Absorption Refrigeration System as an Integrated Condenser Cooling Unit in Geothermal Power Plant

Tesha

PT. Pertamina Geothermal Energy Kamojang. Jl. Raya Kamojang, Kecamatan Ibun, Bandung

tesha@pgeindonesia.com

Keywords: Absorption, power, plant, utilization

ABSTRACT

Getting the condenser at a lower pressure is a reasonable way to increase power plant power capacity. But, sometimes any effort to build the desired condenser pressure has to be constrained by the temperature of the cooling water.

The condenser temperature regulates the lowest pressure that can be applied to the condenser, not counting the presence of non-condensable gases from geothermal fluids. In some cases, the preferred condenser pressure is not achievable due to the environmental factor i.e. high ambient temperatures in tropical countries. Hence, the environment cannot serve plant systems with such a low temperature of cooling water. Based on this fact, an artificial cooling system such as an absorption refrigeration system could be built in order to produce the preferred temperature of the cooling water. Here, the single effect absorption refrigeration system takes it place by lowering the cooling water from the cooling tower just before it enters the condenser.

Two absorption refrigeration technologies, lithium bromide-water pairs and water-ammonia pairs are compared and combined with three types of geothermal power plant cycles. Several combinations of temperature differences between the inlet and the outlet of an ARS evaporator and the evaporator's temperature were simulated to determine the optimum combination for the given geothermal heat source. Other parameters, for example the weak-strong solution concentration difference, were also selected so that the ARS would work in high refrigeration efficiency with the least heat exchanger area.

1. INTRODUCTION

In tropical and some other areas, high air temperature and the availability of low temperature cooling water emerge as obstacles to the steam condensation process. If the steam condensation process occurs at a higher temperature the leftover steam within the condenser increases, which increases condenser pressure and lowers turbine capacity.

Low grade thermal energy is produced during the separation process of geothermal fluid especially in flash plant cycle, and is considered wasted energy, awaiting further utilization processes or just injected back into the earth without any effort to harvest the heat. Hence, depending on its energy content, this low grade thermal energy could power heat driven processes such as balneology activity heating and cooling purposes, balneology activity or even as a power plant bottoming unit, depending on how much of available energy remains.

Absorption refrigeration system (ARS) as a heat-activated thermal cycle seems to be a good combination of utilization for any geothermal resource where applicable, especially with a power generation system which disposes of low grade thermal energy. An absorption cycle uses a heat source which could include the low temperature geothermal resource or a waste heat resource from the geothermal power plant. This waste energy powers the absorption machine and the chilled water from the absorption machine feeds the plant's condenser, mutually benefiting both systems.

The aim in lowering the temperature of the cooling water is to accommodate a situation where it is hard to find a low temperature water resource, especially in tropical countries. The lack of low water temperature availability will affect the steam condensation process and will, moreover, decrease efficiency and power production.

2. ABSORPTION REFRIGERATION SYSTEM

An absorption refrigeration system replaces the mechanical compressor in a compression refrigeration system with two heat exchange units, a desorber and an absorber, which create a heat-driven heat transfer from a low temperature to a high temperature. Even though these two units replace the function of a mechanical compressor, electric pump still can be found in most absorption refrigeration system as a common and simple way to circulate the low to the high pressure level. However, the electric pump only consumes a small amount of energy compared to the overall system, and is considered negligible.

An absorption refrigeration system could be, at its simplest, a single effect or more advanced multiple effect absorption system. A single effect can be considered to occupy two pressure levels where the pressure difference only occurs in the flow restrictors and solution pump, neglecting the pressure drop along the circuit and changes in elevation. A single effect refrigeration system basically consists of one solution pump, two flow restrictors and four heat exchangers.

The working fluid in an absorption refrigeration system consists of two or more substances which will act as the absorbent and refrigerant. The refrigerant actually is the real working fluid for the refrigeration process while the absorbent will treat the refrigerant to a specific condition for a complete cycle continuation. Lithium bromide-water and water-ammonia as conventional fluids still have desirable properties compared to other working fluid variants, especially for the high number of latent heat so can minimize the need of refrigerant flow rate.

