Thermodynamic Analysis of Superheated Geothermal Steam Scrubbing Using Aqueous Potassium Carbonate Solution

Vijay Chauhan¹, Maria Gudjonsdottir¹, Gudrun Saevarsdottir¹

¹ School of Science and Engineering, Reykjavik University, Menntavegur 1, 101 Reykjavík, Iceland

Keywords
exergy; geothermal; potassium carbonate; chloride; scrubbing; superheat;

ABSTRACT

The paper describes a novel approach for utilizing superheated geothermal steam with high silica and chloride content in gaseous phase as encountered in IDDP-1. The elevated boiling point of aqueous potassium carbonate solution as compared to that of saturated water is exploited to enable scrubbing of the geothermal steam while retaining superheat. Case study for fluid characteristics from the well IDDP-1 was performed. Thermodynamic performance of a power cycle using aqueous potassium carbonate solution for scrubbing was compared to a basic wet scrubbing technique. Exergy analysis for the cycle utilizing the proposed technique was performed to know the overall contribution of each component to the total exergy destruction. Simulation results for the production curve of IDDP-1 well shows an increase in utilization efficiency up to 7% and an increase in net work output up to 12% using aqueous potassium carbonate for scrubbing rather than basic wet scrubbing.

1. Introduction

Although most geothermal fields deliver saturated two-phase geothermal fluid consisting of saturated steam and liquid water, a number of vapor dominated geothermal fields have been reported to deliver superheated steam (Ellis and Anliker, 1982). Such vapor dominated geothermal fields with superheated steam offer potential to extract more power and provide better thermodynamic efficiency. To investigate the technical and economic feasibility of using unconventional, very high temperature geothermal systems, the Icelandic Deep Drilling Project was established in the year 2000 (Fridleifsson et al., 2014). In an attempt to achieve supercritical
or superheated steam, well IDDP-1 was drilled at the Krafla field which ended in magma intrusion at a depth of 2104m. The well produced fluid with an enthalpy of > 3170 kJ/kg and pressures up to 15 MPa. The well, however, suffered from a problem of unusual high quantity of volatile chloride and silica in the superheated steam (Armannsson et al., 2014). The concentration of chlorine in condensate ranges up to 166 mg/kg. Volatile chloride present in the steam incurs significant costs and maintenance difficulties. Problems caused by corrosion and its characteristics have been reported by Allegrini and Benvenuti (1970). The presence of chloride causes pitting corrosion in pipelines, and stress corrosion cracking reduces the turbine reliability. Due to high pressure, the fluid contains a considerable amount of silica up to 66 ppm in gaseous form since the silica solubility in superheated steam increases with pressure approaching the supercritical region. Lowering pressure of the steam causes silica to precipitate as particles in the superheated steam, in the absence of a liquid phase as observed in IDDP-1 (Markusson and Hauksson, 2015). Impact of silica scaling on geothermal heat exchangers and its effect on performance for the Wairakei power plant performance was studied by Zarrouk et al. (2014). The study shows a decrease in power plant efficiency with time. It is, therefore, necessary to mitigate both silica and chloride before utilizing steam for power generation.

Corrosion due to volatile chlorides in the geothermal application is well explained by Hirtz et al. (1991). The process of corrosion in the absence of oxygen is governed by the following reaction:

\[ 2 \text{HCl}(g) + \text{Fe}^0 \rightarrow \text{H}_2 + \text{FeCl}_2(aq) \]  

(1)

The reaction product is a highly soluble salt. The salt can exist with the solvent up to a higher degree of superheat before it gets precipitated. Such solution, however, can dissolve some of the HCl present in the steam to form a more corrosive solution which causes the corrosion process to accelerate. It is therefore required to have some degree of steam superheat greater than the precipitation limit of the salt formed. Hirtz et al. (1991) suggested a temperature range of 20°C superheat, above which condensation and corrosion is unlikely to continue.

Various techniques have been proposed for cleaning geothermal steam. The techniques include ‘steam washing’ where clean water taken from the condenser is mixed with the steam so as to dissolve unwanted substances present in the steam. This water is subsequently removed in a separator (or ‘demister’) prior to the turbine. Another scrubbing technique is to utilize the mechanism of absorption or adsorption, popularly known as ‘dry scrubbing’ since the impurities can be removed from dry steam. The mechanism requires a reactor vessel or a fluidized bed which is followed by a separation process.

