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The Potential for Energy Recovery and Electricity Generation in High-Pressure Production Wells and Gathering Systems Using Turboexpanders

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ABSTRACT

The potential for energy recovery and electricity generation in production wells and gathering systems with high pressures currently not used in two geothermal fields is discussed. Losses of available high-pressure include the pressure drop at the wellhead production orifice plates which reduce the wellhead pressure to that of the current steam separation and transportation, and pressure drops occurring in the flow regulation valves of some steam transportation pipelines. Two cases were analyzed, one for the Cerro Prieto Geothermal Field (CPGF) and one for the Los Humeros Geothermal Field (LHGF), which involve the use of a high-pressure steam separator-turboexpander system to take advantage of the pressure drop occurring in the production orifice plate of some wells. The results show a potential of energy recovery equivalent to 20.7 MWe and 10.6 MWe, respectively. A third case involves replacement of two regulation valves located near the inlet of the Cerro Prieto 4 area (CP4) power plants by turboexpanders to take advantage of the large steam flow rate and pressure drop occurring at these valves. The analysis for this case shows a potential for energy recovery of 6.3 MWe. No additional mass or energy needs to be extracted from the reservoir nor would any additional pollution would be involved.

1. INTRODUCTION

In steam production and gathering systems it is common to find high available pressures that are not used advantageously during system operation since they are reduced to pressure levels adequate for steam separation and transport or for steam delivery to power plants at the required inlet pressures. The reduction of such available high pressures results in a waste or loss of important amounts of the energy extracted from the reservoir. Such losses commonly occur at the production orifice plate of geothermal wells which reduce the wellhead pressure to that of steam separation and transportation. Wellhead pressures may range between 300 and 1000 psig while separation pressures may be of the order of 150 to 250 psig, thus pressure drops are large and energy is wasted. Another case of large pressure drops occurs when the steam pressure prior to delivery to a power plant is too large and has to be throttled down to match the turbine inlet pressure.

However, there are alternatives to use advantageously these available high pressures in order to improve energy utilization and to generate additional electricity without additional mass or energy extraction from the reservoir, and with no added pollution. Such an alternative is the use of separator- turboexpander systems at the wellhead of very high pressure geothermal wells to separate and expand steam to a pressure after expansion suitable for normal steam separation and transportation to the power plants. Another alternative is to replace pressure reducing devices of steam pipelines with turboexpanders when the steam flow rate and pressure drop across the throttling devices are high to recover that energy and generate additional electricity.

This paper describes the potential for energy recovery and electricity generation using turboexpander systems in the CPGF and LHGF fields to take advantage of the pressure drops occurring in the production orifice plates of high wellhead pressure wells an in the flow control valves at the inlet of the Cerro Prieto 4 area.

2. BACKGROUND

Turboexpanders, turbo expanders or expansion turbines are centrifugal or axial flow turbines through which a high pressure gas is expanded to produce work that is often used to drive a compressor. Also a turboexpander is defined as a radial in-flow or centrifugal turbine capable of efficient extraction of energy from any high-pressure gas being expanded through it (Lat, 2013). There exist three basic combinations of the expansion unit: (a) expander-compressor; (b) expander-generator, and (c) expander-brake. The expander-generator arrangement may be in three configurations: Expander-Gearbox-Generator; Expander-Generator, and Expander-High-speed Generator. Turboexpanders are high-efficiency, high rotational speed compact units suitable for energy recovery from high-pressure gas streams and their cost may be lower than steam turbines (Cryostar, 2013: Lat 2013). Typical applications include: (i) industrial refrigeration-cryogenic treatment of natural gas to extract some hydrocarbons or oxygen from air; (ii) Air separation in steel or glass plants; (iii) Energy recovery in petrochemical and gas pipeline pressure letdown, and (d) in power generation as in geothermal and ammonia cycles (e.g., Lat, 2013, OC, 2013). Turboexpanders range in size from a few kW up to 10 MW in binary cycle plants and up to 18-20 MW for electricity generation using steam. Fig. 1 shows schematic diagrams of an expander-compressor and an expander-generator, while Fig. 2 shows some views of turboexpanders.

