Feasibility of Utilizing Boiler Blowdown Waste Heat for Operating an Absorption Refrigeration Chiller

A. P. T. S. Peiris[1,2,3], R. P. Vitharanage[1,2,3], Ruchira Abeyweera[1,2], N. S. Senanayake[1] and Jeevan Jayasuriya[2]

[1] Department of Mechanical Engineering, The Open University of Sri Lanka
[2]Department of Energy Technology, Royal Institute of Technology, Stockholm, Sweden
[3]University of Gävle, Gävle Sweden

Abstract- This paper presents results of a study carried out to determine the feasibility of utilizing boiler blowdown heat for operating an absorption refrigeration chiller. In the study the coal power plant situated in Sri Lanka was used. This consists of three identical power plant units operated on “Rankine Reheat – Regenerative Steam Cycle. Each unit has 300MW rated capacity with an overall efficiency between 35%-40%. Continuous blowdown of the plant boiler is done at the rate of 10tons/hour. The temperature of the blow down water is at 97.5^{o}C. The study aimed at investigating the possibility of utilizing heat recovered through boiler blowdown water to operate a vapor absorption refrigeration plant to supply required chill water for site air conditioning needs. The power plant at present has three central air conditioning units with cooling capacities of 900, 960 and 640kW operating on vapor compression refrigeration to produce chill water requirements. The amount of heat that could be extracted from the blowdown water (from one unit) was estimated as 496kW. Accordingly, an absorption chiller was selected to match the available heat and based on inlet and outlet temperatures recommended by the manufactures. All necessary auxiliary equipment for the installation of the selected the absorption chiller which replaces the present vapour compression refrigeration system was determined together with economic feasibility. The study demonstrated the possibility of successful utilization of boiler blowdown water for useful application, hence savings in energy.

Index Terms- Boiler blowdown, Waste heat, Absorption refrigeration, Energy savings

I. Introduction

Waste heat recovery has been a common practice in industry to gain economic benefits in short term by saving fuel costs and contributing to the sustainable use of energy resources. Especially, heat recovery has become increasingly important as an integral part of thermal power generation systems, i.e. waste-to-energy units are included to the best possible extent [1]. The rising cost of energy and global warming concerns in recent years have highlighted the need to develop energy systems with higher efficiency and to reduce emissions. Waste heat recovery, renewable energy sources, cogeneration and combined cycle power generation systems are receiving a greater attention [2].

Heat recovery from exhaust gases is often practiced in many instances. Other area in which a potential exists to recover heat is from the boiler blowdown water in large power generation plants. The boiler blowdown process involves the periodic or continuous removal of water from the bottom section of the evaporator of a boiler to remove accumulated dissolved solids and/or sludge. During this process, water is discharged from the boiler to avoid the negative impacts of dissolved solids or impurities on boiler efficiency and maintenance. However, boiler blowdown results in waste of energy, because the blowndown liquid is at about the same temperature as that of the saturated steam produced. Much of this heat can be recovered by routing the blowndown water through a heat exchanger that preheats the boiler's makeup water.

In the present study, power plant which uses coal as the fuel to run three units of steam turbines each having 300MW rated power was selected. The plant uses Rankine Reheat-Regenerative Steam Cycle with three stages and the overall thermal efficiency of the plant lies between 35% - 40%. The steam pressure used is 16MPa.

In the plant, boiler feed water is pumped into the boiler (steam drum) through high pressure heat exchangers (feed water heaters) and an economizer located at the boiler exhaust side. Then water is distributed over boiler water walls. Burning of the coal heats water in pipes coiled (water wall) around the boiler, turning it into steam. This steam re-enters the steam drum and then it separates (from water in steam drum) by cyclone separators in the steam drum. Separated steam then enters into a set of super heaters. The hot steam expands in the pipes, and emerges under high pressure and high temperature. The high pressure, high temperature steam enters the High Pressure (HP) steam turbine. HP turbine’s outlet steam is conveyed through the re-heater panels of the boiler and then it enters the Intermediate Pressure (IP) steam turbine. Outlet of the IP turbine directly enters the Low Pressure (LP) Steam Turbine.

Outlet steam from LP turbine is condensed back to water by a sea water cooled condenser. HP turbine, IP Turbine and LP Turbine are connected to a common shaft (tandem compound type). This shaft connects with the turbine generator.

The power station has two types of air conditioning systems namely, centralized type air conditioning system (chill water) and split type air conditioning units. This study focused on the centralized type air conditioning system at the power plant. There are three centralized air conditioning systems at the plant, details of which are given in Table 1.

