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

Thermal Efficiency of the Los Humeros Geothermal Field Fluid Transportation Network

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Keywords: Los Humeros, transportation network, thermal performance, efficiency, heat and mass losses.

ABSTRACT

First and Second Law thermal efficiencies the Los Humeros geothermal field (LHGF) fluid transportation network were evaluated from mass, energy and exergy flows at different points of the network, including mass and heat losses from the pipelines, fittings, condensate drains and steam separators. Efficiencies of the transportation sub-processes and overall steam field (wellhead to power plant inlet) were evaluated. The 1st law efficiency between wellheads and the wells flow measuring orifice plates was found to be 100%, while the corresponding 2nd law efficiency was 91.4%. The transportation network, between the wells flow measuring orifice plates and the power plant steam delivery points, showed 1st law and 2nd law efficiencies of 93.5% and 90.5%, respectively. For the overall steam field, the 1st law efficiency was 93.5% whereas 2nd law efficiency was 82.7%. The analysis excluded the existing power plants..

1. INTRODUCTION

Geothermal power plants are normally fed with the fluid from producing wells which are sited a few hundred of meters or even several some kilometers away. The produced fluid is transported to the power plants through complex pipeline networks with varying complexity, interconnectivity and physical conditions of their components. The fluid being transported may be either single phase (separated steam or water) or two-phase water-steam mixtures. Thus, the performance of the pipeline transportation network is affected among others, by the type of fluid being transported (one- or two-phase), the network geometry and complexity, the actual thermal insulation condition and steam field operating strategies.

Analysis of geothermal fluid transportation and performance of gathering networks, often including power generation units, appears to have started with the evaluation of a small network of Larderello (Marconcini and Neri, 1979). Later on, studies of different geothermal fields appeared in the literature several (Betaggli and Bidini, 1996; DiMaria, 2000; White and Morris, 2000; Quijano, 2000; Kwambai, 2005; Kaplan and Schochet, 2005; Aqui et al., 2005; Otzurk et al., 2006).

In Mexican geothermal fields, Garcia-Gutierrez et al. (2006, 2009) carried out simulation studies of the Cerro Prieto and Los Azufres geothermal fields, which included optimization of some study cases- Later, Garcia-Gutierrez et al. (2012) carried out an overall assessment of the Cerro Prieto network thermal-hydraulic performance whereby a series of opportunities for improving energy utilization of the produced energy within the field were detected. In a further study, Garcia-Gutierrez et al. (2015) performed an energy analysis of the CPGF fluid transportation system and evaluated its thermal performance and the source of main energy losses.

The present paper describes an evaluation of the LHGF fluid transportation network thermal performance. The study is a snapshot of the steam field operation on June 2012 while operating on steady-state mode. It covers only the fluid production and transportation system, composed of the production wells and the pipeline network for fluid transportation to the power plants.

2. DESCRIPTION OF THE LHGF FLUID TRANSPORTATION NETWORK

The LHGF is the third geothermal field in importance in Mexico, after Cerro Prieto and Los Azufres. It started commercial operation in 1990 and currently there are eight back-pressure units of 5 MWe each with a total operating capacity of 40 MWe. The more recent unit (Unit 8) was commissioned in April 2008 (Gutiérrez-Negrin et al., 2010). At the time this study was carried out two-25 MWe condensing power plants (U-9 and U-10) were under construction and near to be commissioned as part of project Humeros II (Vazquez-Sandoval, 2011).

The eight power plants are fed with steam from 21 producing wells which produce a mixture of steam and water with steam qualities in the order of 90% or more. The mixture is not separated at the well but is conducted to the power plants through a complex network of pipelines, approximately 20 km long, and then separated just before entering the generating units. The network is oriented in the North-South direction and is divided into three areas: North, Central and South zones (Fig. 1), which are interconnected by a 7 km long, 24” in diameter pipeline. In the network, pipeline diameter values range from 8 to 30”.

