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

Energy Recovery in the Cerro Prieto Geothermal Field Fluid Transportation Network

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Keywords: Cerro Prieto, transportation network, thermal performance, energy losses, improved energy utilization

ABSTRACT

An analysis of energy recovery in the Cerro Prieto Geothermal Field (CPGF) fluid transportation network was performed to determine the potential for energy utilization improvement. Six areas of opportunity were considered. Four of them involve diverse alternatives for energy recovery in the steam gathering network, one for energy recovery from the separated water, and one to reduce heat losses from the pipelines and fittings. The analysis shows a potential for installing 71.6 MWe of additional power which represents an increase of 9.9 % over the field installed capacity of 720 MWe. In addition, it is possible to gain an equivalent of 11.2 MWe by reducing heat losses from the steam transportation pipeline network and fittings. Hence, by maintaining the same rate of fluid and energy extraction and the same number of producing wells, it is possible to increase the field energy utilization by 83 MWe or 11.5 % of the present installed capacity.

1. INTRODUCTION

The CPGF is the largest liquid-dominated geothermal field, and the second largest field, in the world. It is also the oldest Mexican geothermal field as it started electricity generation in 1973. Exploitation and growth with time gave place to a complex gathering system with multiple steam sub- and main collectors and interconnections among the field areas to provide an adequate steam supply to the power plants wherever needed. However, the growth of the gathering network was not optimized and some pipelines operate at higher than needed inlet pressures, with large pressure drops or pressure throttling at the end of the steam collectors to adequate the steam pressure to the power plant inlet pressure. Furthermore, the impact of operational and weather conditions resulted with time in varying degrees of wear, including geometric deformation, loss of the outer cover, replacement of insulation type, or even total loss of thermal insulation in some parts of the pipelines which has increased the system heat losses. The CPGF being a liquid-dominated geothermal field produces about 35-40% of separated water whose thermal energy is unused due mainly to its scaling characteristics. Hence, the departure from operational design specifications of the gathering network components, growth and exploitation with time and operating philosophy are some of the factors that affect the fluid transportation network thermal performance. In the case of the CPGF, the size, complexity, interconnectivity, physical condition of the pipes, thermal insulation and operating philosophy are some of the factors that affect the fluid transportation network thermal performance such that it is possible to improve utilization of the energy extracted from the reservoir and maintain the highest possible rate of electricity generation without any additional wells.

Energy and exergy analysis of geothermal fields started in the late 70´s with the analysis of a 6-well network of Larderello (Marconcini and Neri, 1979). But it was not until the mid-90´s that more studies continued to appear in the literature when an energy-exergy analysis of the Larderello-Farinello-Valle Secolo network was published (Betaggli and Bidini, 1996). White and Morris (2000) did an energy and efficiency audit of the Wairakei geothermal power plant operation with operational data of 15 February 2000. DiMaria (2000) studied a pipeline network operating under design and off-design conditions. Quijano (2000) analyzed the exergy flows of the Ahuachapan and Berlin geothermal fields. Kwambai (2005) studied the Olkaria-I power plant and computed exergy flows and efficiencies of the production and separation processes. The fluid transportation was analyzed and improvements to the plant were suggested. Kaplan and Schochet (2005) analyzed ways of improving geothermal power plant performance and stated that additional generating capacity could be obtained without drilling new wells. Aqui et al. (2005) carried out an exergy assessment of the Palinpinon production field and found that the current power generation can be increased significantly with the existing steam production. Otzurk et al. (2006) analyzed the Kizildere geothermal power plant, Turkey, and determined energy and exergy efficiencies and destructions in the plant. Garcia-Gutierrez et al. (2009) evaluated the network thermal-hydraulic performance of the CPGF and detected a series of opportunities for improving the network performance and the energy utilization of the produced energy within the field. A summary of these results are described by Garcia-Gutierrez et al. (2012).