Two single effect absorption refrigeration technologies, Lithium bromide-Water and Water-Ammonia absorption refrigeration systems are going to be modeled. A single geothermal well will feed them directly as a heat source while the machines refrigerate a stream of water for a specific cooling load. Performance for each machine is

observed and compared while the variables are maintained to achieve the best performance with the least heat exchanger area. The single effect absorption refrigeration system was modeled with the solution heat exchanger (SHX) and refrigerant heat exchanger (RHX) installed in order to gaining up the efficiency.

## 2.1. Modeling a Lithium Bromide-Water System

Temperature at the outlet of ARS condenser was set to 20°C higher than the cooling water temperature while at the outlet of the absorber was set to 7°C. Temperature along the expansion valve and the absorber was monitored to have 10°C margin from the crystallization temperature for the specific pressure and solution concentration.

2.2. Modeling a Water-Ammonia System

Temperature at the outlet of the ARS condenser and absorber was set to the similar parameters as in lithium bromide system. Additional ammonia purification unit was installed after the desorber to achieve a higher concentration of refrigerant solution. The ammonia concentration at the outlet of the desorber and rectifier were set as input where there were set to 0.9444 and 0.9996, respectively.

3. INTEGRATED ABSORPTION REFRIGERATION AND POWER GENERATION SYSTEM

An integrated power generation and absorption system is modeled and simulated where both systems are designed to support each other and operate side by side. The waste heat from the power generation process feeds the absorption refrigeration system heat demand and the ARS supplies cooling water to the power plant.
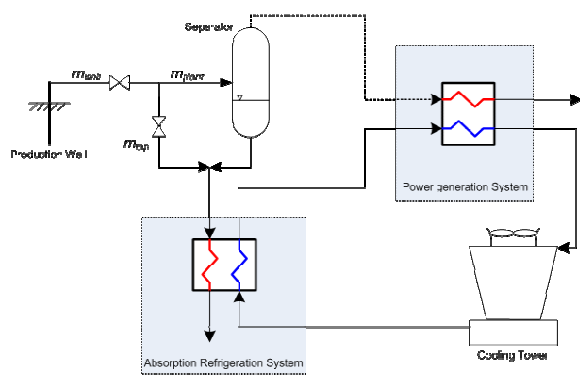
Figure 1: Basic design of integrated power generation and absorption refrigeration system.

By adding the absorption refrigeration system onto the power plant cooling system some extra power generation should be expected. For reference, the maximum power generation that could be generated by each regular geothermal power generation system, for the given geothermal resource and 1MW power generation, is put as the base power of each scenario. Power generation from each integrated power and refrigeration system should refer to this base power to see whether the refrigeration system has a positive or negative impact on power generation capacity.

The first step was to calculate the amount of geothermal fluid that had to be delivered to each single flash, double flash and organic rankine geothermal power plant so they can generate 1MW of electricity. This mass flow then became the reference for the next step where the absorption

machine was attached to each power plant system. The ARS could only use the waste heat source either from the power plant or un-utilized geothermal fluid. In this way, we had constant geothermal fluid supply from the geothermal well (m_{well}) for each power plant (m_{plant}) and ARS unit (m_{excess}).

Table 1: General design parameters for integrated power plant and ARS system

Parameter	Value
h_{well}	1,400 kJ/kW
m_{well}	10 kg/s
P_{well}	1,255 kPa
T_{well}	190 °C
$P_{environment}$	101.3 kPa
$T_{environment}$	25 °C
$\eta_{generator}$	0.85
$\eta_{turbine}$	0.85

The power plant's condenser was simulated to have a temperature level 20°C higher than the cooling water inlet temperature and the cooling water temperature at the outlet of condenser increased as high as 12°C during the condensation process. Specific conditions were set for the organic rankine cycle where the minimum temperature difference between the inlet of the working fluid and the outlet of geothermal fluid at the boiler was 5°C.
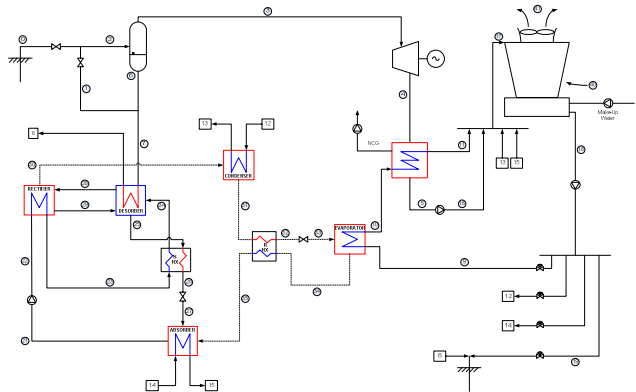
Figure 2: Integrated single effect water-ammonia ARS and single flash geothermal power plant.