Table 1 Details of Centralized Air Conditioning System [3]

Location of Centralized Air Conditioning System	Chiller's Cooling Capacity (kW)	Users
Main Power Block – Unit 01 Power Plant	900	Central Control Room, Electronic Cabinet Rooms (Unit 01 and 02), Electro-Static Precipitator (ESP) and Ash Handling Control Room (Unit 01)
Main Power Block – Unit 03 Power Plant	960	Electronic Cabinet Rooms (Unit 03), ESP and Ash Handling Control Room (Unit 02 and 03), Engineers Room (Unit 03)
Boiler Make-up Water Plant Block	640	Boiler makeup water plant control room, Laboratory rooms, Canteen, Administration building

II. Methodology

As the first step, the waste heat that could be recovered from the continuous blowdown water was estimated using measured data. The capacities of air conditioning were examined in order to decide which air conditioning system given in Table 1 could be replaced with an absorption chiller which is to be operated with the recovered waste heat. After deciding on the air conditioning plant to be replaced with the new system, the specifications given by the suppliers of the present system was analyzed to ensure that the same operating conditioning are achieved [3].

III. Proposed Absorption Chiller

In general blowdown rate is taken as 1% of the feed water flowing into the boiler. Therefore, for a single power plant unit of 300MW capacity, the boiler blow down rate is 10.25ton/h. According to the past operating data of the power station [4] (for the month of October 2015), average blowdown flow rate is 10 ton/h (in liquid water state) and it has an average temperature of 97.5°C at the exit after the heat exchanger placed as an additional feed water heater.

Absorption chiller manufacturers recommend various heat sources to drive the absorption refrigeration cycle. After reviewing a number of available product catalogues, a chiller with the specification given in Table 2 was selected as it matches the conditions of the proposed application in terms of cooling demand.

Table 2 Specifications of the Chiller [5]

Manufacturer	LS Mtron Ltd
Selected Model	LWM-T009
Refrigerant	Water - LiBr
Cooling Capacity	316 kW
Chilled water Data	
Temperature	13°C (Inlet) 8°C (Outlet)
Water flow rate	54.4 m^3/h

Table 2 (cont.)

Cooling Water Data	
Temperature	31°C (Inlet) 36.5°C (Outlet)
Water flow rate	128 m^3/h
Hot Water Data	
Temperature	95°C (Inlet) 55°C (Outlet)
Water flow rate	10.6 ton/h

For the selected absorption chiller, the heat input requirement was computed with the other data quoted by the manufacturer for the hot water stream as given below.

$$Q_{in} = mC(T_{in} - T_{out})$$

Where;

$Q_{in} = Heat\ supplied\,(kW)$

$C = Specific\ heat\ capacity\ \ (KJkg^{-1}\,^oC^{-1})$

$m = Mass\ flow\ rate\ of\ hot\ water\ (ms^{-1})$

$T_{in} = Inlet\ water\ temperature(\,^oC)$

$T_{out} = Outlet\ water\ temperature(\,^oC)$

Substituting the values given in Table 1;

$$Q_{in} = \frac{(10.6)(10^3)}{3600}(4.2)(95 - 55) = 494.667kW$$

The heat energy available from the boiler blowdown water was then calculated using the available data, and assuming water is cooled down to 55°C.

$$Q_{av} = m'C(\,T'_{in} - T'_{out})$$

Where;

$Q_{av} = Avialble\ heat\ (kW)$

$C = Specific\ heat\ capacity\ \ (KJkg^{-1}\,^oC^{-1})$

$m' = Avialble\ flow\ rate\ of\ water\ (ms^{-1})$

$T'_{in} = Inlet\ water\ temperature(\ ^oC)$

$T'_{out} = Outlet\ water\ temperature(\ ^oC)$

$$Q_{av} = \frac{(10\ )(10^3)}{3600}(4.2)(97.5 - 55) = 495.883kW$$

Since, the available heat recovered from the boiler blowdown is greater than the requirement for the selected absorption chiller; it can be accepted as suitable for this application.

The actual temperature of the available hot water stream is higher by an amount 2.5-^{o}C than the recommended value and on the other hand mass flow rate is slightly less (by an amount 0.6 ton/h). Because of these opposing slight variations, the selected chiller will be able to absorb the required heat energy.