The conventional way of cleaning steam in geothermal power plants is wet scrubbing using condensate or caustic injection into the steam. Injection of caustic into steam causes the following reaction to occur, with aqueous hydrochloric acid formed by gaseous chloride below dew point:

\[ \text{NaOH} + 2 \text{HCl} \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O} \]  

(2)

The salt formed as the product of the reaction is in the solution state which is removed in the separator placed after the wet scrubbing unit. The other impurities such as silica stay with the liquid phase as a solution and hence also separated easily. Analysis regarding optimization of scrubbing efficiency of wet scrubbing was done by Hirtz et al. (1990). An analytical model for predicting the performance of wet scrubbing for different flow conditions and geometry of the
unit is given by Paglianti et al. (1996). Results from the model shows good agreement for the existing power plant scrubbing units.

Though a robust way of cleaning steam is achieved using wet scrubbing, the method causes a loss in power output when applied to superheated steam. This loss occurs due to exergy destruction while mixing and a decrease in turbine efficiency. It is important to quench the superheat to make the fluid with two phase as required for separation. The exergy destruction increases with increase in superheat quenched.

Performance analysis of different cycles utilizing different chlorine mitigation methods for IDDP-1 was done by Hjartarson et al. (2014). Results shows heat recovery system as an efficient way to retain superheat in the geothermal fluid while mitigating the chloride using traditional wet scrubbing. The work done, however, does not take the presence of silica in superheated steam into consideration. The heat recovery cycle proposed allows superheated steam to enter the heat recovery system directly from the wellhead. Presence of silica due to precipitation causes its deposition along the heat exchanger surface and hence reducing its effectiveness with time. This makes it necessary to mitigate silica before entering superheated steam into the heat recovery system.

A possible way of using the heat recovery system without silica scaling can be achieved by treatment using a solution with a high boiling point elevation as proposed in this current work. The amount of solution injected is far less than required in normal wet scrubbing since the superheated steam does not need to be made saturated for acquiring wetness for removal in the separator. The high dielectric constant of salt ions causes the salt solution to stay in the liquid phase in the superheated steam without boiling. The injected salt solution droplets scrub gaseous impurities by the process of diffusion and adsorption. For solid impurities such as silica, scrubbing occurs by collision and attachment with the droplets. The droplets are then separated from the superheated steam in the cyclone separator. This makes scrubbing possible without considerable superheat loss. A comparison of the thermodynamic performance of traditional wet scrubbing with venturi scrubbing which uses boiling point elevation property of sodium chloride as a byproduct of scrubbing was done by Chauhan et al. (2016). The study shows improved thermodynamic performance achieved considering boiling point elevation property of salt. The degree of superheat retained without precipitation of sodium chloride is however limited. Application of potassium carbonate solution for chlorine mitigation in superheated steam by injecting in bore hole was proposed by Weres and Kendrick (2010). Gaseous chloride present in superheated steam on coming in contact with the cold film of injected potassium carbonate solution causes following reaction to occur with hydrochloric acid formed below dew point:

\[
\text{K}_2\text{CO}_3 + 2\text{HCl} \Rightarrow 2\text{KCl} (aq) + \text{H}_2\text{O} + \text{CO}_2
\]  

(3)

The solution having high dielectric potential offers a greater degree of superheat. Treatment by injecting a salt solution in the bore hole works well for neutralizing acid chloride impurity without losing superheat. Injection in bore well, however, suffers from two major drawbacks. First, it is difficult to get rid of potassium chloride formed as the by-product of reaction which precipitates once saturation limit is achieved because of its low boiling point elevation. Second, the silica present in gaseous form is left untreated, and precipitates whenever pressure drop occurs due to decrease in solubility at lower pressure. This adds to the problem of deposition. A better way to overcome these drawbacks is the treatment above the surface at a lower pressure,
with simultaneous removal of gaseous and particulate impurities. The presence of chloride in steam is mitigated by the potassium carbonate solution in droplet form similar to wet scrubbing. Chloride in superheated steam existing in gaseous form is adsorbed by diffusion on the droplet surface. The by-product salt formed having lower boiling point elevation temperature than the injected salt solution can precipitate. However, the salt if precipitated stays with the droplets forming a solution similar to other impurities which are removed with the potassium carbonate solution droplets in the separator.

Application of aqueous potassium carbonate for scrubbing superheated steam is proposed in this work. To demonstrate the improved performance obtained using the proposed technique, a case study for well IDDP-1 is done. A comparative study of power cycle with heat recovery system utilizing scrubbing with aqueous potassium carbonate is done with that of traditional wet scrubbing cycle. Conservation laws for each component and a cycle as a whole are applied. Thermodynamic performance is calculated in terms of exergy which represents the true performance of a thermodynamic system. Exergy destruction and loss of each component are calculated to know the overall contribution of each component to the cycle performance.