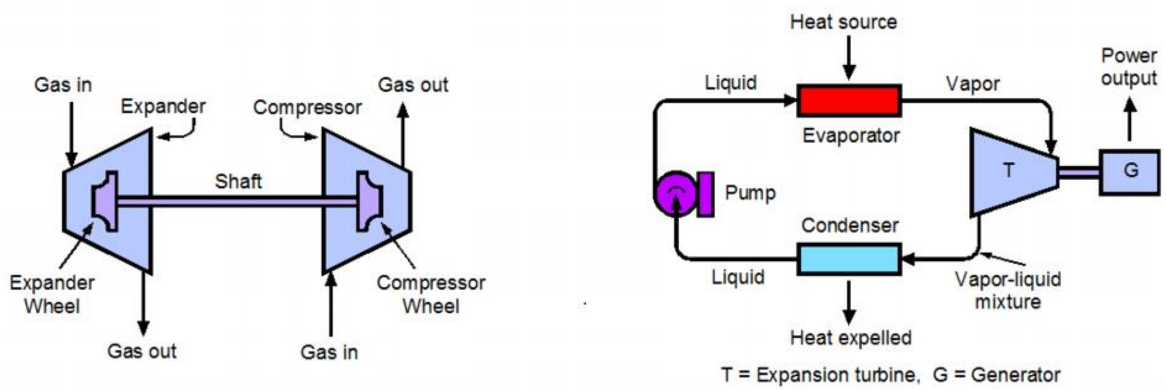

Figure 1. Schematic diagram of an expander-compressor (left-side) and an expander-generator (right-side) system.

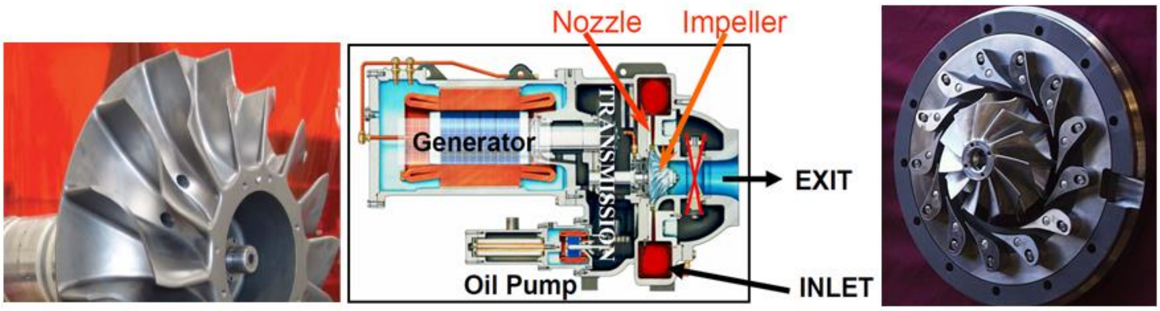

Figure 2. Turboexpander views (see e.g., Lat, 2013; Cryostar, 2013).

Previous applications of turboexpanders for electricity generation from geothermal resources include those at Mammoth Pacific and Steamboat, Nevada in binary cycle power plants. Turboexpander technology using the direct steam process has also been used in Salton Sea (Lat, 2013). The Mammoth complex has eight radial flow turboexpanders with a generating capacity of 29 MW (Buchanan and Nickerson, 2011). The Steamboat 2 and 3 geothermal power plants owned and operated by Ormat Nevada, Inc., included four radial flow turboexpanders. Nameplate capacity of each of the four units is 11.31 MW (Buchanan, et al., 2009). Binary cycle power plants with radial inflow turboexpanders have also been operated in France and Germany (Cryostar, 2013). Binary cycles with radial inflow turbines have been discussed by Marcuccilli and Thiolet (2009) whereas binary turboexpanders were also analyzed by Hirsch (2009).

