ijcrr
Vol 04 issue 12
Category: Research
Received on:10/04/12
Revised on:27/04/12
Accepted on:17/05/12

THERMAL ANALYSIS OF EXHAUST WASTE HEAT FOR COOLING USING NH_3-H_2O ABSORPTION REFRIGERATION SYSTEM

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ABSTRACT

This research paper includes the detailed thermodynamic analysis of waste heat from DG set system and power plants and also the analysis of NH_3-H_2O vapour absorption refrigeration system. This work proposes the direct utilization of waste heat to power absorption refrigeration system. This analysis includes theoretical calculation of heat required for generator, refrigerating effect produced and required mass flow rate of refrigerant for the typical power generating unit. This research shows that considerable amount of cooling effect and energy saving would result from direct utilization of the exhaust waste heat of DG set system or power plants which will reduces the losses of energy, therefore reduces the emission of green house effect gasses..

Keywords: Waste heat, Vapour absorption refrigeration system (VARS), Circulation ratio

INTRODUCTION

Most of industrial process uses a lot of thermal energy by burning fossil fuel to produce steam or heat. After the processes, heat is rejected to the surrounding as waste. This waste heat can be converted to useful refrigeration by using a heat operated refrigeration system, such as an absorption refrigeration cycle [1]. Despite a lower coefficient of performance (COP) as compared to the vapor compression cycle, absorption refrigeration systems are promising by using inexpensive waste energy from industrial processes, geothermal energy, solar energy etc [2].

The absorption refrigeration system is heat-operated unit, which uses a refrigerant that is alternately absorbed by and liberated from the absorbent. Absorption units operate on the simple principle that under low absolute pressure, water will boil at a low temperature. The two-shell cooling units use heat to produce refrigeration efficiently. The lower shell contains an absorber and evaporator, while the upper shell consists of generator and condenser sections [3].

A survey of absorption fluids suggested that, there are some 40 refrigerant compounds and 200 absorbent compounds available [4]. However, the most common working fluids are NH_3-H_2O and LiBr-H_2O. It is reported that LiBr-H_2O has a higher COP than for the other working fluids though it has a limited range of operation due to the onset of crystallization occurring at the point of the recuperator discharge into the absorber and stopping solution flows through the device [5].

In this research work vapour absorption refrigeration systems based on ammonia-water (NH_3-H_2O) pair has been considered in which ammonia is the refrigerant and water is the absorbent. These systems are more versatile than systems based on water-lithium bromide as they can be used for both sub-zero (refrigeration) as well above 0 ^{o}C (air conditioning) applications.

The NH_3-H_2O system requires generator temperatures in the range of 125°C to 170°C with air-cooled absorber and condenser and 80°C to 120°C when water-cooling is used. The coefficient of performance (COP), which is defined as the ratio of the cooling effect to the heat input, is varies from 0.6 to 0.7 [6].

This research includes thermodynamic analysis of waste heat from power generating units and NH_3-H_2O vapour absorption refrigeration system. The unique feature of present work is that the direct utilization of waste heat to power in the NH_3-H_2O absorption refrigeration system will reduces the losses of energy resulting in reducing pollution.

MATERIALS AND METHODS

Waste heat energy sources

For the analysis of cooling effect produced by waste energy, three systems are considered including:

1. A typical DG set system of 5 MW operating at different loads. The details are given in the table 1.
2. The combined cycle gas turbine power plant in Pragati Power Corporation Ltd., Delhi. It consists of 2 x 104 MW Frame 9-E Gas turbine and 1x122MW steam turbine. These turbines, namely gas turbine#1 (GT1) and gas turbine #2 (GT2) are selected for the present analysis. Performance data of gas turbines are given in table 2.
3. 500 MW steam power plant installed in MTPS-DVC, Bankura, in which the waste heat from the boiler exhaust is utilized. The performance data of boiler is given in table 3.

Cooling System

NH_3- H_2O Vapour absorption chiller specifications:

Average Generator temperature = 100 ^{0}C.
Average Condenser temperature = 46 ^{0}C.
Average Absorber temperature = 40 ^{0}C.
Average Chilled-water temperature= 7 ^{0}C.
COP of the system= 0.6.

Calculation of heat energy

Available maximum exhaust heat, heat available for generator and refrigeration effect from above sources are calculating as per the relation given in table 4.