2. Methodology

Figure 1 shows the fitted curve for the measured mass flow rates for IDDP-1 as a function of wellhead pressure obtained during the flow test. The fluid enthalpy is 3100kJ/kg. Conventional Rankine cycle with wet scrubbing represents a technically feasible way of utilizing superheated steam. Details of the cycle are available in the literature (Hjartarson et al., 2014).

For thermodynamic analysis, superheat (boiling point elevation) of the potassium carbonate solution as a function of temperature is required. The superheat for a given concentration can be obtained using activity of the solvent in equilibrium with the vapor expressed as a function of degree of superheat ($\Delta T$) and heat of vaporization ($\Delta H_{vap}$) as given by Bialik and Sedin (2008). The relation is expressed as:

$$\ln a_{salt} = \frac{\Delta H_{vap}}{R} \left( \frac{1}{T_0 + \Delta T} - \frac{1}{T_0} \right)$$

Where $T_0$ is temperature of pure solvent and $R$ is the gas constant. The solvent activity required in Eq. (4) is calculated using osmotic coefficient related to solvent activity by following equation:

$$\phi = \frac{-1000 \ln(a_{salt})}{M_{water}(2m_k+m_{CO_3})}$$

where $M$ is the molecular mass, $m_i$ is the mass of species $i$ and osmotic coefficient ($\phi$) is given as:

$$\phi = 1 + \frac{2}{(m_k+m_{CO_3})} \left( \frac{A_\phi I^{1/2}}{1+1.2 I^{1/2}} \right) + m_km_{CO_3} \left( R_{ca} \phi + Z \phi \right)$$

where $I$ is the ionic strength and $A_\phi$ is the Debye-Hückel slope expressed as a function of
The parameter $Z$ is expressed as:

$$Z = \sum m_i[z_i]$$  \hspace{1cm} (7)

where $z_i$ is the charge on ions.

Parameters defining thermodynamic property of single salt solution in Eq. (6) are given by following equations:

$$B_{ca}^\phi = c_1 + c_2 e^{x p(-I^{1/2})}$$  \hspace{1cm} (8)

$$C_{ca} = \frac{c_3}{2!x_{ca}^{1/2}}$$  \hspace{1cm} (9)

where $c_1$, $c_2$ and $c_3$ are the Pitzers parameters available in literature (Kamps et al., 2007) for aqueous potassium carbonate defined as a function of temperature. The relations in literature are derived empirically valid up to certain concentration and temperature limit. Following the approach by Weres and Kendrick (2010), superheat values for higher limits are obtained by extrapolation.

The solubility of saturated solution is obtained by curve fitting the experimental values obtained from Moore et al. (2007). The curve fit for solubility as a function of temperature is given as:

$$m_{solubility} = 4 \times 10^{-4}T^2 - 0.4119T - 86.943$$  \hspace{1cm} (10)

Schematic diagram of the baseline cycle utilizing aqueous potassium carbonate solution for scrubbing is shown in figure 2. The superheated steam from the well is passed through a scrubbing unit before entering the heat recovery system. The minimum amount of potassium carbonate solution to be injected is limited by the final steam temperature at scrubber outlet which is to be within the superheat limit of the solution at saturation pressure. In addition, the solution to steam flow ratio should also be sufficient to enable effective scrubbing of steam. However, an increase in scrubbing efficiency can be obtained by increasing the residence time of solution droplets in the scrubbing unit. The saturated solution droplets mixed with the impurities and by-product of the scrubbing are removed in the separator ($S_1$). Steam passing through turbine requires a high degree of purity. Presence of minute impurities, if not removed in the separator, can cause the problem to the turbine effectiveness because of deposition occurring mainly due to impaction mechanism due to curved profile of blades. The superheated steam is therefore passed through heat recovery system until saturation. Since particles with higher relaxation time are mostly removed by scrubbing in the separator, the deposition in heat recovery system is very low because of its straight surface profile where turbulent and Brownian diffusion are the major forces contributing to deposition. These forces contribute far less to deposition as compared to impaction (Chauhan et al., 2018). The saturated steam at the end of heat recovery system is then throttled and the second separation is done. This causes leftover silica to be removed in the liquid phase. The steam then regains the superheat before entering the turbine. For the purposes of analysis, turbine exit pressure is set at 0.1 bar. A vapour dryness fraction limit of 85% is kept as a constraint at the exit of the turbine in order to avoid problems occurring due to wetness inside the turbine. Simulation assumes flashing and separation in the intermediate stage if minimum dryness fraction limit occurs before exit pressure limit. A wet cooling tower is used to cool the cooling water of the condenser. The cold water temperature is assumed to be 20°C.
3. Cycle Analysis