3. ENERGY RECOVERY AT THE CPGF

Energy recovery using turboexpanders at the CPGF include two cases. One involves energy recovery at the wellhead of three groups of wells having pressures greater than 600 psig currently being throttled down to 200-230 psig for steam separation. The other discusses replacement of the pressure control valves at the inlet of the CP4 area power plants with turboexpanders to take advantage of the high pressure drop and steam flow rate through these valves.

3.1 Description of the fluid transportation network

The CPGF has an installed capacity of 720 MWe and is composed of four field areas: Cerro Prieto One (CP1) through Cerro Prieto Four (CP4). There are thirteen condensing power plants fed with separated steam from 165 producing wells through a large and complex steam gathering network. Currently, steam is separated at the wellheads and individual pipelines transport it to the main steam collectors. CP1 has high pressure (HP) separation only, whereas CPD, CPT and CPC have both high- and low-pressure (LP) separation. A more detailed description of the CPGF steam transportation network is given by Garcia-Gutiérrez et al., (2015).

3.2 Energy recovery from wells with wellhead pressures above 600 psig

Several wells of the CPGF have wellhead pressures between 600 and 1,000 psig. These pressures are throttled down using wellhead (production) orifice plates so that primary separation produces HP steam at 200-230 psig and secondary separation provides LP steam at 60-70 psig. The HP and LP steam then flows through the corresponding gathering networks to the power plants. Fig. 3(a) shows the present arrangement for steam separation.

In order to use the available wellhead pressure to generate electricity, it is proposed (Garcia-Gutiérrez et al., 2015) to add a separator-turboexpander system to those wells having wellhead pressures above 600 psig as shown in Fig. 3(b). 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 turboexpander inlet pressure was assumed to be 500 psig (to provide for some pressure decline with time) with expansion to 230 psi, so that the resulting fluid could be separated at the current primary separation of 200-230 psi, see Fig. 3(a). Power from these wells was computed using the equation:

$$P = \dot{m}\ \eta_t\ (h_1 - h_{2s}) \qquad (2)$$

where P denotes power, $\dot{m}$ *the* steam flow rate of each group of wells, 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.

Table 1 shows the characteristics of each well with wellhead pressure greater than 600 psig and the operational data for primary and secondary steam separation. The table also shows that the estimated power that can be obtained from each group of wells are 6.4, 6.3 and 8.0 MWe, respectively, or a total of 20.7 MWe.

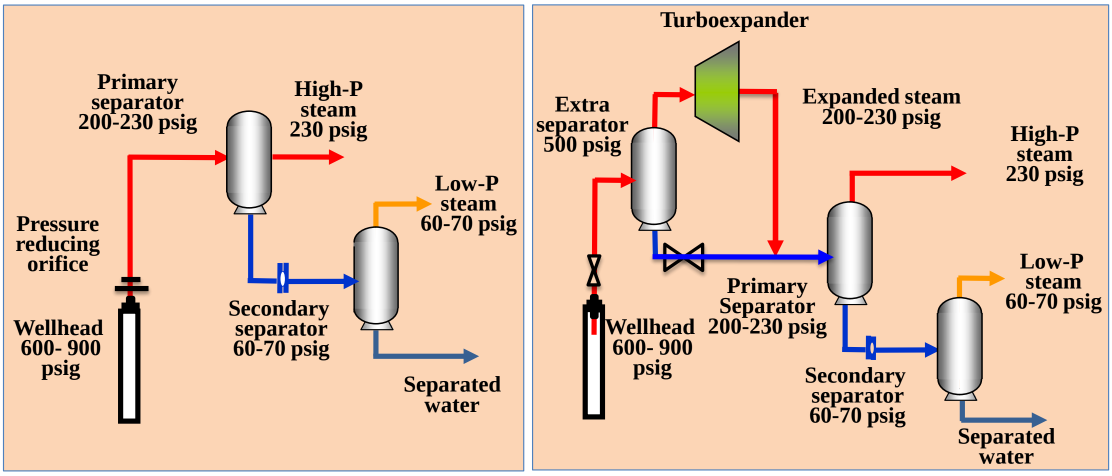

Figure 3. Present scheme of steam separation at the CPGF (a), and proposed scheme for using a separator-turboexpander system (b).