This paper describes the evaluation of several areas of opportunity with potential for improving utilization of the energy extracted from the reservoir. The study is a snapshot of the plant´s operation on June 2009 while operating on steady-state mode. It covers only the fluid production and transportation system, i.e., the production wells, the steam gathering network and the separated water handling system. It excludes the existing power plants.

2. DESCRIPTION OF THE CPGF STEAM GATHERING NETWORK

The CPGF has an installed capacity of 720 MWe and comprises four areas; i.e., Cerro Prieto-1 (CP1), Cerro Prieto-2 (CP2), Cerro Prieto-3 (CP3) and Cerro Prieto-4 (CP4). The field has thirteen condensing power plants (Gutiérrez-Negrin et al., 2010), however, the four 37.5 MWe units of CP1 have been decommissioned and the current operating capacity is 570 MWe. The power units are fed with the steam of 165 producing wells through a complex pipeline or gathering system that includes high-pressure (HP) and low-pressure (LP) as well as a network for transporting two-phase mixtures of water and steam. The networks have lengths of 92.1 km, 47.6 km and 26 km, respectively, totaling 165.72 km. Pipeline diameters range from 203.2 to 1219.2 mm (8 to 48”). Originally, the pipelines were thermally insulated with a 50.8 mm (2”) thick mineral wool or fiberglass insulation and an outer protection (cover) of aluminum or galvanized iron.

Steam is separated at each production well and individual pipelines transport steam to the sub- and main collecting ducts, or branches. The network is highly complex and has several arrangements for steam separation. CP1 has HP steam separation only, whereas CP2, CP3 and CP4 have both HP and LP separation. In CP2 and CP3 there are also several “sites” for steam separation. In such a “site” the HP steam is separated first and the separated water is sent to the LP separator together with the brine from other neighboring wells. In CP4 there are “separation islands”, which are square areas, divided into four modules. Each module has four HP separators that receive the two-phase flow from individual wells to separate the HP steam. Then, the separated water of the four streams is mixed and fed to a single separator to obtain LP steam. There also exist some auxiliary wells, which do not actually produce water or steam, but their facilities are used to separate the steam from the mixture produced by a neighbor well. The large majority of the separated water is finally sent to an evaporative pond via open channels, however some of the separated water is reinjected either hot or cold. As a consequence of the pressure level of steam separation, CP1 has eight HP branches, while CP2, CP3 and CP4 have both HP and LP parallel branches, two per field area. The steam transportation network also has several interconnections among the different field areas to ensure an adequate steam supply to the power plants. However, some of the main steam collectors and interconnections operate at high inlet pressures and very high steam flow rates which cause large pressure drops or require pressure throttling at the downstream end to adequate the steam pressure to the power plant inlet pressure. Fig. 1 shows the steam pipeline network of the entire geothermal field.

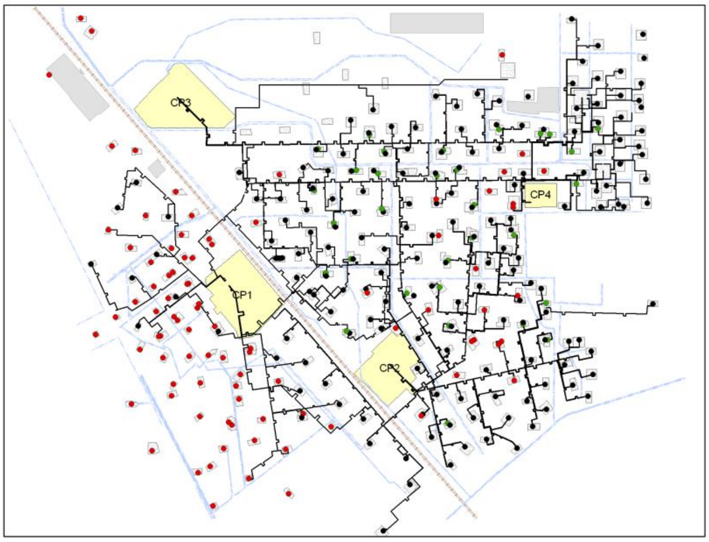

Figure 1. The Cerro Prieto Geothermal Field steam gathering network.