A. Performance of selected absorption chiller

The performance of a refrigeration cycle is described by its Coefficient of Performance (COP), defined as given below

$$\text{COP} = \frac{\text{Cooling capacity}}{\text{Heat input} + \text{Pump Work}}$$

Assuming work input to the pump is negligible, the COP of the selected absorption chiller can be determined with recommended parameters as given below.

$$\text{COP} \quad = \frac{316}{494.667} = 0.64$$

But, available hot water flow (Boiler blowdown water flow) has slightly different conditions with compared to the recommended parameters. Considering the COP of the absorption chiller remains constant for the real situation, the cooling capacity obtainable at evaporator is calculated as follows.

$$Actual\ cooling\ capacity = COP\ x\ Actual\ Heat\ input$$

$$Actual\ cooling\ capacity = 0.64\ x\ 495.833$$

$$= 316.837kW$$

This proves that expected cooling capacity could be obtained by the selected absorption chiller (316 kW cooling capacity) with the boiler blowdown water flow.

B. Integration of Absorption Chiller with the Existing System

The present vapor compression refrigeration chiller at the main power block meets the cooling loads of three locations, namely; Central Control Room, Electronic Cabinet Rooms, and ESP and Ash Handling Control Room (see Table 1). Total capacity of the chiller is 900kW. Since, the selected absorption chiller can supply only 316kW of cooling load with the available boiler blowdown water, only a part load can be handled by this absorption chiller. The Central Control Room and the Electronic Cabinet Rooms have cooling loads of 100kW and 200kW respectively, totaling to 300kW, and therefore the proposed chiller is recommended to be used for the cooling needs of these two locations.

In the present system, chill water supply and return are done through separate pipes from chill water supplying and returning headers as shown in Figure 1. Hence the proposed absorption chiller can be integrated to the existing system as shown in Figure 2.

Further, the existing vapor compression refrigeration based chiller can be adjusted to its cooling capacity within a range of 25-100% of rated capacity (900kW). Therefore, the existing vapor compression system can be used to supply the remaining cooling load of 600 kW in other locations except Central Control Room and Electronic Central Cabinet Rooms without any disturbances.

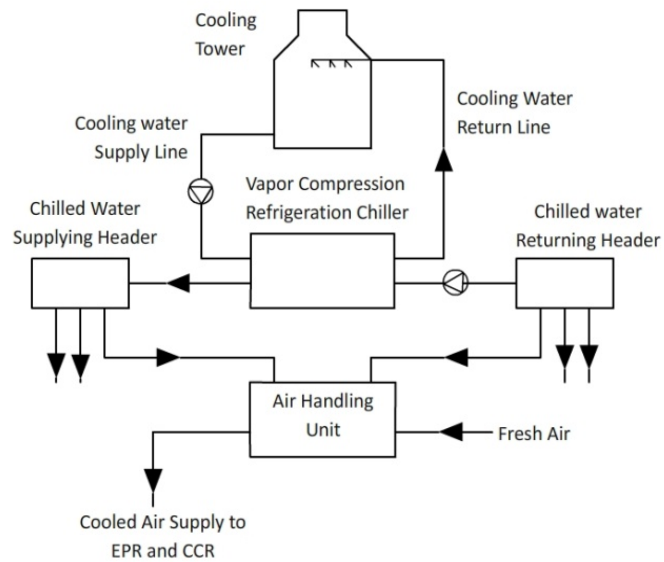

Figure 1 Present chilled water supply system

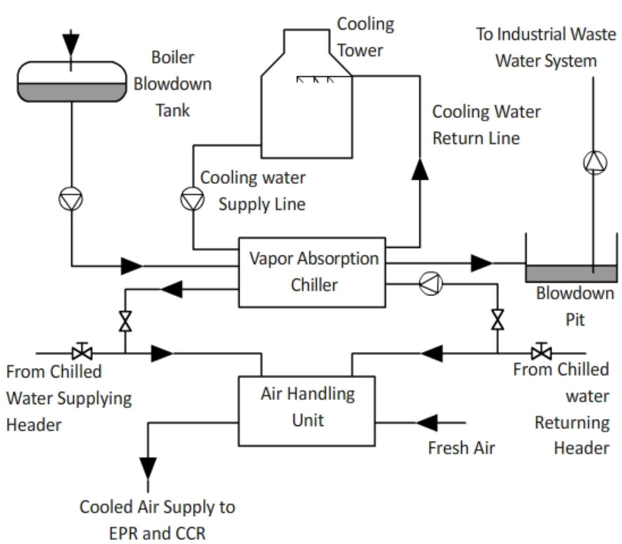

Figure 2 Modified Chilled water System with the Absorption Chiller

C. Auxiliary Components for the Absorption Chiller

When integrating an absorption chiller into the existing system, the following main components are required with necessary insulated pipe lines.