Table 1. Characteristics of the wells with wellhead pressure greater than 600 psig and estimated power from each group of wells.

Well Group	Wells	P_{WH} (psig)	T_{WH} (°C)	m_{WH} (t/h)	X_{WH} (%)	P_{PS} (psig)	X_{PS}	P_{SS} (psig)	X_{SS}	Net Power, MWe
CPD-1	235-D	700	299.02	66.5	0.79	190	0.83			6.4
	228-D	680	297.25	105.1	0.49	200	0.57	56.00	0.10	
	234-D	820	308.86	116.1	0.69	210	0.74	56.00	0.10	
CPD-2	237-D	640	293.61	69.1	0.83	193	0.86			6.3
	E-56	680	297.25	87.1	0.78	187	0.82			
	M-200	655	295.00	110.0	0.53	200	0.60	60.00	0.09	
CPC	415	632	292.86	120.6	0.31	190.00	0.41	63.00	0.09	8.0
	423	723	301.00	69.0	0.96	188.00	0.97			
	431-D	643	293.89	67.5	0.88	190.00	0.91			
	440-D	705	299.45	82.7	0.82	190.00	0.85			
TOTAL										20.7

3.3 Energy recovery by replacing the regulation valves located before the inlet of the CP4 power plants by turboexpanders

The CP4-area power plants are fed with 800 tons/h of steam at 145 psi at the delivery point from the steam field. However, just before this point, two regulating valves receive the steam at ~180 psi and reduce its pressure to ~150 psi. Fig. 4 shows schematically the present arrangement.

The present study consists of replacing the pressure regulation valves with steam turboexpanders and estimating the energy that could be recovered. The net power takes into account the steam condensation after expansion in the turboexpander and the specific steam consumption of the current power plants. Fig. 5 shows the proposed arrangement (Garcia-Gutiérrez et al., 2015).

The results of the analysis are shown in Table 2 where it is observed that the estimated gross and net power are 6.3 MWe and 5.2 MWe, respectively.

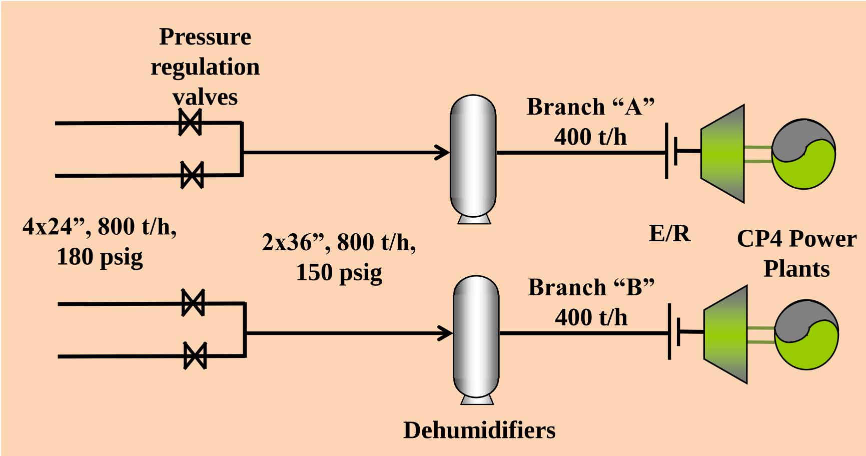

Figure 4. Present arrangement for steam delivery to the CP4 power plants.