Thermodynamic analysis of a power plant requires applying three different laws for each component and the cycle as a whole. First relates to conservation of mass entering and exiting a system in a steady flow. Second, refers to the conservation of energy for any system given by the
first law of thermodynamics. Third restricts the total conversion of heat energy into useful work given by the second law of thermodynamics. The second law of thermodynamics describes a term exergy which defines the maximum amount of useful work that can be obtained from a given heat source. The actual work obtained is always less than maximum useful work because of entropy generation in any real process.

For a control volume with no chemical reaction, the equations for mass balance, energy balance, and exergy flow rate for steady flow are as follows (Yuksel and Ozturk, 2016):

a) For any component of the cycle with no mass generation, the law of mass conservation is given as:
\[ \sum m_{in} = \sum m_{out} \]  \hspace{1cm} (11)

where \( m \) is the mass flow rate.

b) The first law of thermodynamics defining general steady state energy balance for each component and the whole cycle is given as
\[ \sum m_{out} h_{out} - \sum m_{in} h_{in} = Q - W \]  \hspace{1cm} (12)
where \( h \) is the enthalpy, \( Q \) is the heat and \( W \) is the work exchange.

c) The flow exergy (\( \varepsilon \)) at each point of the system in a steady state is given as:
\[ \varepsilon_i = \dot{m}_i [(h_{in} - h_{out}) - T_o (s_i - s_{out})] \]  \hspace{1cm} (13)
where \( s_i \) is the entropy at point \( I \) and \( T_o \) is the reference temperature.

For any real thermodynamic system, work loss occurs due to exergy destruction and exergy loss. Exergy destruction can occur due to friction or heat transfer across a temperature gradient and cannot be recovered. Exergy loss, on the other hand, defines the exergy lost to the outside environment which could have been used to extract work. In geothermal systems, exergy loss occurs when geothermal brine is reinjected to the ground.

For a system with no heat exchange with the surroundings, the actual work done (\( W \)) is then given as:
\[ W = \dot{\varepsilon}_{in} - \dot{\varepsilon}_{out} - \dot{\varepsilon}_D - \dot{\varepsilon}_L \]  \hspace{1cm} (14)
Where subscript \( D \) and \( L \) denotes destruction and loss of exergy.

3.1. Component Analysis

Equations for thermodynamic analysis for each component of the geothermal power plant are described as follows:

3.1.1. Turbine

Work output is calculated assuming a value of isentropic efficiency (\( \eta_I \)) for the turbine is given by
\[
\eta_T = \frac{h_{\text{in}} - h_{\text{out}}}{h_{\text{in}} - h_{\text{out,iaw}}} 
\]

(15)

The actual work output from a turbine (\(\dot{W}_T\)) is then given as

\[
\dot{W}_T = \dot{m}_{\text{in}}(h_{\text{in}} - h_{\text{out}}) 
\]

(16)

Since the efficiency of a turbine changes with the quality of steam, the isentropic efficiency of turbines (\(\eta_{T,\text{wet}}\)) in wet region is estimated using the Baumann rule (DiPippo, 2008):

\[
\eta_{T,\text{wet}} = \frac{\eta_{\text{turb},\text{dry}}(1+x_{\text{out}})}{2} 
\]

(17)

where \(\eta_{\text{turb},\text{dry}}\) is the efficiency of the turbine with dry steam which is assumed to be 85\% and \(x_{\text{out}}\) is the dryness fraction at the exit of the turbine.

3.1.2. Injection and Separation

For the case of traditional wet scrubbing, the amount of water added must surpass that required to make the steam saturated at that pressure. In case of aqueous potassium carbonate injection, the final state of steam is still kept superheated within the limit of precipitation of solution at the saturated pressure. The degree of superheat available without salt precipitation as a function of pressure is calculated using the model discussed. The amount of liquid injection is, therefore, smaller than in wet scrubbing. A concentration balance is required between the injected liquid and the droplets at the exit of the scrubber. The concentration balance equation is given as:

\[
\dot{m}_2c_2 = \dot{m}_3c_3, l 
\]

(18)

Where \(c_i\) is the concentration of salt at point \(i\) and subscript \(l\) denotes the liquid phase.

