International Journal of Advance Research and Innovation
Vol. 6(4), Oct-Dec 2018, pp. 130-136
Doi: 10.51976/ijari.641815
www.gla.ac.in/journals/ijari

Article Info

Received: 07 Oct 2018 | Revised Submission: 28 Oct 2018 | Accepted: 02 Nov 2018 | Available Online: 15 Dec 2018

Thermodynamic Analysis Of vapour-Absorption (H_2O- LiBr)-Compression Combined Refrigeration System Energized Bya Microgas-Turbine

ShyamAgarwal, BB Arora** and AkhileshArora****

ABSTRACT

The current analysis comprises the configuration of combined refrigeration system which is integration of a vapour compression and vapour absorption system. The integrated system is energized by a microgas turbine to generate cooling at the low temperatures. The waste heat from the exhaust of microgas turbine is used to drive the vapour absorption system while the vapour compression system is directly powered by the small gas turbine. The compression system is at the low temperature stage while the absorption system is at high temperature stage boost the performance of compression system. A computational thermodynamic analysis of the combined system is carried out using mass energy governing equations. It has been concluded on the basis of result obtained that the performance of combined refrigeration systems is higher and less energy consuming.

Keywords: *Micro-Gas Turbine, Absorption-Compression Combined Refrigeration System, Exergy, VAR, VCR.*

1.0 Introduction

The power generation using gas turbine as combined heat and power (CHP) as well as the heat-power-refrigeration (Tri-generation) systems are gaining momentum due to their beneficial overall efficiency about 70-85%. The Tri-generation system consists Gas-turbine, Heat-recovery steam generator (HRSG) and Vapour-absorption refrigeration system. The most fundamental purpose of the Tri-generation is to produce energy for buildings, steam for the industries and refrigeration for the preservationaries. Wang et al. [1] have proposed a combined cooling, heating and power (CCHP) system to produce cooling output, heating output and power output simultaneously. The trigeneration system has a large number of benefits include increased efficiency, high part-power efficiency, small lapse rate, compactness, low emissions, lower air and exhaust flows (which decrease filtration and duct size), and condensation of fresh water. Pilavachi[2] has introduced mini-and micro-gas turbines for combined heat and power. He emphasized number of advantages and potentials of mini-and micro-turbines compared to other technologies. He predicted about the uncertainty about their market potential but they could be used for power generation in the industrial, commercial and residential sectors. Sun and Yitai[3] have integrated refrigeration system with a gas engine, a vapor-compression chiller and an absorption chiller has been set up and tested. They have shown that this system saves running costs as compared to the conventional refrigeration system by using the waste heat. Hwang[4] has presented and analyzed the performance potential of a refrigeration system that is integrated with a microturbine and an absorption chiller. This system with subcooler, precooler, and with condenser air precooler can reduce the annual energy consumption by 12, 19, and 3%, respectively, as compared to a refrigeration system operating without any waste heat utilization from the microturbine. Khattam[5] have presented the application of deregulation in the electric power sector, He surveyed a new identity in the electric power system map known as “distributed generation” (DG). The size of DG is from kW to MW. Sung et al.[6] presented a novel meso-scale vapour compression refrigeration system (mVCRS) which consists an evaporator, a compressor, a condenser and an expansion nozzle. The unit was of compact size and based on film-wise condensation. The compression ratio achieved through rotary vane type

**Corresponding Author: Department of Mechanical Engineering, , Delhi Technological University, Delhi-42, India (E-mail: sh_agar@rediff.com)*
***Department of Mechanical Engineering, , Delhi Technological University, Delhi-42, India*
****Department of Mechanical Engineering, , Delhi Technological University, Delhi-42, India*

meso-scale compressor was 3.07 and the flow rate was 10L per minute (LPM). The overall size of the unit was 60x60x100mm^3 (widthxlengthxheight) It has been validated that the proposed mVCRS can keep the temperature of heat source around 46$^{\circ C}$ with the maximum cooling capacity of 80W and that the average coefficient of performance (COP) was up to 2.15. Invernizz [7] proposed the strategy for the coproduction of electrical, thermal and refrigerating power (a Trigeneration system). The proposed work dealt with the potential use of ejector-powered refrigeration cycles for heat recovery from a micro-gas turbine.