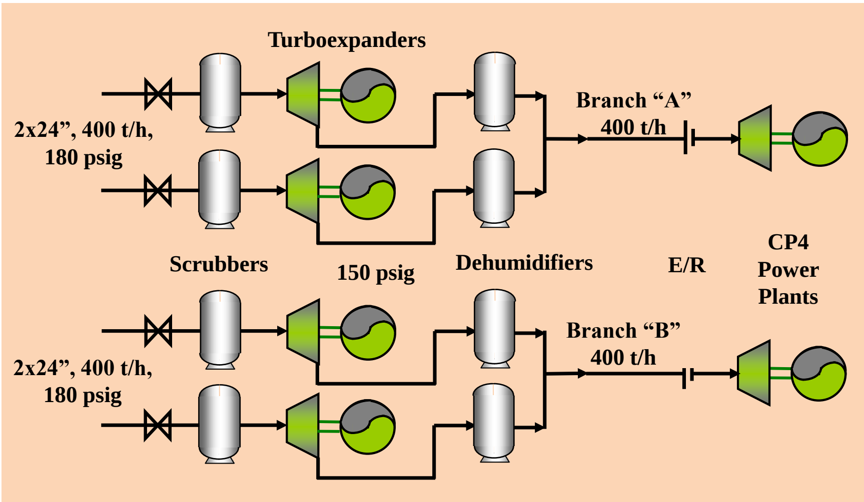

Figure 5 Proposed scheme for using turboexpanders for energy recovery and steam delivery to the CP4 power plants.

Table 2. Gross and net power estimated by replacing the pressure control valves at CP4 by turboexpanders.

Steam flowrate, t/h	Upstream pressure, psig	Downstream pressure, psig	Isentropic efficiency, %	Steam quality at exit, %	Condensed water, t/h	Power, MWe	
						Gross	Net
800	180	130	87	99	8.0	**6.3**	**5.2**

4. ENERGY RECOVERY USING TURBOEXPANDERS IN THE LHGF

For this field one case is presented for energy recovery at the wellhead of six wells having pressures greater than 285 psig currently being throttled down to a line pressure suitable for transportation of the water-steam mixture in a gathering network to the steam separators of each power plant (Garcia-Gutiérrez et al., 2012).

4.1 Description of the fluid transportation network

In 2012 the LHGF had an installed capacity of 40 MWe based on eight 5 MWe backpressure units, and two 25 MWe condensing units were in construction .The backpressure units are supplied with steam from 22 production (Vazquez- Sandoval, 2011). Each unit receives a mixture of water and steam through a two-phase fluid gathering system and the steam is separated before entering each power plant. The gathering network is 20.3 km long and pipe diameters range from 8" to 30". It is oriented in South-North direction and is divided into three zones: South, Central and North zones. The three zones are interconnected by a 7 km long, 24" in diameter duct. In the South zone two power units (U-3 and U-8), and 5 wells are located, while in the Central zone one unit (U-2) and two wells are located. Both zones are connected by the South-Central 24" diameter interconnection which transports fluid from the South to the Central zone. In the North zone, 5 units (U-1, U-4, U-5, U-6 and U-7) and 14 are located. The South-Central 24" interconnection joins the Central- North interconnection, also 24" in diameter, so that the 24" duct connects all three zones. Flow in the gathering system is controlled by gate and butterfly valves while steam flow to the turbines is controlled from the control room of the unit.

4.2 Energy recovery from wells with wellhead pressures above 285 psig

For this analysis, wellhead pressures of 285 or greater were considered. Also, a 5-year decline in wellhead pressure was considered at a rate of 1%/yr although wellhead pressures have been stable in the last few years. Six wells fulfilled this condition. Table 3 shows the data for the wells including the power estimated for each well by expanding the separated steam from the wellhead pressure with a 5 year decline (third column of Table 3) to the current line pressure of each well (see Fig. 6). A total of 10.4 MWe could be obtained from the individual wells.

Table 3. Characteristics of the LHGF wells with wellhead pressure greater than 285 psig and estimated power from each well.