3. THEORETICAL ASPECTS

Energy of a flow stream and power obtained by steam expansion in a turbine are defined (DiPippo, 2005) as

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

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

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

4. AREAS FOR ENERGY RECOVERY

Six areas of opportunity were detected and evaluated to estimate the potential of increasing energy utilization in the field while keeping constant the rate of fluid and energy extraction, without addition of new wells Four cases involve diverse energy recovery in the steam gathering network, one involves energy recovery from the separated water, and one considers reduction of heat losses from the pipelines and fittings.

4.1 Use of a total-flow turbine or a very high-pressure separator-steam turbine system at wells with wellhead pressures at 600 psig or more.

Ten wells met these conditions: two 3-well groups from CP2 and a 4-well group from CP4. This grouping was done according to their location in the field and to make an optimum use of existing installations. The turbine inlet pressure was assumed to be 500 psi (to provide for pressure decline with time) with expansion to 230 psi, so that the resulting fluid could be processed as is normally done in the field: the present high-pressure separation process occurs at 200-230 psi. The power from these wells was computed using Eq. (2) and the mass flow rate of each well, along with turbine efficiencies which were obtained directly from turbine manufacturers. A rotary separator turbine (Fig. 2), a steam turbine and a turboexpander (Fig.3) were considered in this study.

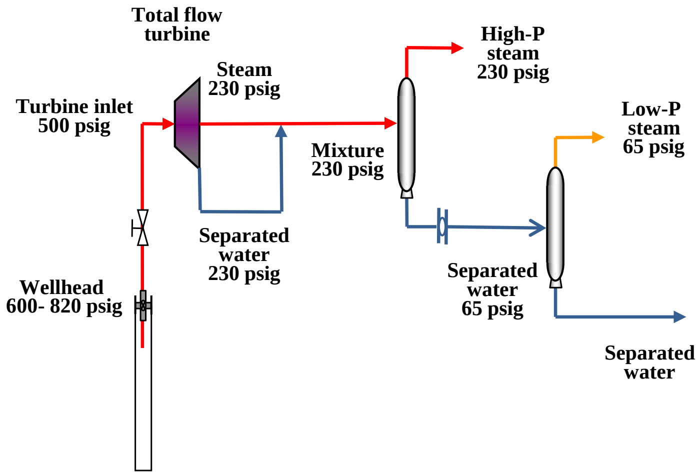

Figure 2. Schematics for energy recovery from with high wellhead pressure wells using a total flow (rotary separator).

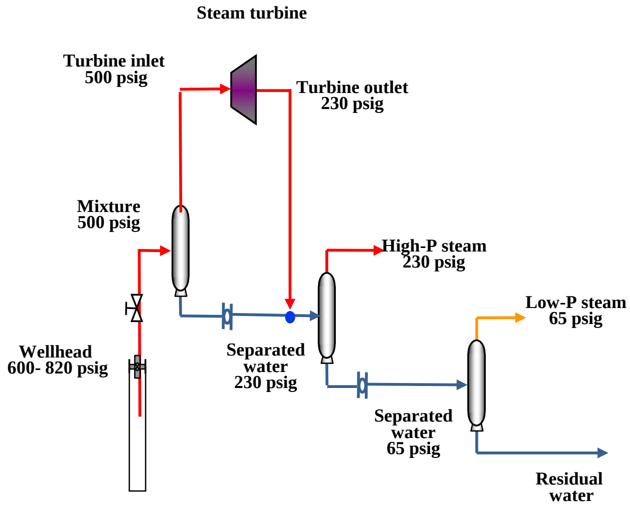

Figure 3. Schematics for energy recovery from with high wellhead pressure wells using a steam turbine or turboexpander.