Water, Ammonia and HFC-134a were the selected working fluids for the analysis. The COP of the system at condensation temperature of about 40$^{\circ C}$ was 0.30. They have investigated heat recovery from a micro-gas turbine of 30kWe for the (i) the complete recovery of the available heat (2) the generation of refrigerating thermal power together with the production of sanitary water (3) the partial recovery of heat of heat in order to cool air before gas turbine intake. Bruno et al.[8] have studied the performance of micro-gas turbines of different power capacities directly coupledto double effect water/LiBr absorption chillers. The MGT exhaust was the heating medium to drive the chiller. In these systems post-combustion natural gas has been used to increase the cooling capacity of the system. They concluded that the new technology over the conventional system was advantageous and the COP of the chillers was higher. Pilavachi [9] have suggested Mini-and micro-gas turbines for combined heat and power. He proposed that the uncertainty about the market potential and technical and non-technical barriers to the implementation of technology. He concluded that the market potential could increase substantially if the cost, efficiency, durability, reliability and environmental emission of the existing design were improved. Cameretti[10] have examined the response of a micro gas turbine (MGT) combustor when supplied with gaseous fuels from biomass treatment or solid waste pyrolysis or from an anaerobic digestion process. The objective of the study was to optimize the combustor behaviour under the point of view of combustion efficiency and pollutant control. CFD study has been carried out for MGT. They examined the solutions in order to improve the combustion efficiency with poor calorific value fuels. Bruno et al. [11] have analysed various integrated configurations of several types of commercially available absorption cooling chillers and MGT cogeneration systems driven by biogas .MGTs are fuelled with biogas and their waste heat is used to drive absorption chillers and other thermal energy users. They conducted a case study for the existing sewage treatment plant. They have investigated trigeneration system that uses biogas and micro gas turbine. They predicted that the trigeneation plant uses all available biogas may replace the existing conventional plant. Ho et al.[12] have investigated a cogeneration system powered by microgasturbine which provides electrical power and space cooling to a laboratory. They observed the performance of the cogeneration system under varying heat load in the cooling space and longer microturbine operating period. Garimella at al.[13] have studied a novel cascaded absorption-vapour compression cycle with a high temperature lift for a naval ship application. They have observed and analyzed the performance of the system with an equivalent two-stage vapour compression cycle. Kalla et al. [18, 19] reviewed vapour compression refrigeration system for alternative refrigerants and investigated the performance of R22 and its substitutes in air-conditioners. Dixit et al. [20, 21] carried out energy and exergy analysis of absorption-compression cascade and waste heat driven triple effect refrigeration cycles. Arora and Kaushik [22] carried out various energy, exergy and parametric analysis of an actual vapour compression refrigeration and vapour absorption cycle. They reported that the efficiency defect was highest in the condenser and lowest in the liquid vapour heat exchanger. COP and exergetic efficiency were higher for R-22 than R-407C and R-410A. Arora et al. [23-25] have investigated vapour absorption and vapour compression refrigeration systems for performance improvement using liquid vapour heat exchanger subcooling techniques energetically and exergetically. They observed that subcooling of vapour compression refrigeration cycle enhances the COP and exergetic efficiency of the cycle. They have also analysed half effect water lithium bromide, double effect parallel flow vapour absorption refrigeration system on the basis of energy and exergy.

In the present analysis, integrated vapour absorption and vapour compression systems has been investigated for the performance improvement of the system. The integrated system has energized by a micro-gas turbine. The generator of vapour absorption system received heat from the exhaust of the micro-gas turbine while the compressor of the vapour compression has been driven by the electricity produced through the micro-gas turbine. The Integrated unit may provide the low temperature air-conditioning at the desirable space.

2.0 Thermodynamic Modelling of the System

2.1 Description of system

The combined unit consists of small gas turbine, vapour absorption refrigeration system (H_2O-LiBr) and vapour compression refrigeration system using R1234ze. The thermodynamic analysis of each component has been carried out using mass-energy governing equations.

A computational analysis has been performed using Engineering Equation Solver (EES) software. The evaporator of Vapour absorption refrigeration system has been coupled to the vapour compression refrigeration system in order to obtain low temperature air at vapour compression unit.

Absorption chillers are thermally driven chillers that are well suited for the use of exhaust heat from prime movers such as microturbines. There are various types of absorption cycles. They can be single effect, double effect or triple effect and can powered by hot water, steam or combustion gases. Two preferred refrigerant and absorbent pairs in the absorption cycles are water/LiBr and Ammonia/water. Ammonia/water system requires higher generator inlet temperatures than water/LiBr system and higher pressures and hence higher pumping power.

Also it requires a separation system to separate ammonia from water at the generator outlet but the water/LiBr chiller do not requires any separation system. Though water/LiBr system has a limited range of operation, because of the crystallization, but the low cost and excellent performance of this working fluid combinations make it favourable to use (Sun and Yitai[3]). In this study, single effect, hot water driven water/LiBr absorption chillers are considered.