The mass of steam at the exit equals the sum of mass entering and mass of liquid vaporized given by

\[
\dot{m}_{3,s} = \dot{m}_1 + \dot{m}_2 - \dot{m}_{3,l} 
\]

(19)

where subscript \(s\) denotes the steam phase. The enthalpy of the steam exiting corresponds to the superheated state at a temperature of precipitation limit of the salt solution injected.

3.1.3. Heat Recovery and Separation

The superheated steam entering the heat exchanger is made saturated with some wetness and then throttled down before separation. Throttling cause temperature drop required for heat exchange. A minimum pinch point difference of 3 °C is kept in the heat exchanger. The energy balance equations for the unit are given by:

\[
\dot{m}_5(h_5 - h_6) = \dot{m}_9(h_{10} - h_9) 
\]

(20)

\[
h_6 = h_7 
\]

(21)

3.1.4. Condenser and Reinjection

The heat transfer in the condenser section is given as

\[
\dot{Q}_c = \dot{m}_c(h_{11} - h_{12}) 
\]

(22)
The total exergy destruction in the condenser is considered as the sum of exergy destruction due to heat transfer and exergy loss by transfer of exergy to the colder fluid. Since no useful work is done in the condenser, the total exergy destruction is represented as given in Table 1.

Reinjection causes loss of the remaining exergy in the geothermal fluid. The equation for calculation is given in Table 1.

3.1.5. Cooling Tower Assembly

An induced draft-type wet cooling tower is chosen for cooling flow through the condenser. Recirculating cooling water is used to transfer waste heat to the atmosphere. Referring to Figure 2, the mass and energy conservation equations are expressed as

\[m_{17}h_{17} + m_{\text{air,x}}h_{\text{air,x}} = m_{14}h_{14} + m_{\text{air,y}}h_{\text{air,y}} \quad (23)\]

\[m_{14} - m_{17} = m_{m} = m_{\text{air}}(\omega_y - \omega_x) \quad (24)\]

\[m_{\text{air,x}} = m_{\text{air,y}} \quad (25)\]

The surrounding air is assumed to be at a constant relative humidity of 76% and 2.5°C which were the average conditions nearby IDDP-1 for 4 years (Hjartarson et al., 2014).

For pump analysis, the isentropic efficiency of 85% is assumed which is related to flow enthalpies as:

\[\eta_P = \frac{h_{\text{in}} - h_{\text{out,isen}}}{h_{\text{in}} - h_{\text{out}}} \quad (26)\]

3.2. Performance evaluation

The performance of a geothermal power plant is measured in terms of utilization efficiency which is defined as the ratio of net power output to the total exergy input from the geothermal steam flow at the wellhead conditions:

\[\eta_{ll} = \frac{W_{\text{net}}}{m_{\text{geo}}[(h_{\text{geo}} - h_0) - T_0(s_{\text{geo}} - s_0)]} \quad (27)\]

Performance of each component of the cycle can be evaluated using exergy destruction or loss occurring in it. Additional loss in efficiency occurs due to geothermal fluid reinjection to the ground causing exergy loss. Referring to Figure 2, Table 1 shows the relations for evaluating exergy destruction or loss in each component of the cycle.

| Table 1: Relations for exergy destruction and loss in cycle components |
|-----------------------------|-----------------------------|
| Component       | Exergy relations              |
| Turbine         | \( \dot{\epsilon}_{D,T} = \dot{\epsilon}_{10} - \dot{\epsilon}_{11} - W_T \) |
| Throttle        | \( \dot{\epsilon}_{D,T'} = \dot{\epsilon}_6 - \dot{\epsilon}_7 \) |
| Heat Exchanger  | \( \dot{\epsilon}_{D,HX} = (\dot{\epsilon}_5 - \dot{\epsilon}_6) + (\dot{\epsilon}_9 - \dot{\epsilon}_10) \) |
| Reinjection     | \( \dot{\epsilon}_{L,RA} = m_4[(h_4 - h_0) - T_0(s_4 - s_0)] \) |
| Condenser       | \( \dot{\epsilon}_{L,RR} = m_4[(h_8 - h_0) - T_0(s_8 - s_0)] \) |
|                 | \( \dot{\epsilon}_{L,R12} = m_12[(h_{12} - h_0) - T_0(s_{12} - s_0)] \) |
|                 | \( \dot{\epsilon}_{D,C} = m_{11}[(h_{11} - h_{12}) - T_0(s_{11} - s_{12})] \) |
4. Results and Discussion

Figure 3 shows the degree of superheat achieved corresponding to different temperatures by aqueous potassium carbonate at a saturated concentration at that temperature. The values show a significant degree of superheat possible to attain without precipitation.