Well	Wellhead pressure, psig		Water/steam flow rate, t/h	Steam quality, fraction	Separated steam, t/h	Line pressure, psig	Power, MWe
	Avg 2 yrs	5-yr decline					
H-06	541	515	55.24	0.894	49.38	197	2.09
H-09	285	270	53.29	0.928	49.44	145	1.34
H-12	451	430	63.43	0.921	58.39	152	2.64
H-35	424	400	32.25	0.921	29.71	195	0.94
H-32	595	570	38.84	0.918	35.65	216	1.52
H-20	436	415	42.19	0.920	38.84	138	1.84
TOTAL			**285.24**		**261.39**		**10.37**

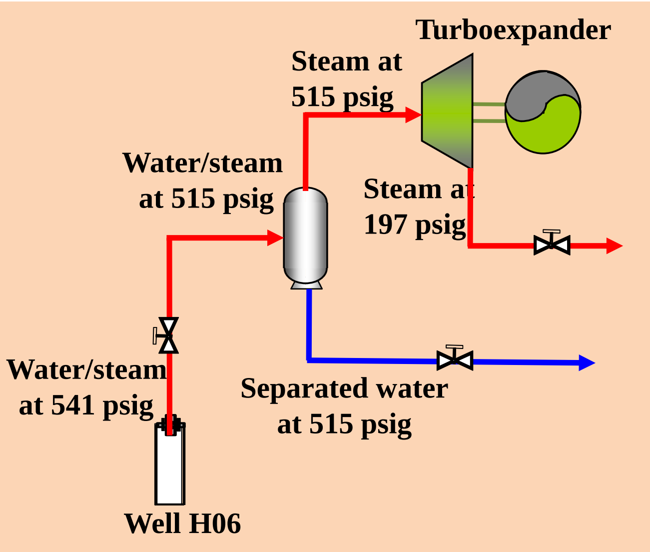

Figure 6. Schematics for energy recovery using a separator-turboexpander system at well H-06.

One issue to be considered is the wells location in the field since they are widely spread in the field. As shown on Fig. 7, wells H-12 y H-06 are in the South zone some 600 m apart; wells H-09 y H-35 are in the Western part of the North zone separated some

500 m, and wells H-20 y H-32 are in the Eastern part of the North zone separated some 900 m. These distances are in straight direction.