The model equations are formulated from mass and energy balances for each component of absorption cycle. The following assumptions based on Hwang [4] were considered

in this study:

- Refrigerant in the evaporator and condenser is pure water.
- Stream exiting the condenser is saturated water, and the condenser pressure is the saturated pressure at condenser temperature (P_{high}).
- Saturated vapor leaves the evaporator and the evaporator pressure is the saturated pressure at evaporator temperature (P_{Low}).
- The efficiency of pump is 50%.
- Air cooled condenser and absorber are used. Condensing temperature and absorbent temperature are $10^{°C}$ higher than air temperature.

The compression chiller in this study, similar to conventional vapour-compression chiller, includes compressor, condenser, evaporator and expansion valve and using R22 as its working fluid. The model equations similar to absorption cycle, formulated from mass and energy balances. The following assumptions based on Hwang[4] are used in this model:

- The pressure level in the generator and condenser is P_{high} while the pressure level in the absorber and evaporator is P_{Low}.
- The solution concentration at the outlet of the generator is the equilibrium concentration to the generator temperature and P_{high}.
- The solution concentration at the outlet of the absorber is the equilibrium concentration to the absorber temperature and P_{Low}.
- The generator temperature is assumed as $90^{°C}$ at the ambient temperature of $30^{°C}$.
- The evaporator temperature is assumed as 5 at the ambient temperature of $30^{°C}$.
- The solution heat exchanger has been modeled according to the available literature (Lansing[14]).
- The power input to the condenser and absorber fan motor is 775Wfor $1m^3$ /s air flow rate and the air flow rate through these components is 0.0537 m^3 /s for 1 kW heat transfer.
- Evaporation temperature was considered 10 K lower than the refrigerated air temperature.
- Condensing temperature was considered 10 K higher than air temperature.
- Degree of superheating at evaporator outlet is 5 K and the water exiting the condenser is 5 K subcooled.
- Pressure drop at evaporator and condenser is 50 kPa.

- Compressor isentropic efficiency depends upon the pressure ratio (PR). This change of efficiency has been described in the equation 1 and 2 [4].

$$\eta_{ise} = 0.85 - 0.0467PR \qquad \ldots (1)$$

Microturbines are small, compact high-speed turbo-generators of between 28 and 200 kWe, which consist of a centrifugal compressor, a radial turbine and a permanent magnetalternator rotor operating as a Brayton cycle. The main advantages that MGTs have over other technologies are the fuel flexibility, low emissions, quiet operation and low maintenance (Bruno et al.[8,11]). The electrical efficiency of the current regenerative MGTs is in the range of 25-30% depending on the MGT size (Bruno et al. [8]). However the microturbine efficiency depends on the ambient temperature. As the ambient temperature increases, the efficiency and the power of microturbine both decrease (Fig. 1). This is mainly because the air density at high air temperature is lower and, for the same inlet volume of air, a lower mass of fluid circulates the system (Bruno et al.[8]). The electrical efficiency change depending upon the ambient temperature. In this study was assumed based on the performance of the C65 & C65-ICHP MicroTurbine Natural Gas (Capstone TurbineCorporation, 2010) as equation below:

$$\eta_{MGT} = 30.8 - (0.12x\, T_{amb}) \qquad \ldots(2)$$

Fig. 1 shows the schematic diagram of combined vapour absorption-compression combined refrigeration system energized by micro-gas turbine. The combined system consists a low temperature circuit of vapour compression system and a high temperature circuit of vapour absorption sytem. The vapour compression system is energized by the microgasturbine while the exhaust of microgatrubine is being used into the vapour absorption system. The use of vapour absorption system improves the overall efficiency of the system by reducing the electricity consumption in to the vapour compression system.

2.2 Performance parameters

1. The coefficient of performance of vapour compression refrigeration system, is defined as:

$$COP = \frac{\text{Refrigerating capacity of the system}}{\text{Input power to the compressor} + \text{Input power to the fan}}$$

2. The thermal efficiency of the system is defined as the ratio of net work output to the heat energy supplied by the fuel.

$$\eta_{Thermal} = \frac{\text{Net work output}}{\text{Heat supplied by the fuel}}$$

3. The exergetic efficiency of the system is defined as the ratio of net available output energy to the input energy.

$$\eta_{Exergetic} = \frac{\text{Cooling Power}}{\text{Input energy to the Micro - gas turbine}}$$

$$\eta_{Exergetic} = \frac{\text{Cooling Power}}{\text{Input energy to the Micro - gas turbine}}$$