Each scenario was simulated for several evaporator temperatures and chilled water temperature differences at the inlet and outlet of the evaporator. All electric power generated by any integrated power and refrigeration system is in the form of net electric power; electric power from the generator was deducted to feed the refrigeration energy demand such as in the solution and cooling water pump.

As listed in Table 2, the highest net power gain is given by the integrated single flash and lithium bromide system. The lithium bromide machine still gave more refrigeration effect than ammonia for the same amount of waste heat from the separator. This situation is in line with the fact that a water-ammonia absorption refrigeration system needs more power than the lithium bromide-water for similar refrigeration capacity. There was still enough heat to run the ammonia ARS up to 7°C of chilled water temperature difference at

10°C evaporator temperature. Beyond this point, there was not enough heat to run the system. The lithium bromide ARS still ran and gave maximum power generation at a temperature difference of 16°C and 8°C evaporator temperature (Figure 3).

Table 2: Maximum possible net power output for each combinations of power plant and ARS system

| Combination	$W_{e,ref}$ (kW)	$W_{e,opt}$ (kW)	ΔW_e (kW)
Single Flash w/ LiBr-H_2O	1,000	1,131	131
Single Flash w/ H_2O-NH3	1,000	1,040	40
Double Flash w/ LiBr-H_2O	1,000	1,123	123
Double Flash w/ H_2O-NH3	1,000	1,047	47
ORC w/ LiBr-H_2O	1,000	1,047	47
ORC w/ H_2O-NH3	1,000	1,015	15
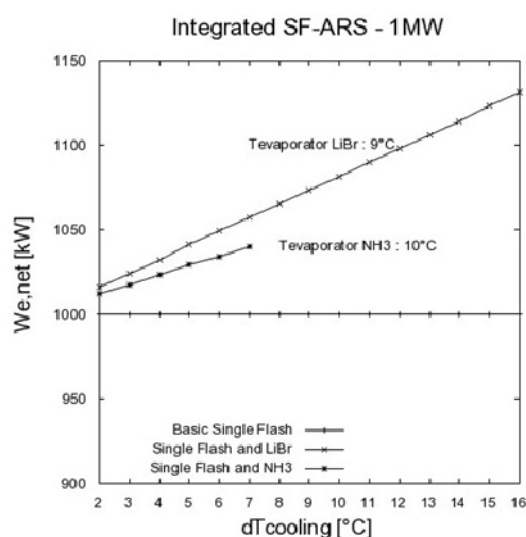
Figure 3: Single flash net electric generation for various ARS cooling effect

Analyzing the lithium bromide system, the maximum net power output was produced at 16°C cooling temperature and a range of evaporator temperatures of 7-9°C. Temperature at the outlet of the evaporator could not go beyond 9°C due to evaporator pinch temperature restrictions, making the optimum parameter for this scenario 9°C evaporator temperature and 16°C cooling temperature. At the evaporator temperature of 10°C, the cooling temperature cannot go beyond 15°C due to pinch restrictions even though the heat source still can go for higher refrigeration capacity. Changing the evaporator temperature to 9°C makes it possible for the cooling temperature to go up to 16°C and indeed gives more power output. Again the evaporator temperature was changed to 8°C but the refrigeration machine could not successfully operate at 17°C cooling temperature due to the lack of energy; the cooling temperature stuck at 16°C as before. As the evaporator temperature got lower, the cooling temperature had to be lowered in order to make the refrigeration machine operate.

