}{2\rho_f(1-K_2)}+\rho_m g\Delta Z\right)\cdot 10^{-5} \quad (4)$$

Local pressure, P, of the calculated pipeline plays an important role in the calculation since $\rho_g,\rho_f,\mu_f,R_e,\lambda,$ and ρ_m are all pressure-dependent constants or variables. It is a great advantage to have a computer to deal with this kind of problem.

The pressure drop for pipe fittings are calculated as for an equivalent length of a straight line.

Heat loss is calculated by:

$$\Delta Q=UA_s(T_s-T_a) \quad (5)$$

where U is a global heat transfer coefficient, A_s is pipe surface area, T_s is the local temperature of the pipe flow, und T_a is the atmospheric temperature. This calculation also applies to single-phase pipelines.

2.3.2 Steam pipe line

A saturated "pure" steam without any gas has been assumed. For a superheated steam line, the pressure drop should be very close to the calculated pressure drop using saturated steam properties while the enthalpy calculation might be quite different. The calculations for pressure drop are shown by following equations:

$$Re=\frac{m_s D}{A_t\mu_g} \quad (6)$$

$$V_s=\frac{m_s}{\rho_g A_t} \quad (7)$$

$$\Delta P=\frac{\lambda\Delta L}{D}\frac{\rho_g V_s^2}{2} \quad (8)$$

where m_s is steam mass flow rate, μ_g is dynamic viscosity of steam, and V_s is velocity of steam.

The pressure drop on fittings is calculated by:

$$\Delta P_f=\frac{8m_t^2}{\rho P^2 D^4}\frac{K}{10^5} \quad (9)$$

where K is the pressure loss factor for the fitting.

2.3.3 Water pipe line

Pressure drop calculations for water pipe are the same as shown in equations (6), (7),(8) and (9) using the property of saturated water.

2.3.4 Condensation

Heat losses along the pipe produce water in the steam (condensate) whilst the drop in pressure dries the water-steam mixture. The final condensate produced is a function of both these effects.

For a length of pipe AL as shown in Fig 2, energy and mass conservation equations are expressed as:

$$m_1 h_{g1} = m_2 h_{g2}+m_c h_{f2}+Q \quad (10)$$

$$m_1 = m_2+m_c \quad (11)$$

So the condensate of steam pipe, m_c, can be written as:

$$m_c=\frac{UA(T_V-T_a)-m_1(h_{g1}-h_{g2})}{h_{g2}-h_{f2}} \quad (12)$$

where m_c is mainly dominated by global heat transfer coefficient U and input steam mass flow rate m_1. For a special case when

$$UA(T_V-T_a)\le m_1(h_{g1}-h_{g2}) \qquad (13)$$

the condensate tends to be negative, which indicates, a "drying" process caused by an over-insulated pipe and a large pressure drop along the pipe line. For a geothermal steam pipeline, a certain amount of condensate is necessary for removing the dissolved solids (Cl) and other possible deposits in the steam flow, the saturation described by equation **(13)** should **be** avoided.

The steam traps along the pipeline are designed to abstract all the condensate *so* as to keep the steam in saturated **state.**

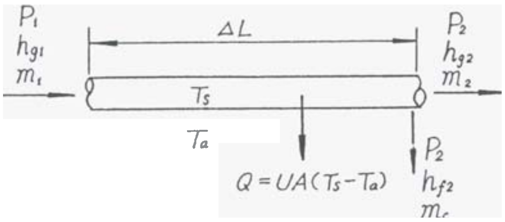

Fig. **2** Energy and mass conservation

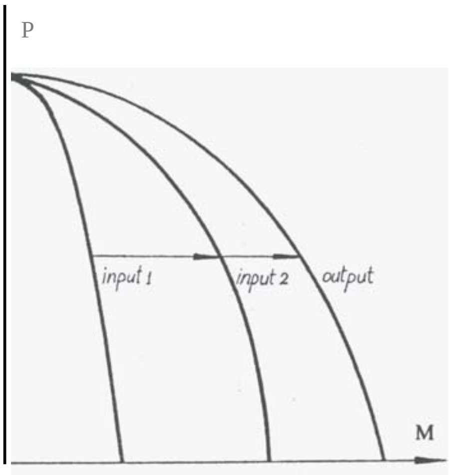

Fig. 3 Mixing process.