4.2 Use of the residual energy contained in the separated water.

In the CPGF only steam turbines are installed so that binary cycle power plants could be used to take advantage of the residual energy of the separated water. Only wells producing 30 tons/h or more of separated water at 145°C were considered. Eighty-one wells met these conditions and were grouped into nine clusters or groups of wells according to their location in the field. Each cluster was assumed to have a power plant, and hot water at 140°C was delivered to the power plant, except for CP1 where water was delivered at 120°C, and cooled to 100°C. The thermal energy delivered by the separated water to the power plants was converted to electric power using a graph of efficiency vs. the temperature of the geothermal fluid (Tester et al., 2006). Scaling due to cooling the separated water was not considered. Fig. 4 illustrates the concept.

4.3 Replacement of the regulation valves located just before the inlet to the CP4 power plant by steam turbines in order to take advantage of the pressure drop occurring at these valves.

The power plants of the CP4 area are fed with about 800 tons/h of steam at 145 psi at the delivery point from the steam field. However, just before this point, there are regulating valves that receive the steam at ~180 psi and reduce it to ~150 psi. The study of this case considers replacement of those valves with steam turbines or turboexpanders and estimating the power that would be generated using Eq. (2). The net power takes into account the steam reduction that would be sent to the present power plants after expansion since some condensation will occur. This steam reduction is accounted for by considering the specific steam consumption of the power plants. Fig. 5 shows a schematic representation using a steam turbine and Fig. 6 shows the use of turboexpanders.

4.4 Use of parallel steam pipelines to transport high-pressure steam from the CP2 and CP3 to the CP1 area and use of turbines before entering the CP1 power plant in order to take advantage of the excess steam pressure.

At present, the CP1 power plants are fed with steam from the CP2 and CP3 areas using an interconnection in each case. However the steam flow rate in these interconnections is very high and a large pressure drop occurs along the pipelines so that the arrival pressure at CP1 is low. In this study, it is proposed to add a parallel steam pipeline to each interconnection so that the pressure drop is much lower and the pressure of the steam arriving at CP1 is higher. This higher pressure steam at the inlet of the CP1 power

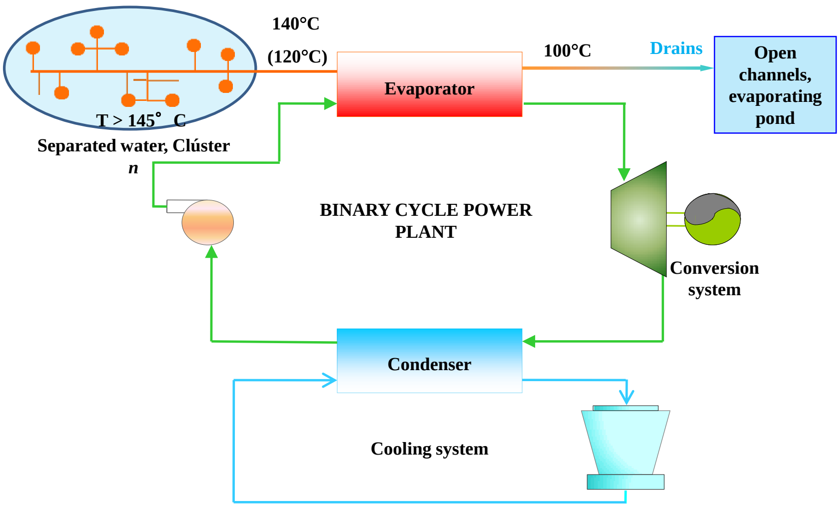

Figure 4.Use of the residual energy in the separated water employing a binary cycle power plant.