The North Zone is the largest one with 5 generating units installed (U-1, U-4, U-5, U-6 and U-7) which are fed by 14 wells (H-03, H-09, H-11, H-15, H-17, H-19, H-20, H-30, H-31, H-32, H-34, H-35, H-37 and H-44). Two other wells, H-33 and H-43, are also connected to this network but they are currently out of service. Units U-4, U-5, U-6 and U-7 are fed by a pipeline gathering the fluid produced by ten wells, which is known locally as “ring collector duct” (Rosales-Lopez, 2006). Unit U-1 is located separately from the rest although it is interconnected to unit U-4 by a 16” duct that allows two wells (H-35 and H-37) to send fluid to either of these two units. The two new 25 MWe generating units mentioned previously are located at the northern edge of this area.

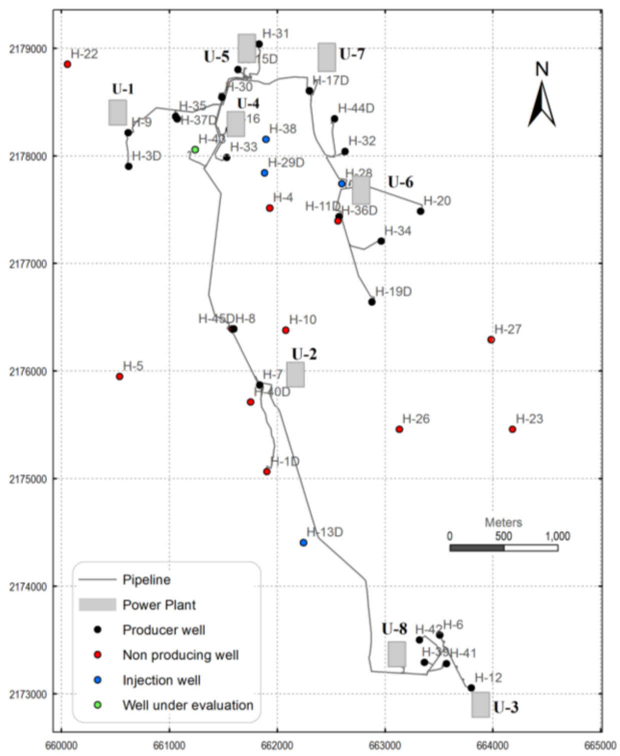

Figure 1. LHGF fluid transportation network.

The Central Zone is located approximately half distance between the North and South zones. Unit U-2 and wells H-07 and H-45 are located in this zone. In addition unit U-2 also receives excess steam from the South zone through the 24" duct. Units U-3 and U-8 are installed in the South zone and are fed by five wells: H-06, H-12, H-39, 41-H and H-42.

A system of collectors and interconnections in the North and South areas allow flexibility for steam delivery to any sector of the field where required, particularly in the northern zone of the field where the fluid production and power generation are more concentrated. The network operation is controlled by gate and butterfly valves. Also, throughout the network there exist various valves, usually manual type, which helps to control the flow and distribution of the fluid. The flow of steam entering the turbine is controlled by regulating valves operated automatically from the central control room.

3. THEORETICAL ASPECTS

Energy and exergy are defined (DiPippo, 2005) as

$$e_n = m\ h \tag{1}$$

$$e_x = m\left[\left(h_i - h_o\right) - T_o\left(s_i - s_o\right)\right] \tag{2}$$

where e_n denotes energy, e_x is exergy, *h* enthalpy, $\dot{m}$ mass flow rate, *s* entropy and T temperature, the index *0* denotes the reference state or ambient conditions and index *i* indicates the system conditions at point i.

Energy and exergy efficiencies are given by:

$$\eta_{e_n} = e_{n_{out}} / e_{n_{in}} \tag{3}$$

$$\eta_{e_x} = e_{x_{out}} / e_{x_{in}} \tag{4}$$

where η denotes efficiency and the indexes in and out denote inlet and outlet.

The power obtained by steam expansion in a turbine is given by

$$P = m\ \eta_t\ (h_1 - h_{2s}) \tag{5}$$

where P is power, $\dot{m}$ is steam mass flow rate, η_t *is* turbine isentropic efficiency, h_1 is the steam enthalpy at the turbine inlet and h_{2s} is the steam enthalpy after the isentropic expansion process.