Available maximum exhaust heat = $m_{ex.}C_{p,ex.}(T_{ex} - T_a)$ kW

Heat available for generator (Q_g) = $m_{ex}.C_{p,ex}.(T_{ex} - T_g)$ kW

Refrigeration effect (Q_e) = COP * Q_g kW

Thermal analysis of NH_3-H_2O vapour absorption refrigeration system using available exhaust heat

Assuming pure ammonia vapours are evolved in generator, we have for pressures from the table of properties of ammonia [9].

$P_c = P_{sat}(T_c)$

$P_e = P_{sat}(T_e)$

Strong solution concentration of NH_3 from enthalpy-composition diagram for NH_3 – H_2O system

ξ_{ss} [sat. liquid at absorber temperature (T_a) & pressure (P_a)]

Weak solution concentration of NH_3 from enthalpy-composition diagram for NH_3 – H_2O system

ξ_{ws} [sat. liquid at generator temperature (T_g) & pressure (P_g)]

The concentration of NH_3 in vapour leaving generator

ξ_v [sat. vapour at generator temperature (T_g) & pressure (P_g)]

The properties of NH_3-H_2O solution at different temperature state (Figure 1) are given with the help of enthalpy-composition diagram for NH_3 – H_2O system, and given in table 5.

Now specific strong solution circulation rate

$\lambda = (\xi_v - \xi_{ws}) / (\xi_{ss} - \xi_{ws})$

Specific weak solution circulation rate

$\lambda - 1$

Mass flow rate

Required mass flow rate of refrigerant, $m_r = Q_e / (h_4 - h_3)$ (1)

mass flow rate of strong solution, $m_{SS} = \lambda m_r$ (2)

mass flow rate of weak solution, $m_{WS} = (\lambda - 1) m_r$ (3)

Heat transfer rates at various components

Evaporator Q_e

Absorber From energy balance:

$Q_a = m_r h_4 + m_{ws} h_8 - m_{ss} h_5$ (4)

Generator From energy balance

$Q_g = m_r h_1 + m_{ws} h_7 - m_{ss} h_6$ (5)

Condenser From energy balance

$Q_c = m_r (h_1 - h_2)$ (6)

Solution pump work (assuming the solution to be incompressible)

$W_P = v_{sol}(P_6 - P_5) = (P_6 - P_5)/\rho_{sol}$ (7)

Where

m = Mass (kg)
C_p = Specific heat (kJ/kg K)
COP = Coefficient of performance
P = Pressure (kPa)
T = Temperature (^{0}C)
ξ = Mass fraction
λ = Circulation ratio
Q = Heat energy (kW)
h = Specific enthalpy (kJ/kg)
W = Work (kJ)
v = Specific volume (m^3/kg)
ρ = Density of the flue gas kg/m^3

Subscripts

ex	exhaust flue gas
a	absorber
g	generator
e	evaporator
c	condenser
r	refrigerant
ss	strong solution
ws	weak solution
sat	saturation state
p	pump
sol	solution
hx	heat exchanger
v	superheated water vapour

The theoretical calculated values of mass flow rate of refrigerant, strong and weak solution along with heat transfer rate at various components with respect to refrigerating effect for this analysis are given in table 6 and mass flow rate of refrigerant required for calculated values of refrigerating effect from different available waste heat sources are also shows in chart 1.

RESULTS

The purpose of the present research was to analyze the methods and means of utilizing the waste heat of power generating units for driving an absorption refrigeration system. The following results are calculated from the research work:

- In the steam power plant (500 MW), the waste heat analysis applied to boiler (MTPS-DVC Bankura) could produce cooling effect up to 13667.91 kW.
- In the combined cycle power plant of 330 MW, waste heat analysis applied to GT1 & GT2 of (PPP-Delhi), produces the cooling effect up to 2727.22 & 2889 kW respectively.
- In the DG set system of 5 MW, waste heat analysis at 100%, 90%, 70% & 60% load, produces the cooling effect up to 2186.61, 1846.8, 1415.94 &1144.13 kW respectively.

DISCUSSION

The present research work concluded that direct utilization of waste heat to heat solution in generator and the operation of an absorption refrigeration system on that hot exhaust flue gas could be a successful approach. The theoretical analysis for both the power generating units and the NH_3-H_2O vapour absorption refrigeration system showed that the suggested inexpensive heat recovery load would be in the form of hot flue gases will be in the operating range of the absorption refrigeration cycle.

It is recommended that the utilization of rectification column and dephlegmator in NH_3-H_2O absorption refrigeration system could improve the performance of the system.

ACKNOWLEDGEMENT

Authors acknowledge the immense help received from the scholars whose articles are cited and included in references of this manuscript. The authors are also grateful to authors / editors / publishers of all those articles, journals and books from where the literature for this article has been reviewed and discussed.