There are some combinations of evaporator and cooling temperature that give similar power output with differing total areas of the heat exchanger. Hence, it is reasonable to compare the power gain over the area of heat exchanger needed by the refrigeration system. Figure 4 shows the ratio between extra power produced by the generation system and the total area of the heat exchanger necessary for such extra power.
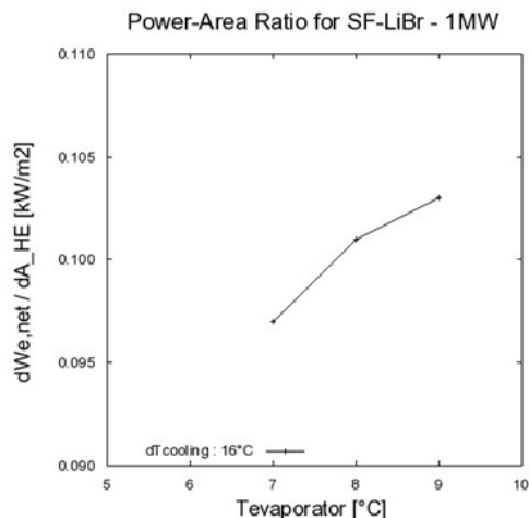
Figure 4: Net power-area ratio of integrated single flash and lithium bromide-water ARS

The net power-area ratio curve describes how much net electric power gain is achieved for each area of exchanger installed, thus the highest ratio is preferable. Hence, the optimum condition – considering the electric gain and total area needed for heat exchanger – was given by the 9°C ARS evaporator temperature as previously mentioned.

Table 3: ARS main parameters for the optimum electric gain

Component	ARS Parameters
Electric gain[kW]	131
Evaporator capacity [kW]	4,414
$T_{evaporator}$ [°C]	9
$\Delta T_{cooling}$ [°C]	16
ARS cooling water [kg/s]	161.48
Absorber [m^2]	608.60
SHX [m^2]	16.66
Desorber [m^2]	224.90
Condenser [m^2]	116.90
RHX [m^2]	10.26
Evaporator [m^2]	296.00
Total HE Area [m^2]	1,273

4. OBSTACLES IN LOWERING THE CONDENSER PRESSURE

A lower condenser pressure can be achieved by employing a lower cooling water temperature in the condenser. However, there are some potential obstacles to be faced such as non-condensable gas content and steam quality during the steam expansion process across the turbine.

Tesha

4.1. The non-condensable gases

The presence of non-condensable gases in geothermal fluid controls how low the condenser pressure can go. The higher the non-condensable gases content, the more work is needed to remove the accumulated gases from the condenser. A large quantity of non-condensable gases and very low condenser pressure limit the gas extraction equipment because it deals with a high gas specific volume and huge equipment.

Geothermal fluid that comes from the well is assumed to have 0.15% non condensable carbon dioxide content. Power plants are modeled with a vacuum pump unit attached to the condenser to remove unwanted non condensable gas. Here, the saturated temperature for the gas extraction process was set to 4°C below the temperature of condensation. Thus, most of the steam phase is condensed before passing the gas extraction process.

4.2. Steam quality at the outlet of the turbine

As the pressure at the condenser (at the outlet of the turbine) is shifted to a lower level, the steam quality after the expansion process decreases and more water droplets are created within the steam mixture. The presence of water droplets can harm the turbine blade. Depending on the turbine design, there is a limit for the maximum allowed steam quality at the outlet of the turbine.

5. GENERAL INVESTMENT OVERVIEW

Once the area of each heat exchanger component for the absorption machine is known, the investment cost for each of them can be roughly calculated. Material that is used to construct the heat exchanger becomes the main factor that affects the heat transfer coefficient and the investment cost, but selecting the correct material for such working fluid is the most important thing compared to the investment cost because it will affect the life expectancy and maintenance complexity of the absorption machine.

Carbon steel and copper are the preferred materials for the single effect aqueous lithium bromide absorption system environment, even though the presence of oxygen in aqueous lithium bromide makes it aggressive to many metals including carbon steel and copper. Since the presence of oxygen is very little in an absorption machine, the aggressiveness and corrosion rates are much slower (Herold, Radermacher, & Klein, 1996) and preventive action should be taken to minimize the effects. Steel and stainless steel are the most common materials to put in an ammonia-water environment because ammonia is a very good solvent for copper. A corrosion inhibitor is still needed when steel is considered as the heat exchanger material.