![Figure 3: Superheat corresponding to different temperature for a saturated solution of potassium carbonate](image)

A comparative study of the thermodynamic performance of power cycle utilizing scrubbing using aqueous potassium carbonate with that of traditional wet scrubbing was carried out. The cycle simulation was done up to wellhead pressure limit of 7MPa considering the validity of modeling equations for potassium carbonate superheat. This analysis, however, does not ignore the point of maximum output obtained at much lower pressure as shown later. Figure 4 shows the variation of cycle utilization efficiency with wellhead pressure, based on flow test and enthalpy results from IDDP-1 shown in Figure 1. The utilization efficiency first increases and then decreases with wellhead pressure. Variation of cycle efficiency with wellhead pressure is governed by the inlet state of working fluid to the turbine. For low inlet pressures, the exit state of the vapor has dryness fraction greater than the minimum assumed value for the fixed value of condenser pressure. On increasing the inlet pressure, the exit state approaches the minimum dryness fraction value, increasing specific enthalpy change of fluid along the turbine hence increasing the efficiency. The steam at the entrance of the turbine in the proposed cycle is superheated, offering greater efficiency in the turbine compared to that of the cycle using a traditional wet scrubbing. A decrease in utilization efficiency is observed with further increase in wellhead pressure. This decrease occurs due to limiting values of the minimum dryness fraction in the turbine, requiring a higher pressure at the exit. Cycle efficiency up to 65% using aqueous potassium carbonate for scrubbing at 5MPa wellhead pressure is obtained. The highest efficiency for using wet scrubbing is 58% obtained at same wellhead pressure. The wellhead pressure of
5MPa also represents the pressure for maximum work output. A gain up to 7% is observed in utilization efficiency by using potassium carbonate scrubbing at the wellhead pressure at which maximum work output occurs.

Figure 4: Variation of utilization efficiency with wellhead pressure

Figure 5 shows the variation of net work output with wellhead pressure utilizing conventional wet scrubbing and scrubbing using potassium carbonate solution based on the production curve of IDDP-1. The net work output first increases and then decreases with wellhead pressure. The net work output first increases with the increase in enthalpy change across the turbine as the turbine dryness fraction approaches lower limit for the fixed value of condenser pressure. This increase is then countered by a decrease in mass flow rate (Figure 1) of geothermal fluid which causes total work output to decrease later. Greater turbine efficiency obtained by having superheated steam at the turbine entrance in the proposed cycle causes more work output than traditional wet scrubbing. An increase in work output up to 4.3MW is observed at 5MPa of wellhead pressure using treatment with aqueous potassium carbonate compared to wet scrubbing.

Figure 5: Variation of net work output with wellhead pressure
Figure 6 shows the exergy flow diagram for the case of the cycle utilizing scrubbing using potassium carbonate solution. The exergy loss due to reinjection is that from separator 1 and 2 and from the exit of the condenser. The net work is calculated by deducting fan and pump power from the total turbine work output. The exergy input from cold salt solution added is almost negligible. Result shows condenser and turbine as major components in the proposed cycle contributing to exergy destruction which holds same for cycle with wet scrubbing unit also. The heat recovery system added in the proposed cycle contribute least to exergy destruction. The analysis, however, needs to take exergy destruction due to pressure loss into consideration.

Figure 6: Exergy flow diagram at a wellhead pressure of maximum work output for cycle utilizing aqueous potassium carbonate for scrubbing

4. Conclusion

A comparative study regarding the usage of aqueous potassium carbonate for scrubbing in a geothermal cycle versus traditional wet scrubbing shows improvement in utilization efficiency. An increase in work output close to 4.3 MW is achieved at wellhead pressure of 5MPa at which maximum work output is obtained. This corresponds to nearly 12% increase in work output. A 7% point increase in utilization efficiency as compared to traditional wet scrubbing was found at wellhead pressure corresponding to maximum work output. The current analysis was done for production curve for a particular well, IDDP-1. The percentage increase in values is significant in terms of revenue for a geothermal power plant considering a number of similar wells. The boiling point elevation property of the salt solution helps to retain the superheat during scrubbing. Application of the proposed technique for superheated geothermal steam scrubbing can help in improving the output of the power plant.
REFERENCES