4. NETWORK PERFORMANCE

In order to evaluate the LHGF fluid transportation network performance mass, energy and exergy flows were estimated using operating and environmental data of June 2012. These quantities were evaluated at three boundaries: B1 (wellhead), B2 (the wells flow measuring orifice plates located near each well, and B3 (the power plant steam delivery points from the steam field). Once these quantities were known, the partial and overall efficiencies were estimated. The evaluation was complemented by an estimation of the heat losses from the pipelines and fittings. Fig. 2 shows schematically these boundaries and the corresponding mass, energy and exergy flows.

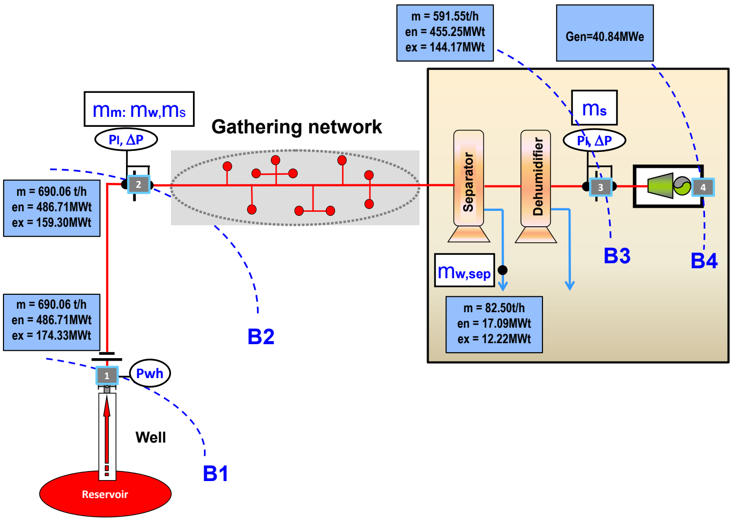

Figure 2. LHGF boundaries showing the computed mass, energy and exergy flow rates.

From Fig. 2 it is seen that there are no energy losses from wellheads (boundary B1) to the well measuring plates (boundary B2), while exergy losses between these boundaries amounted to 15.03 MWt, due to the pressure drop through the production orifice. The energy losses during fluid transportation between the wells flow measuring orifice plates (boundary B2) and the power plants steam delivery points (boundary B3) amounted to 31.46 MWt, while exergy losses were 15.3 MWt. The main sources of energy and exergy losses in the network are due to heat transfer through the pipeline insulation and fittings, pipe legs, condensate purges and flow friction.

The energy and exergy carried by the steam to the power plant delivery points (boundary B3) amounts to 455.25 MWt and 144.17 MW, respectively, while the generated power was 40.84 MWe (boundary B4). The losses of energy between these two boundaries are associated with the conversion of thermal energy into electrical energy in the power generating units. Finally, the total water flow rate obtained from the separators was 82.5 t/h and had a residual energy of 17.09 MWt and an exergy of 12.22 MWt. Fig. 3 shows the energy and exergy efficiencies for the individual sub- and overall process.

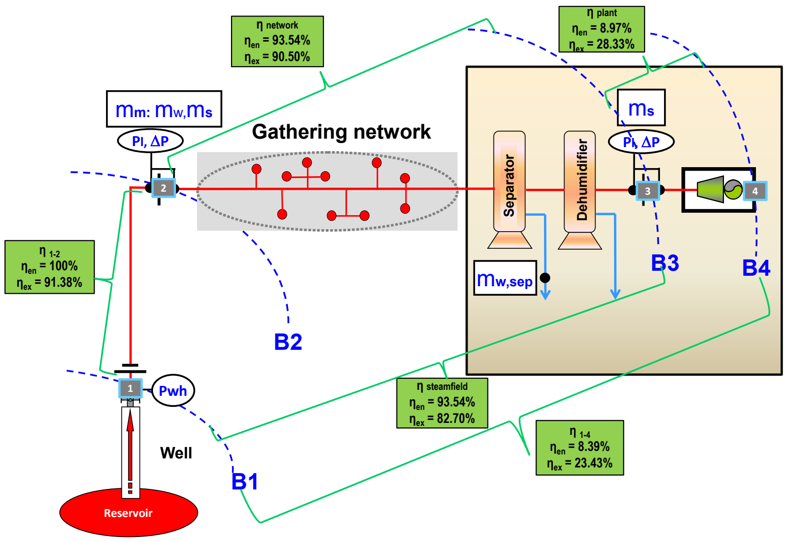

Figure 3. Energy and exergy efficiencies of the individual and overall flow processes.