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Table 1: A typical flue gas temperature and flow pattern in a 5-MW DG set at various loads [7, 8]

Load (%)	Ambient temperature(^{0}C)	Exhaust flue gases		Specific heat (KJ/kg K)
		Temperature (^{0}C)	Quantity (kg/s)	
100	40	370	11.84	1.14
90	40	350	10.8	1.14
70	40	330	9.08	1.13
60	40	325	7.5	1.13

Table 2: Performance Data for Unit in the MW combined cycle Power Plant

Turbine each (104MW)	Load (MW)	Ambient temperature (^{0}C)	Exhaust gases of HRSG		Specific heat of exhaust flue gases (kJ/kg K)
			Temperature (^{0}C)	Quantity (kg/s)	
GT1	95.4	23	112	354	1.07
GT2	103.2	23	112	375	1.07

Table 3: Performance Data of 500 MW Steam Power Plant Boiler

Boiler type	Made by	Air preheater type	Ambient temperature (^{0}C)	Exhaust flue gas		Specific heat of exhaust flue gases(kJ/kg K)
				Temperature (^{0}C)	Quantity (kg/s)	
Tangential firing system	BHEL	Regenerative tri sector	40	140	527.8	1.079

Table 4: Heat Energy & Refrigeration Effect From Above Sources

Heat system	Source of waste heat	Ambient temperature(^{0}C)	Exhaust flue gases		Specific heat (KJ/kg K)	Available maximum exhaust heat (kW)	Heat available for generator (kW)	Refrigeration effect (kW)
			Temperature (^{0}C)	Quantity (kg/s)				
Steam power plant (500 MW)	Boiler tangential firing system	40	140	527.8	1.079	56949.6	22779.8	13667.91
Combined cycle power plant (330 MW)	GT1 (104MW)	23	112	354	1.07	33711.4	4545.4	2727.22
	GT2 (104MW)	23	112	375	1.07	35711.3	4815.0	2889.00
DG SET (5 MW)	100% Load	40	370	11.84	1.14	4454.2	3644.4	2186.61
	90% Load	40	350	10.8	1.14	3816.7	3078.0	1846.80
	70% Load	40	330	9.08	1.13	2975.5	2359.9	1415.94
	60% Load	40	325	7.5	1.13	2415.4	1906.9	1144.13

Table 5: Properties of NH_3-H_2O solution at different state temperature

State point	Temperature (^oC)	Pressure (bar)	Mass fraction (ξ)	Enthalpy (kJ/kg)
1	100	18.33	0.955	1845
2	46	18.33	0.955	520
3	7	5.55	0.955	520
4	7	5.55	0.955	1815
5	40	5.55	0.5	100
6	40	18.33	0.5	100
7	100	18.33	0.43	380
8	40	5.55	0.43	380

Table 6: Mass flow rate of strong and weak solution along with heat transfer rate from absorber and condenser with respect to refrigerating effect

Refrigeration effect (kW)	Mass flow rate of refrigerant (kg/s)	Mass flow rate of strong sol. (kg/s)	Mass flow rate of weak solution (kg/s)	Heat transfer rate at absorber (kW)	Heat transfer rate at generator (kW)	Heat transfer rate at condenser (kW)	Pump work (kW)
13667.91	10.554	79.158	68.603	37309.7	37626.3	13984.5	1.62
2727.22	2.106	15.795	13.689	7444.6	7507.7	2790.4	1.62
2889.00	2.231	16.732	14.501	7886.2	7953.1	2955.9	1.62
2186.61	1.689	12.664	10.975	5968.9	6019.5	2237.3	1.62
1846.80	1.426	10.696	9.270	5041.3	5084.0	1889.6	1.62
1415.94	1.093	8.200	7.107	3865.1	3897.9	1448.7	1.62
1144.13	0.883	6.626	5.743	3123.2	3149.7	1170.6	1.62