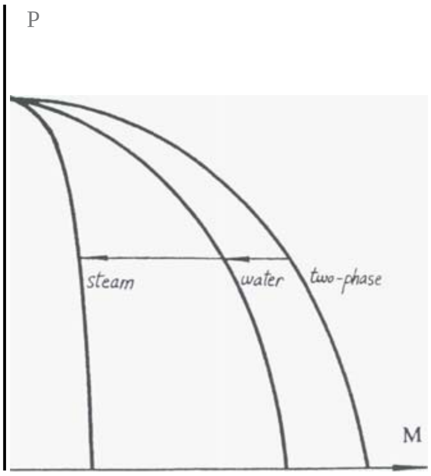

Fig. **4** Separating process.

2.3.5 Mixer

The calculation for the mixing process is based on the mass and energy balance equations. Because of the balance of the two input flows, the pressure in the two inlet pipes should **be** the same, If the pressure drop in the mixer is small enough, the output flow is the sum of the two input flows under the same mixing pressure individually. Then the following equations can be written:

$$P_o=P_{i1}=P_{i2}$$

$$m_o=m_{i1}+m_{i2}$$

$$h_o=\frac{h_{i1}m_{i1}+h_{i2}m_{i2}}{m_o}$$

where subscript "i" indicates the input flow and "o" the output flow. The whole range for mixing is shown in figure 3.

2.3.6 Separator

Two-stage separation is designed for a wider range of applications. The process is considered **to be** similar to that of mixer but in the opposite direction. Under the separation pressure, the input flow is separated into two different steam **and** water flows according to:

$$P_i=P_{og}=P_{of}$$

$$m_i=m_{og}+m_{of}$$

$$x_{i1}=\frac{h_i-h_{of}}{h_{og}-h_{of}}$$

$$m_{og}=m_i x_i$$

$$m_{of}=m_i(1-x_{i1})$$

where subscript "og" indicates output steam, "of" indicates output water, and x_{i1} is steam quality of input flow for one-stage separator or for the first stage of a two-stage separator. For the second stage of a two stage separator, the input flow is the separated water. that has come out from the first stage separation. This separated water has a process of adiabatic flashing between the two stages while the pressure changes from high pressure in the first stage **to** intermediate pressure in the second stage. This makes only a small change in the calculation of steam quality of input flow for second stage separation:

$$x_{i2}=\frac{h_{i1}-h_{of}}{h_{og}-h_{of}}$$

where h_{i1} is input flow enthalpy which has the same value with the separated water enthalpy at high pressure in stage one; h_{of} and h_{og} **are** enthalpies of separated water and steam at intermediate pressure in stage two.

The analysis of the process in a one-stage separator is shown in fig. **4.**

3.0 REINJECTION SYSTEM

Simulation for geothermal reinjection pipe network, especially for those with a supply system, have not been found in the literature to date. For both the existing and future geothermal reinjection pipe network, evaluating and prediction of the operation curve and working range of the system are of great importance for management and design work. This simulator presents a unique method for this purpose.

For a reinjection system, the water head offered by reinjection pumps should overcome all the pressure losses along the system and match with both production and reinjection well curves at the two ends of the system, i.e.:

$$\Delta P_{pump}=P_{inj}-P_{pro}+\Delta P_{pro-inj} \qquad (14)$$

where ΔP_{pump} is water head offered by reinjection pump, P_{inj} and P_{pro} are well head pressures of the production and reinjection wells. $\Delta P_{pro-inj}$ is the pressure loss along the system from production well to reinjection well.