Fig 1: Schematic Diagram of Combined Vapour Absorption-Compression Combined Refrigeration System Energized by Micro-Gas Turbine

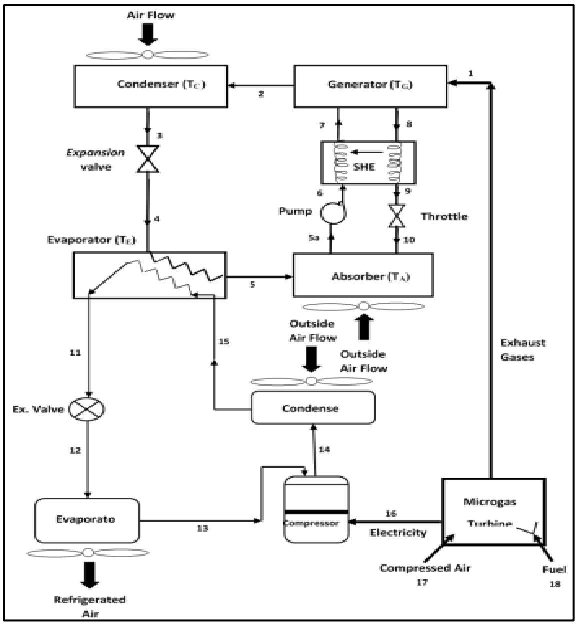
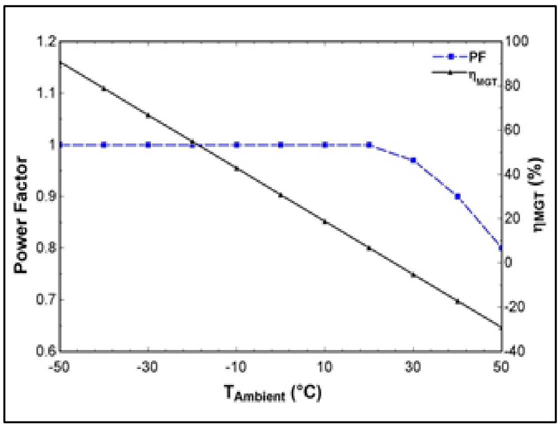


Fig 2: Performance of micro-Gas Turbine vs. Ambient temperature (Hwang [4])



3.0 Results and Discussions

Table 1 shows that the generator temperature and evaporator temperature increase with increasing ambient temperature. The investigation for the effect of ambient temperature on the performance of the combined VAR-VCR system has been carried out over the range of 10-50°C. At the generator temperature 91°C for which ambient temperature is higher than that of 30°C, the generator could not disrobe Lithium-Bromide from the water due to the high concentration of the entering solution to the generator. The generator and evaporator temperature of the absorption chiller may be varied in order to obtain optimum efficiency.

Table 1: Temperature of Generator and Evaporator Temperature of Absorption System for Different Ambient Temperature

Ambient temperature (°C)	10	15	20	25	30	35	40	45	50
Generator temperature (°C)	64	76	79	86	91	96	101	105	111
Evaporator temperature (°C)	2.	2.1	2.2	2.3	5.2	7.9	13.7	21	--

Fig. 3 shows that the thermal efficiency of the micro-gas turbine decreases with ambient temperature. As the amout of heat carrying by the exhaust gases increases for the same input amout of heat. Therefore the net power output of the micro-gas turbine decreases. The performance of micro-gas turbine affect the performance of vapour compression refrigeration system (VCR). As the electricity demand of the VCR system is being fulfilled by the micro-gas turbine. As the ambient temperature increases the demand of electricity consumed by the VAR system also increases as the condensing pressure line goes away from the evaporator pressure line. However the evaporator of vapour absorption refrigeration system (VAR) has been coupled with condenser of the VCR system and due to more refrigerating effect produces in the VAR system due to high temperature of the exhaust gases of micro-gas turbine.

The net COP of the system improves than that of simple vapour compression system.

Fig 3: Variation of thermal efficiency ($\eta_{ThermalMG}$) of micro-gas turbine with ambient temperature