The energy efficiency between wellheads (boundary B1) and the wells flow measuring orifice plates (boundary B2) was found to be 100%, while the corresponding exergy efficiency was 91.4%. The transportation network comprised between the wells flow measuring orifice plates (boundary B2) and the power plants steam delivery points (boundary B3) showed energy and exergy efficiencies of 93.5% and 90.5%, respectively, whereas the overall steam field efficiency, between wellheads (boundary B1) and power plant steam delivery points (boundary B3) had an energy efficiency of 93.5% and an exergy efficiency of 82.7%. The power plant energy efficiency, defined as the ratio of gross power generated and the energy delivered at the inlet of the power plants (boundaries B4 and B3) was 9.0%, while the corresponding exergy efficiency was 28.3%. The overall energy efficiency, defined as the ratio of gross power generated and the energy extracted from the reservoir at the wellhead level (boundaries B4 and B1) was 8.4% while the corresponding exergy efficiency was 23.4%.

Energy and exergy efficiency values of the LHGF fluid transportation network are between the corresponding efficiency values determined for the Cerro Prieto geothermal field high- and low-pressure steam transportation networks (Garcia-Gutierrez et al., 2012).

The mass balance of the LHGF fluid transportation network is shown in Fig. 4. It is observed that total fluid extraction from the reservoir was 690.06 t/h of which 16.01 t/h were extracted from the pipelines drains as condensate, 82.50 t/h were separated water and 591.55 t/h were delivered to the power plants as steam. All these quantities were computed from field production data.

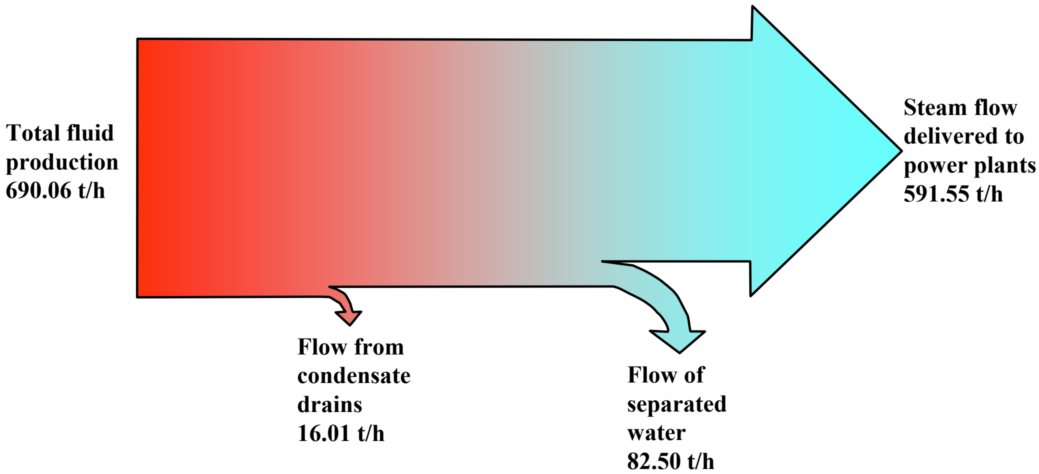

Figure 4. Mass balance of the LHGF fluid transportation network.

Total thermal losses from the pipeline network were computed from the difference of energy flows at the pipeline network exit (or power plant delivery points) and inlet (the wellhead of the wells). The operational data corresponding to the selected study date were used to estimate these energy flows. Subsequently, the thermal losses from the pipeline network were subdivided into losses through pipeline insulation materials, fittings, pipe legs or supports, separated water and condensate drains. Flow friction has a very small effect on energy losses. The energy losses from the pipelines were computed from a detailed field inventory of the physical condition and thickness of the insulation materials and the thermal conductivity data of the commercial insulations which fulfilled the design specifications of the LHGF pipelines. Estimation of thermal losses from pipeline fittings and legs followed the procedure described by Ovando-Castelar et al. (2012). The energy losses from the condensate drains and separated water were estimated from the corresponding flow rates and their pressure and temperature conditions.