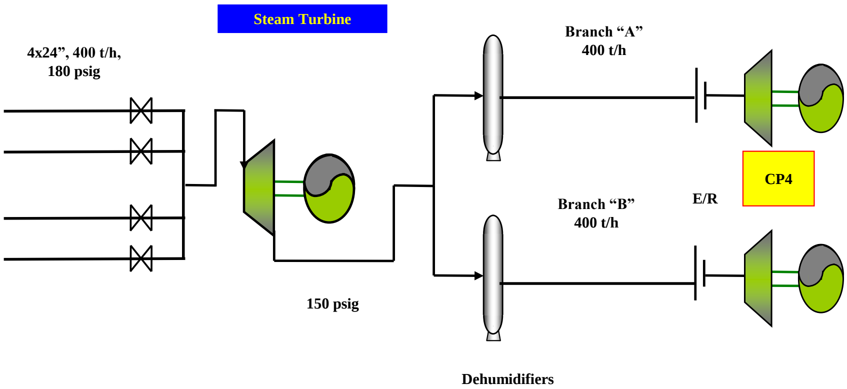

Figure 5.Replacement of the throttling valves at CP4 with a steam turbine.

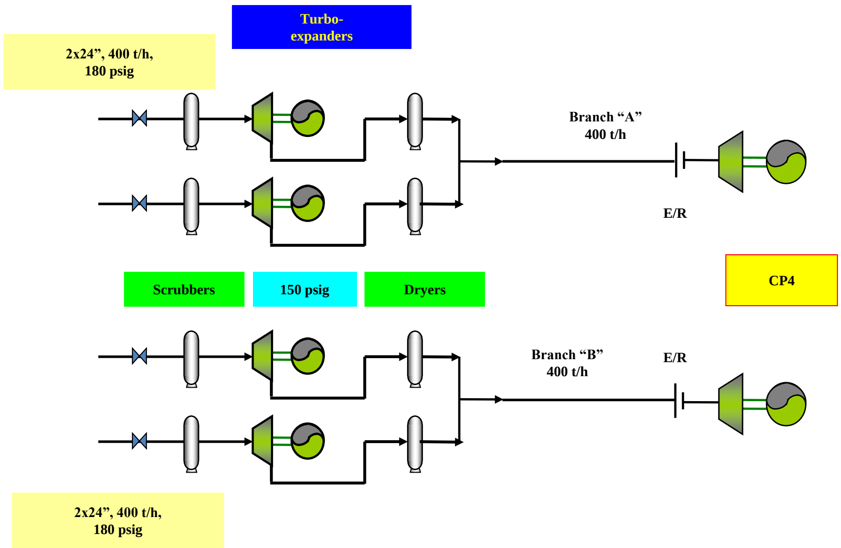

Figure 6.Replacement of the throttling valves at CP4 with a turboexpanders.

plants can be fed into steam turbines to generate additional electricity by reducing the steam pressure to the value required by the present power plants. As in the previous case, the net power takes into account the steam reduction that would be sent to the present power plants after expansion since some condensation will occur. This steam reduction is accounted for by considering the specific steam consumption of the power plants. The CP2-CP1 interconnection carries 375 tons/h of steam at 170 psi. This steam arrives at CP1 at 149 psi in one pipeline or at 159 psi in parallel pipelines. The CP3-CP1 interconnection also carries 375 tons/h of steam at 175 psi. This steam arrives at CP1 at 149.4 psi in one pipeline or at 169.2 psi in parallel pipelines. In each interconnection, a steam turbine is used to expand the steam from the arrival pressure to 110 psi (as required by the actual power plants). Fig. 7 shows the present (top part) and the proposed scheme for this case (bottom part).