The general cost estimations for the heat exchanger components refer to Matches website (Matches' Process Equipment Cost Estimates) where the price is based on F.O.B. Gulf Coast U.S.A. year 2007. Total investment cost for each system was calculated based on heat exchanger and pump initial cost (Bejan, Tsatsaronis, & Moran, 1996) as listed in Table 5.

As the price of electricity is different at a specific place, it gives different investment prospect. Any country with higher electric price can have a bigger chance in implementing this integrated system. Obviously, country

with low electric price, i.e. Kazakhstan is not feasible economically.

Table 4: Typical return of investment for specific national electric price

Country	Investment (US$)[1]	Electric Price (US$/kWh)[2]	ROI (years)[3]
France	2,089,816	0.158	12
Kazakhstan	2,089,816	0.043	42
Netherland	2,089,816	0.285	6
Singapore	2,089,816	0.143	13
United Kingdom	2,089,816	0.219	8

[1] As calculated in Table 5

[2] Price for 2007, Energy Information Administration

[3] Neglecting operational cost, maintenance cost and interest

6. CONCLUSION

As the product of an absorption refrigeration system is flowing water, the need to build a low temperature refrigeration system is not necessary. The advantage of a water-ammonia absorption system which can work far below 0°C is not applicable. Lithium bromide-water ARS and water-ammonia ARS have different refrigeration markets, determined by the temperature of the refrigeration demand.

An integrated power and absorption system generally still cannot fulfill today's feasibility requirements. A power plant cooling system needs a high-cooling rate, meaning that the evaporator has to lower the cooling water temperature very quickly. Such a cooling rate requires a large refrigeration capacity and makes the total investment cost skyrocket.

The development of absorption technology in the future, especially the technology to reduce investment costs and increase the performance of the working fluid could change this paradigm and provide a good market for an integrated power and absorption system. The possibilities of a higher power price and lower steel price in the future more or less should give a positive contribution to the development of this integrated power and refrigeration system.

REFERENCES

Bejan, A., Tsatsaronis, G., & Moran, M: *Thermal Design & Optimization.* Wiley-IEEE., (1996).

Energy Information Administration: Retrieved October 2009, from Energy Information Administration website http://www.eia.doe.gov/emeu/international/elecprih.html.

Herold, K. E., Radermacher, R., & Klein, S. A.: *Absorption Chillers and Heat Pumps.* Boca Raton: CRC Press Inc, (1996).

Matches' Process Equipment Cost Estimates: Retrieved April 2009, from Matche's Home Page: http://www.matche.com/EquipCost/index.htm

Table 5: Estimation of total capital investment for single effect lithium bromide-water ARS

Cost Components	Cost
I. Fixed Capital Investment (FCI)	
A. Direct Cost (DC)	
1. Onsite Cost (ONSC)	
Purchased Equipment Cost (PEC)	
a. Heat Exchanger	$ 570,600.0
b. Pumps	$ 4,100.0
c. Piping System [5% of (a+b)]	$ 28,735.0
d. Electrical Control & Monitoring system [30% of (a+b+c)]	$ 181,030.5
Total Onsite Cost	$ 784,465.5
2. Offsite Cost (OFSC)	
a. Civil, structural & architectural work [20% of ONSC]	$ 156,893.1
b. Service facilities (hot source & cold sink connection) [25% of ONSC]	$ 196,116.4
c. Contingencies [15% of ONSC]	$ 117,669.8
Total Offsite Cost	$ 470,679.3
Total Direct Cost	**$ 1,255,144.8**
B. Indirect Cost (IDC)	
1. Engineering & Supervision [15% of DC]	$ 188,271.7
2. Construction cost incl. Contractor's profit [15% of DC]	$ 188,271.7
3. Contingencies [20% of DC]	$ 251,029.0
Total Indirect Cost	**$ 627,572.4**
Total Fixed Capital Investment	**$ 1,882,717.2**
II. Other outlays	
Total other outlays	**$ 207,098.9**
Total Capital Investment of ARS Machine	**$ 2,089,816.1**