It was found that the total energy losses from the entire pipeline transportation network amounted to 31.46 MWt (boundaries B1 and B3 of Fig. 2), of which 17.09 MWt correspond to the residual energy of the separated water, 3.37 MWt to heat losses through the pipeline thermal insulation, 0.1-0.2 MWt are due to losses in pipeline fittings and legs, and 10.93 MWt are heat losses from the condensate extracted at the pipeline drains. Fig. 5 shows the energy balance for the entire pipeline network. The combined energy losses through pipeline insulations, fittings and legs represent 11% of the total energy lost in the fluid transportation network. The energy losses through the pipeline insulation are equivalent to the condensation of 6.12 t/h of steam or 0.43 MWe, whereas the losses through fittings and supports give rise to the condensation of 0.38 t/h of steam which are equivalent to 0.027 MWe.

5. CONCLUSIONS

The evaluation of the thermal performance of the Los Humeros geothermal field (LHGF) fluid transportation network indicates that 1st and 2nd law efficiencies between the wellheads and the wells flow measuring orifice plates are 100% and 91.4%, respectively. For the transportation network, the 1st law efficiency was 93.5% whereas the 2nd law efficiency was 90.5%. For the overall steam field, the respective1st law and 2nd law efficiencies were 93.5% and 82.7%, respectively. The overall 1st and 2nd law energy efficiencies, defined as the ratio of gross power generated and the energy or exergy extracted from the reservoir at the wellhead level were 8.4% and 23.4%.

Total energy losses in the fluid transportation process were found to be 31.46 MWt of which 17.09 MWt correspond to the residual energy of the separated water, 3.37 MWt to heat losses through the pipeline thermal insulation, 0.1-0.2 MWt to losses in pipelines fittings and legs, whereas 10.93 MWt correspond to heat lost through the fluid extracted at the condensate drains. Energy losses related to pipeline insulations and fittings add up to 11% of the thermal energy lost through the network, which are equivalent to 0.43 MWe.

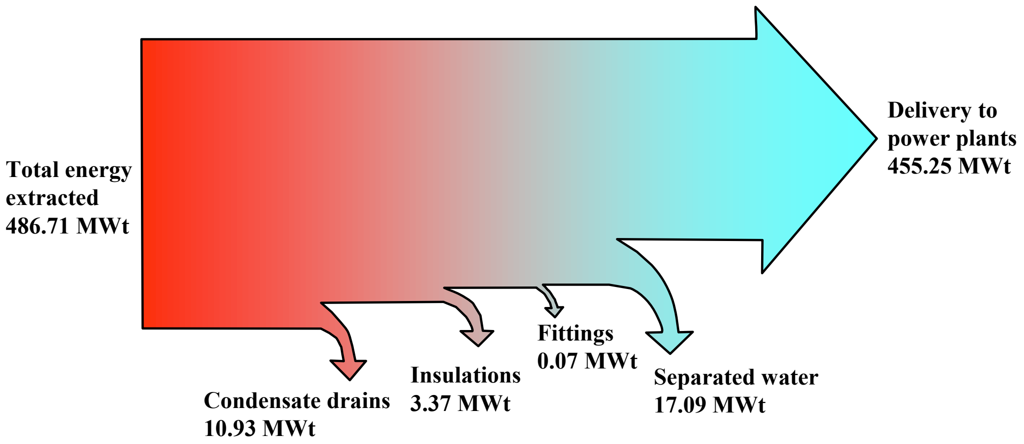

Figure 5. Energy balance of the LHGF fluid transportation network

Acknowledgements. Thanks are due to the authorities of Comisión Federal de Electricidad and Instituto de Investigaciones Eléctricas, Mexico, for permission and support to publish this work.

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