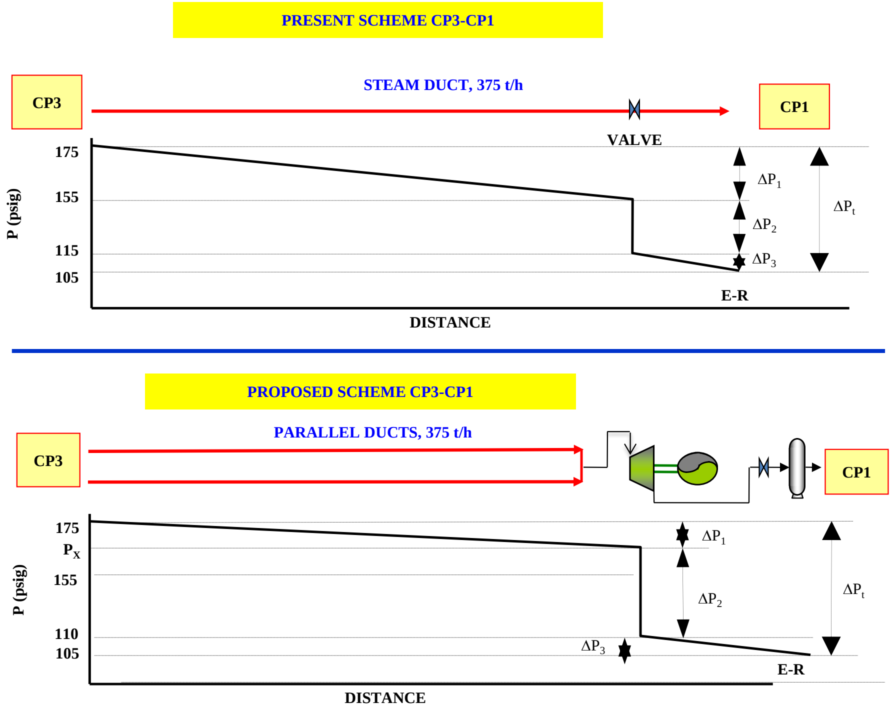

Figure 7. Present and proposed scheme for energy recovery during steam transport from CP3 to CP1.

4.5 Reduction of heat losses from the entire steam and two-phase pipeline networks and fittings.

In the CPGF, the high- and low-pressure steam pipeline networks have lengths of 92.1 km and 47.6 km, respectively, while the two-phase pipelines account for 26 km, totaling 165.72 km. The pipelines have diameters between 8” and 48” and were originally insulated with a 2” layer of mineral wool or glass fiber, and an exterior metallic cover of aluminum or wrought iron. The pipeline fittings are not thermally insulated. Nevertheless, due to the impact of the weather conditions during the time of the field operation, in some parts of the network the thermal insulation has changed compared to its original state and presents varying degrees of weathering, including geometric distortion, loss of the outer cover or replacement by a different insulation, or even the absence of its insulation. In a companion paper (Garcia-Gutierrez et al.,, 2015), it is shown that 18-20% of the thermal insulation of the three pipeline networks is deteriorated, damaged or absent, and the estimated heat loss for all the pipelines that make up the steam transportation network amounted to 72.9 MWt or 17.6 MWe of electric power which represents about 2.5% of the current CPGF installed capacity. In this study, the heat loss reduction due the addition of an extra layer of thermal insulation is analyzed such that each pipeline reaches a total insulation thickness of 2″, 3″ and 4″, considering the diameter of each pipeline and the operating conditions of the field. It is also considered to add a 2″ layer of thermal insulation to the pipeline fittings. The analysis considered three commercial insulation materials: mineral fiber metal mesh blanket-RW-4600, semi-rigid glass fiber board -SCR-fiberglass and tensed glass fiber flexible plate. Semi-rigid glass fiber showed the largest heat losses (or the smallest loss reduction) while the other two materials showed similar heat losses. Due to cost considerations, the third material was chosen for the final calculations. It was found that a 1/2″ thick layer of this insulation reduced heat losses by about 50% but this thickness is impractical so that a 1″ layer of insulation was finally considered.