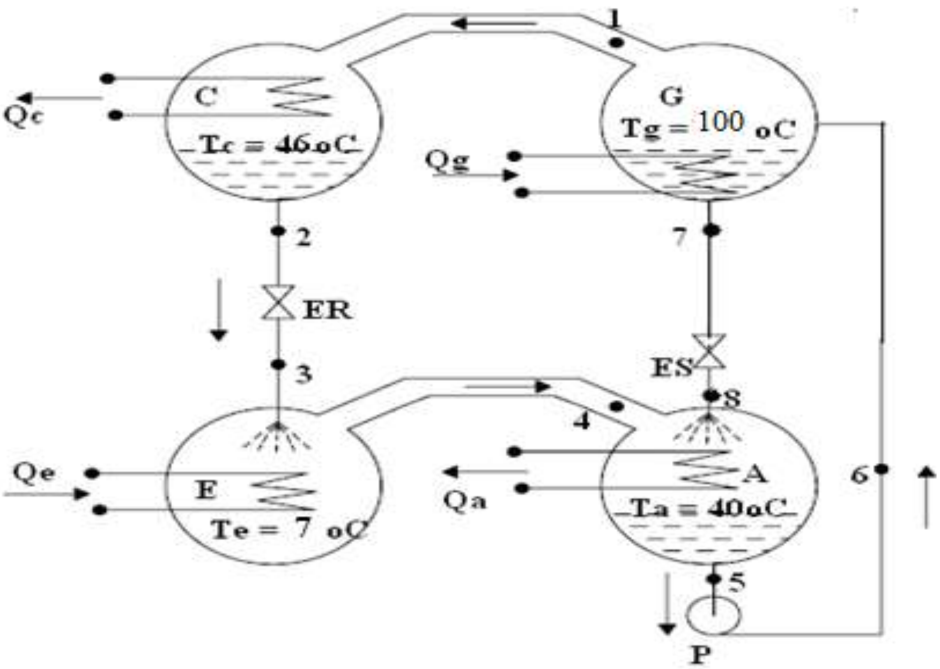

Figure 1: Schematic of a $NH_3 - H_2O$ system
A: Absorber; C: Condenser; E: Evaporator G: Generator; P: Solution Pump
SHX: Solution HX; ER: Refrigerant Expansion valve; ES: Solution Expansion valve

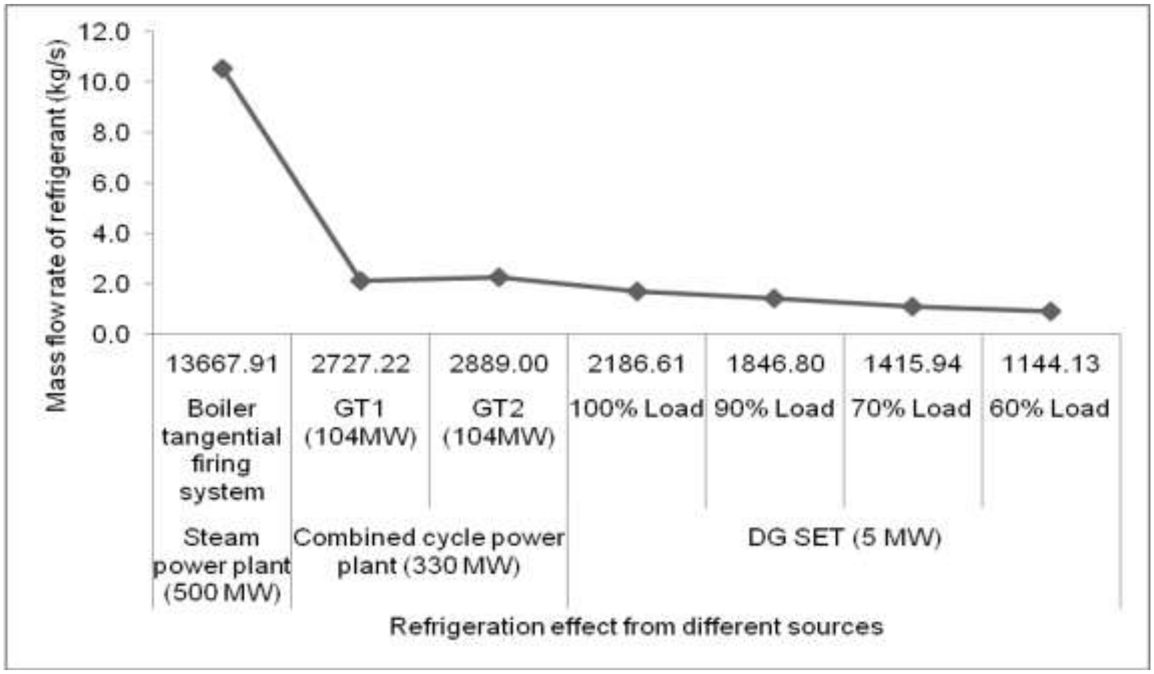

Chart 1: Refrigeration effect from different sources vs mass flow rate of refrigerant