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- A Cooling Tower
- A Pump for cooling water line
- A Pump for chilled water line
- A Pump for supplying hot water to absorption chiller hot water path

Selection criteria of these components are described below. The same Air Handling Unit (AHU) of the vapor compression refrigeration system can be used in the proposed system.

D. Selection of a Cooling Tower

Selection of a cooling tower for an absorption chiller is normally based on cooling water flow rate, cooling mechanism and inlet/outlet temperature of cooling water of the selected absorption chiller. For the proposed absorption chiller, the following conditions shall be fulfilled with regard to the cooling tower in order to match with the absorption chiller.

Cooling water flow rate = 128 m^3/h
Inlet temperature = 31^{o}C
Outlet temperature = 36.5^{o}C

Based on above parameters, the following cooling tower was selected from the catalogue of cooling towers, CTS Cooling Tower Systems, USA [6].

Selected Cooling Tower specifications are as follows:
Model: T-2150
Inlet water temperature : 35 ^{o}C
Outlet water temperature: 29 ^{o}C
Hot water and air flow direction: counter-flow
Ventilation: mechanical draft cooling tower

E. Selection of Pumps

Three centrifugal pumps were selected to match with the designed operational requirements considering easy operation, availability, and maintenance. Table 3 summarized the selection criteria and the specifications of the pumps as per the manufacturer's catalog [7].

Table 3 Selection of Centrifugal Pumps for Proposed Absorption Chiller [7]

Application	Specifications	Manufacturer and Model
Pump for cooling water line	Flow: 128 m^3/h (As per selected absorption chiller) Head: 40 m (As per existing system)	Manufacturer: Ruhrpumpen, Germany Model: CPP
Pump for chilled water line	Flow: 54.4 m^3/h (As per selected absorption chiller) Head: 40 m (As per existing system)	Manufacturer: Ruhrpumpen, Germany Model: CPP
Pump for supplying hot water to absorption chiller hot water path	Flow: 10 m^3/h (As per selected absorption chiller) Head:	Manufacturer: Ruhrpumpen, Germany Model: CPP-L

IV. Challenges during Adaptation

Compared to an electric chiller, an absorption chiller requires about 50% additional space. Outdoor installations are also not possible since the refrigerant is water. Thus a large room is required for the absorption chiller installation. Required dimensions for the selected absorption chiller are: Length (with space for tube replacement) 5200mm, Width 1900mm, height 2260mm. Also the absorption chillers are twice as heavy in general when compared to a normal equivalent electric chiller. The selected model is of 5.5ton operating weight.

As per the selected chiller, the foundation should be properly laid in such a manner that chiller will be horizontally level (2mm per 1000mm) in both directions. The chiller will not operate if the refrigerant and absorbent trays inside the chiller are not level. According to the specifications, the load bearing foundation areas should be of concrete to withstand the load of the chiller.

Similarly, the cooling tower required for an absorption chiller compared to a similar capacity electric chiller is larger. An inherent concern with absorption chillers is the crystallization of the absorbent (Lithium Bromide solution) inside the chiller due to lapses in the tower control pump. This phenomenon is called "rocking up." In order to avoid such situations; pumps have to be in operation even after shut down of the chiller. Thus, there is a requirement to have an emergency power supply to keep the pumps running to avoid crystallization. This additional expenditure is up to the owner to decide based on the availability of uninterrupted power supply.

V. Economic Feasibility

In general the cost of an absorption chiller is expressed as a cost per unit of cooling capacity. According to the market price existed on November 2015, this value was USD 1110/ton of refrigeration (1 ton of refrigeration = 12000BTU/H = 3.5 kW cooling). Based on this figure, the cost for the proposed application, which is 316kW or 90ton, would be USD 99,900. If the plant is assumed to be last for 20 years, the annual depreciation cost based on straight line depreciation and without a scarp value, the annual depreciation chargeable would be USD 4,995.

Since the plant is operational for 24h a day the annual electrical power requirement to drive the absorption chiller was estimated. Since four pumps with electrical power ratings of 2.8kW, 0.6kW, 0.2kW and 0.4kW are in operation for sub-systems of the proposed application the electrical energy demand is estimated as follows.

$$\text{Electrical power} = 2.8 + 0.6 + 0.2 + 0.4 = 4\text{kW}$$
$$\text{Annual Energy consumption} = 4 \text{ x } 24 \text{ x } 365 = 35{,}040\text{kWh}$$

Considering the cost of one unit of electricity (one kWh) as USD 0.1 the running electrical would be USD 3504.