4.6 Use of a third main collector to transport steam to the CP2 power plant to re-distribute steam flow and to reduce steam separation pressure at the beginning of the steam collectors.

Currently**,** two steam collectors feed the power plants of the CP2 area. The collectors are fed by a number of wells whose separation pressures range from 190 to 200 psi (upstream pressures) and deliver 1,649 t/h of steam at 165.4 psi to the power plants (downstream pressure). This study considers the addition of a third collector in parallel with the present collectors to transport steam from some of the wells presently connected to the existing collectors so that the three collectors approximately balance steam flow and separation pressure. In this way, the collectors would require a lower feed pressure, that is, the wells connected to each collector would operate at lower separation pressures and this could result in a larger volume of separated steam. The additional steam would result in a given amount of extra power generation. The original steam flow rates for collectors 1 and 2 were 715.4 and 933.4 t/h, respectively. Using three collectors and according to the spatial distribution of the wells, the flow rates would now be 573.2, 551.2 and 524.4 t/h for collectors 1, 2 and 3, respectively. However, since each steam collector now transports about 1/3 of the total original steam production, the separation pressure of the wells feeding the collectors may be now somewhat lower. The results show that the new separation pressure of the wells would range between 170 and 175 psi, instead of the original separation pressures of 190-200 psi when using two steam collectors. In this way, the total steam production would increase from 1649 to 1669.1 tons/h, a net steam gain of 18.1 t/h. Fig. 8 shows the present and proposed arrangement.

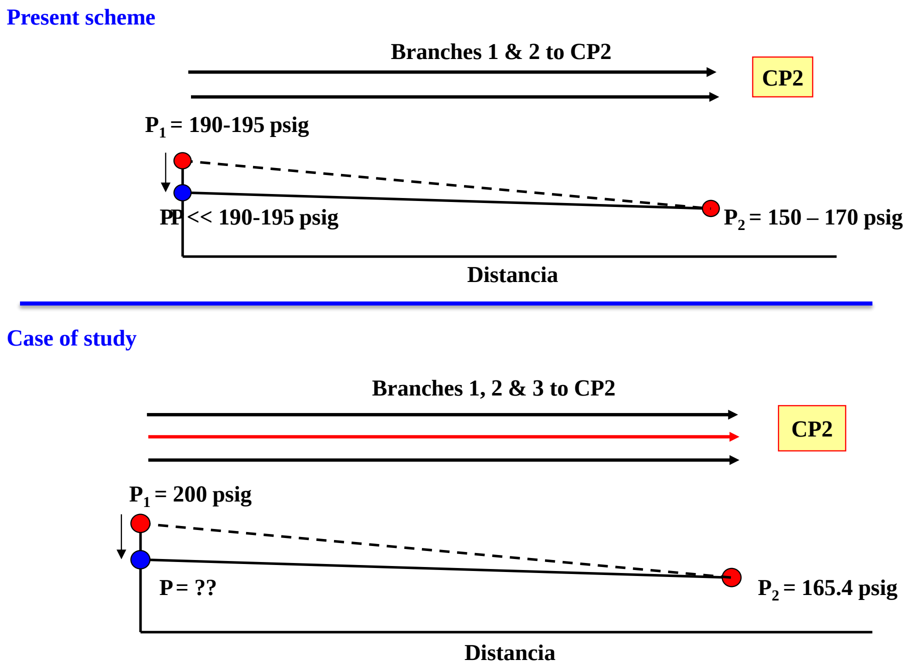

Figure 8. Present and proposed scheme for energy recovery during steam transport to the CP2 power plants.