The calculation of $\Delta P_{pro-inj}$ is treated in two separated pans. First, calculate the pressure losses between production well and the inlet of reinjection well, i.e. $\Delta P_{pro-pump}$. Secondly, calculate the pressure losses between the outlet of the pump and reinjection well, i.e. $\Delta P_{pump-inj}$. By this means, both the pipe characteristic curves before and after the pump could be drawn out separately as shown in Figs 5 and 6.

The dotted curve in Figure 5 indicates the curve before reinjection pump if a two-stage separator is considered.

In figure 7, the reinjection pump operation curve is given according to equation (14). This curve is then plotted on the reinjection pump characteristic curves in figure 8, which show directly how the pump matches with the pipe network character.

The results of the reinjection pipe network simulation, shown in Figure 8, presents a method for either checking the operation state of an existing system or designing the reinjection pump for a new system.

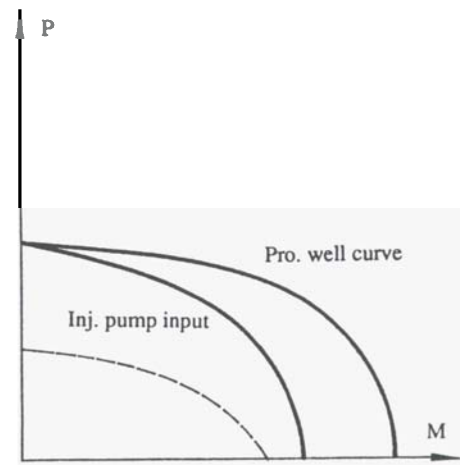

Fig. 5 Characteristic curve of pipe line before reinjection pump.

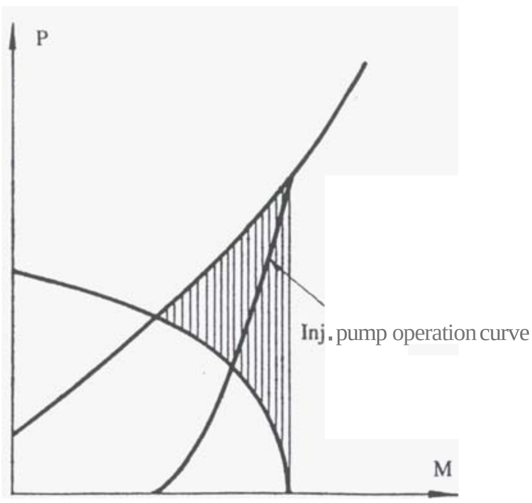

Fig. 7 Reinjection pump operation curve.

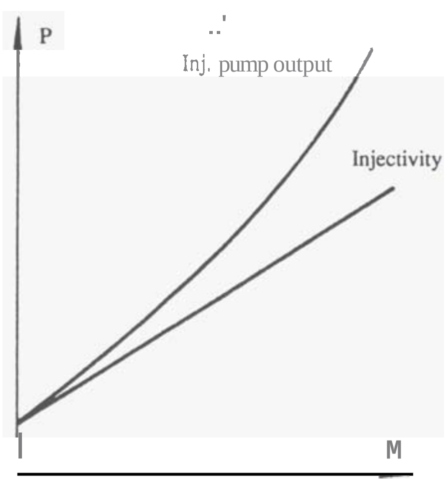

Fig. 6 Characteristic curve of pipe line after reinjection pump.

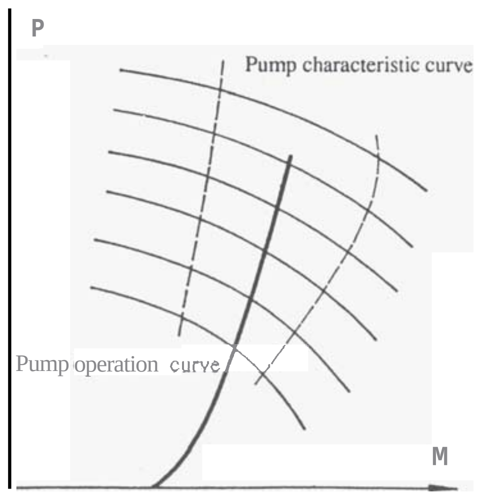

Fig. 8 Simulation result for reinjection pump.