Therefore, the annual total cost for the proposed system with depreciation would be USD 8499. The annual electricity cost that could be saved by replacing the vapour compression refrigeration plant from the absorption chiller based air conditioner of 316kW, is not significant as the same vapour compression refrigeration system is to be operated on part load.

VI. Conclusions

Absorption chillers provide low cost reliable cooling and for a given application it could provide significant energy savings, especially in the form of waste heat recovery. In order to maximize the savings, different scenarios should be evaluated for a given situation and environment. Coefficient of Performance of an absorption chiller plant lies on low values (nominally less than 0.7) with compared to vapor compression systems (nominally between 5-6), but with available of waste heat source or cheap heat source, an absorption chiller can accommodate in air conditioning systems with high rate of return in terms. On the other hand, absorption chiller's refrigerant (water- ammonia or water- LiBr) are not harmful for the ozone layer of the atmosphere which directly prevents contamination of Ultra Violet (UV) rays on earth.

In this study we have only demonstrated the feasibility of utilizing waste heat recovered from boiler blowdown water. As far as costs are concerned, only the cost of chiller, electricity costs for the plant operation and the depreciation have been considered. However, there could be other costs involved with the cooling tower, pumps, installation and insulation, construction of a room to accommodate the chiller, etc.

Also we have considered a single effect chiller where low temperature heat is utilized, thus low efficiencies. But with a small amount of reheating to produce steam, there is a possibility to run a double-effect chiller which is more efficient.

More accurate data on the part load cooling would have helped in accurate calculation of the energy used in the existing chiller, hence more realistic cost savings would have found.

Another advantage of this design is, existing vapor compression system can be used for remaining part load without altering the system. Also during the start-up or shutdown of the plant, it can use existing vapor compression system for essential air conditioning needs by using relevant isolation valves.

References

[1] L. Čuček, H. L. Lam, J. J. Klemeš, P. S. Varbanov, Z. Kravanja, Synthesis of regional networks for the supply of energy and bioproducts, Clean Technologies and Environmental Policy December 2010, Vol. 12 Issue 6 635-645

[2] C. J. Butcher, B. V. Reddy, Second law analysis of a waste heat recovery based power generation system, International Journal of Heat and Mass Transfer 50 (2007) 2355 – 2363.

[3] [3] Air Conditioning and Ventilation Design Guideline of Puttalam Coal Power Project Phase I and II, China Machinery Engineering Corporation, 2009.

[4] Past operating data of Lakvijaya Power Station, Ceylon Electricity Board (01st October 2015 to 31st October 2015).

[5] Product catalogue of single-effect double lift low temperature hot water driven absorption chiller, 2008, LS MTRON LTD, South Korea.

[6] Product catalogue of Cooling Towers, CTS Cooling Tower Systems, USA. From www.coolingtowersystems.com retrieved on 21st November 2015

[7] Pump Catalogue, Ruhrpumpen Group, Germany. From www.ruhrpumpen.com retrieved on 21st November 2015

Authors

First Author – A. P. T. S. Peiris, BSc.Eng (Hon) in Mechanical & Manufacturing Engineering, CEng (UK), MIMechE, AMIE (SL), KTH - Royal Institute of Technology – Sweden, University of Gävle – Sweden, thanushka.peiris@gmail.com

Second Author – R. P. Vitharanage, BSc. Eng(Hon) in Mechanical Engineering(UOM), MBA (SJP), CIMA(UK), BCS (UK), KTH - Royal Institute of Technology – Sweden, University of Gävle – Sweden, rpvitharanage@gmail.com,

Third Author – Ruchira Abeyweera, MSc (KTH) Royal Institute of Technology-Sweden, BTech (Eng) (OUSL), , The Open University of Sri Lanka, ruchira@kth.se

Fourth Author – N. S. Senanayake, PhD (Cranfiled), MSc (Cranfield), BScEng(Hon) in Mechanical Engineering, The Open University of Sri Lanka, nssen@ou.ac.lk

Fifth Author – Jeevan Jayasuriya, PhD (KTH Sweden) KTH –Royal Institute of Technology Sweden, MEng (AIT Thailand) Asian Institute of Technology, Thailand, BSc Eng(Hon) in Mechanical Engineering (UOM Sri Lanka) University of Moratuwa, Sri Lanka, Jeevan.jayasuriya@energy.kth.se

Correspondence Author – N. S. Senanayake, nssen@ou.ac.lk , nssen2010@gmail.com , +94 776645977.