5. RESULTS

Table 1 shows the results of the actual heat losses from pipelines and fittings, heat loss reduction due to adding thermal insulation and obtainable electrical power. The heat losses from the pipelines and fittings are 17.6 and 1.5 MWe, and these can be reduced to 7.82 MWe by adding a 1″ thick extra layer of thermal insulation to the pipelines and a 2″ thick layer to the fittings, resulting in a net power gain of 11.22 MWe. The use of the very high pressure wells (expansion from 500 to 230 psi) results in 15.1 MWe if a total flow machine is used, 19. 8MWe if steam turbines are used, and 20.7 MWe is turboexpanders are used. It is evident that using turboexpanders is more beneficial. Using binary cycle power plants to recover energy from the separated water shows a power recovery of 32.3 MWe of which 1.5MWe are from CP1 (T=120°C, η=8.95%) and 30.8 MWe are from CP3, CP3 and CP4 ((T=140°C, η=10.77%). The substitution of the regulating valves at the inlet of the CP4 area permits recovery of 4.7 MWe if steam turbines are used, and 5.1MWe if turboexpanders are considered. Again, the use of turboexpanders allows for more power generation. The use of parallel steam ducts to transport steam from CP2 and CP3 to CP1 shows a power generation of 10.2 MWe if steam turbines are considered and 11.0 MWe using turboexpanders. The latter option allows more power generation. The use of a third steam collector in CP2 allows better balance of steam flow and pressure in the collectors, with a reduced separation pressure at the upstream wells and a gain of 2.4 MWe. Hence, the total potential for improved energy utilization in the CPGF is 82.8 MWe: 71.6 MWe of additional power generation within the steam field and 11.2 MWe of equivalent power due to reducing heat losses from the pipelines and fittings. The potential for energy recovery from the pipeline supporting legs is not included.

6. CONCLUSIONS

The size, complexity, interconnectivity, physical condition of the pipeline thermal insulation and operating philosophy have affected the fluid transportation network thermal performance such that it is possible to improve utilization of the energy extracted from the reservoir and maintain the highest possible rate of electricity generation without any additional wells. Opportunities for improving energy utilization include management of the operating pressures of the steam gathering network; use of the pressure drops of some high wellhead pressure wells, pipelines and throttling devices, an increase of the thickness of the pipelines thermal insulation to 3”, and the use of the residual energy of the separated water in binary cycle power plants. The potential for energy recovery amounts to 82.8 MWe of electrical power in the fluid production and transportation system: 71.6 MWe of additional power generation within the steam field and 11.2 MWe of equivalent power due to reducing heat losses from the pipelines and fittings. This potential is equivalent to improving energy utilization by 11.5% over the present installed capacity of the field without additional wells and without added ambient pollution. Turboexpanders offer the best alternative to recover energy in high wellhead pressure wells and in the replacement of pressure throttling devices.

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.

Table 1. Equivalent power due to heat losses and loss reduction using an extra layer of insulation in the HP and LP pipeline network and net obtainable electric power.

RECOVERABLE ENERGY, MWe						
Case	Heat losses from pipeline insulation fittings and legs	Binary Cycle	Total flow Turbine	Steam Turbine	Turbo - expanders	Additional steam
Heat losses due to fluid transport	17.6 + 1.46 + 6.17 *					
Case1: Expansion from 500 to 230 psig			15.1	19.8	20.7	
Case2: Residual energy of separated water		32.3				
Case3: Substitution of valves at CP4 inlet				4.7	5.1	
Case4: Parallel Ducts CP2 & CP3 to CP1				10.2	11.0	
Case5: Extra layer of insulation	7.1 + 0.72 + 0.0 **					
Case6: Third branch in CP2						2.4
SUM	10.5 + 0.72 ***	32.3	15.1	34.7	36.9	2.4
TOTAL POTENTIAL	82.82 (71.6+11.22)					

Notes: *Heat loss from pipelines, fittings and supporting legs; **It is assumed that heat losses from fittings are reduced by 50% when covered with a 2" layer of thermal insulation. Pipeline legs not insulated due to technical and practical reasons; ***Difference of actual heat losses from insulation and fittings and losses using a 1" extra layer of insulation on pipelines and 2" on fittings.

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