4.0 COMPUTER PROGRAM

4.1 Running the program

The simulator was designed and written in PASCAL Language and could be run on a Microcomputer IBM compatible.

The input of the simulator includes:

1. Production well data
2. Two-phase flow pipe data
3. Steam pipe data
4. Water pipe data
5. Mixer data
6. Separator data
7. Turbine data
8. Reinjection pump data
9. Reinjection well data

The simulation approach is based on both production and reinjection well curves, arid introduces a method of calculation which "transports" this characteristic production through all the elements along the pipe network. One special treatment to reach the characteristic curve at reinjection pump is to start the simulation from both ends, i.e. production well and reinjection well. As both processes reach the reinjection pump, the result for simulation can be shown as in fig. 8.

The program is able to define up to 25 items of equipment (i.e. well, mixer, separator, turbines, pumps). All this equipment can be defined with some key parameter. Updating of the equipment files is done by interactive procedures which minimize human error and optimize the time expended to input the data. Then, other interactive procedures are run to build up a certain system set so that it can be checked all the time on the screen by condensed graphics.

One of the advantages of the designed simulator is the modular approach. This means that the items of "equipment" have their own procedures, making it possible to replace and update all the modules depending on the new procedures, correlation, and machines etc.

4.2 Testing and evaluating

The work for testing the simulator shows a satisfactory result.

The steam table calculation used in the program has been found to have less than 2% deviation when pressure is less then 50 bar. This is accurate enough for most geothemial surface engineering problems. The calculation results for pressure drop and condensate have also been checked and have a good agreement with manual-calculation as well as some field records.

A simulation has been made for part of a geothermal supply and reinjection pipe network using this simulation. The results were given in the form of a table print-out and plotted curves. The characteristic curves along the pipe network could be "read" directly from the simulation results. The operational curve of the reinjection pump shows satisfactory agreement with the field record.

5.0 SUMMARY

1. A computer simulator for the geothermal supply and reinjection system has been set up. Input for the simulation are the production and reinjection well data, pipe characteristics, equipment operation parameters, etc. Outputs include the characteristic curves (mass flow vs. pressure) of the equipment in the network. Table print-out is also given for the detailed results
2. The simulator is designed for a pipe network which includes two-phase line, steam and water line, mixer and separator, injection pump which are connected to production and reinjection wells. The two-stage separator is designed for a wider range of use. The operational curve for the reinjection pump is reached by "transport" of the characteristic curve from both production and reinjection wells towards the reinjection pump.
3. A simulation for a geothermal supply and reinjection pipe network shows satisfactory results on the operation of the reinjection pump.
4. This simulator can be used either for checking and improving the existing pipe network, or for predicting and designing a possible pipe network. It offers a convenient tool for the management and operation of a geothermal supply and reinjection pipe network.

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SPHALERITE AND CHLORITE GROWING INTO CAVITIES, Br16 CORE.
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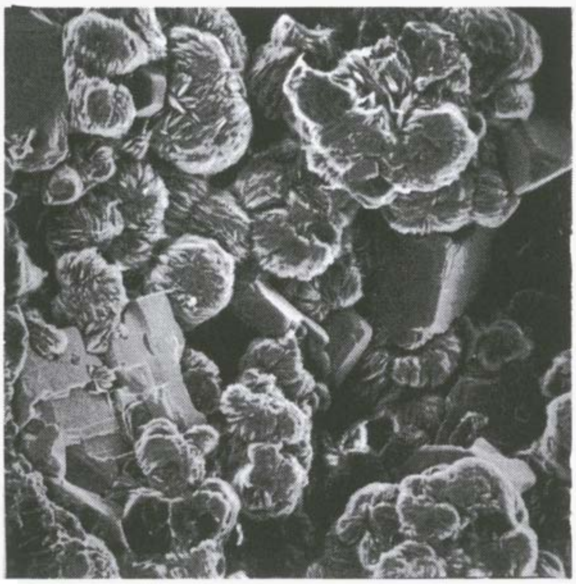

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