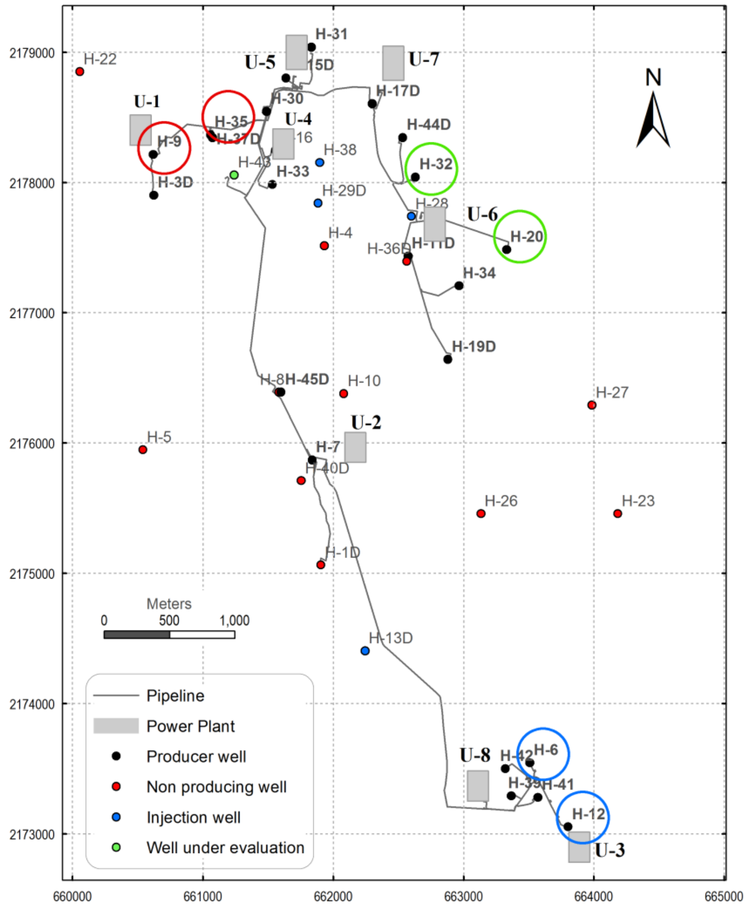

Figure 7. Location of wells included in the analysis of energy recovery using a separator-turboexpander system.

From this figure, it is clear that 3 groups of 2 wells each could be formed. The water/steam flow rate of each pair of wells can then be sent to a separator and the steam expanded in a turboexpander. The separator would operate at the lowest wellhead pressure of the two wells in each group, and the turboexpander outlet steam pressure would be equal to lowest line pressure of each group of wells. Fig. 8 shows the proposed arrangement for the H-06/H-12 well group.

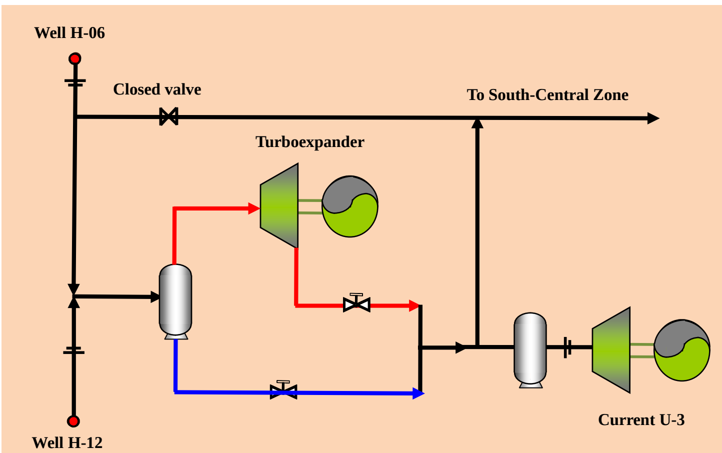

Figure 8. Schematics for energy recovery using a separator-turboexpander system at wells H-06 and H-12

Table 4 shows the estimated gross power that could be obtained for each pair of wells. The largest estimated gross power (4.93 MWe) corresponds to the H-06/H-12well group, while the total for all three groups is 10.62 MWe.

Table 4. Gross power estimated for each pair of wells using a separator-turboexpander system

Well group	Wellhead pressure 5-yr decline, psig	Water/steam flow rate, t/h	Steam quality, fraction	Separated steam, t/h	Line pressure, psig	Steam quality after expansion, fraction	Gross power, MWe
H-06 & H-12	430	118.67	0.921	109.24	152	0.930	4.93
H-09 & H-35	270	85.54	0.928	79.35	145	0.960	2.15
H-20 & H-32	415	81.03	0.920	74.59	138	0.928	3.54
TOTAL		**285.24**		**263.18**			**10.62**

5. CONCLUSIONS

Turboexpanders represent an attractive alternative to recover energy from high-pressure flow streams in geothermal steam gathering networks which are presently not used. Areas with significant potential for use of turboexpanders include the currently unused pressure drop at the wellhead production orifice plates of geothermal wells which reduce the pressure of the produced fluid from its wellhead value to that of the present operational steam separation, and pressure drops occurring in some flow devices such as flow regulation valves of steam transportation pipelines. Results of application for energy recovery using turboexpanders at the wellhead of ten wells of the CPGF show a potential of 20.7 MWe of additional capacity and 10.6 MWe at the wellhead of six wells of the LHGF while energy recovery at the regulating valves that control flow at the inlet of the CP4 area field amounts to 6.3 MWe. No additional mass or energy needs to be extracted from the reservoir nor would any additional pollution would be involved.

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