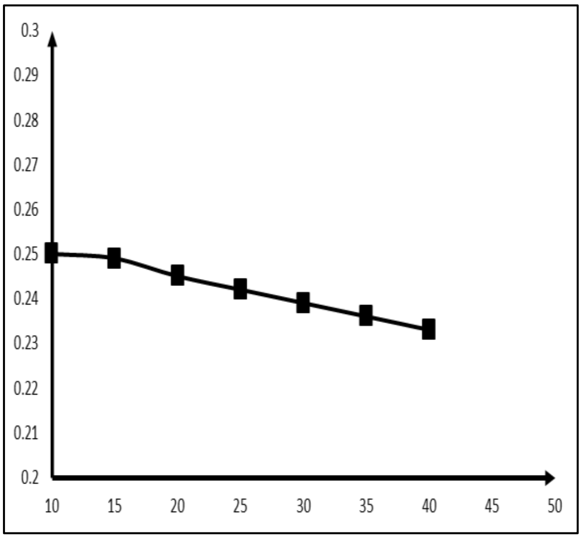


Figure 4 shows that exergetic efficiency of the system decreases with increasing ambient temperature. As the net workout from the micro-gas turbine decreases and the amount of heat carried by the exhaust gases increases with increasing ambient temperature therefore the output exergy of the systeme decreases however the heat of exhaust gases is being used by the VAR system and the output exergy is being recovered upto some extent.

The overall exergy recovered by the system reduces but the exergy recovered is more than that of the simple VCR system therefore the exergetic efficiency of the integrated system is higher than that of the simple VCR system.

Fig. 5 shows that the C.O.P. of the integrated system is higher than that of the simple VCR system. The refrigerating effect recovered from the exhaust gases of the micro-gas turbine is being used for the VCR system in order to get low temperature in low temperature circuit.

In this way the net refrigeration effect produces by the integrated system is higher than that of the simple system. However the C.O.P. of the integrated system follows the trend of decreasing C.O.P. with increasing ambient temperature similar to the simple system.

Fig 4: Effect of Ambient Temperature on Thermal Efficiency ($\eta_{ThermalSys}$) of Combined System

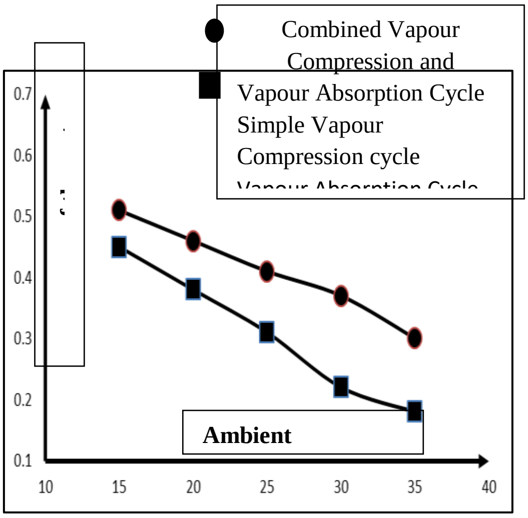
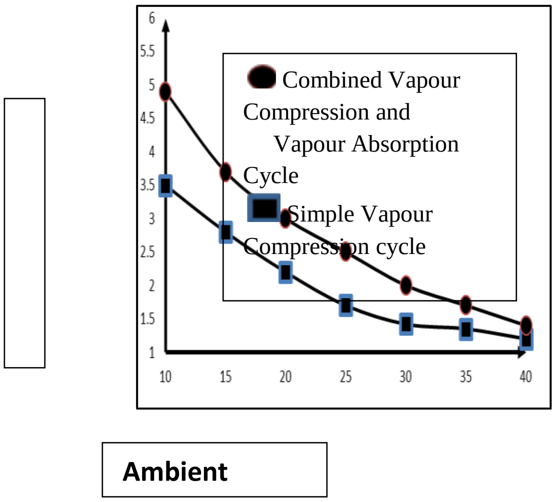


Fig.5 Variation in COP of Combined System with Ambient Temperature



4.0 Conclusions

In the current study the performance of integrated VCR and VAR system has been compared. The integrated system is being energised with micro-gas turbine. The result shows that the integrated system generates low temperature (less than the 0°C) through the lower temperature circuit of the VAR system and energy consumption reduce with the integration of Vapour absorption system. The COP and the exergetic efficiency of the integrated system are higher than that of the simple system for considerable range of ambient temperature. The energy consumption also reduces for the desirable cooling effect/refrigeration effect for low temperature applications obtained from the evaporator of the VCR system.

Therefore the integrated system approach is economical as well as eco-friendly in order to get efficient system.

Acknowledgment

Authors are thankful to Delhi Technological University and supervisors for their guidance and motivation.

Nomenclature

Abbreviation and Symbols	
COP	Coefficient of performance
EES	Engineering equation solver
h	Specific enthalpy (kJ/kg)
$\dot{Q}$	Rate of net refrigerating effect (kW)
VAR	Vapour absorption refrigeration system
VCR	Vapour compression refrigeration system
Greek symbol	
η	Efficiency
Subscripts	
0	Dead state
T	Temperature (°C)

References

[1] J Wang, P Zhao, X Niu, Y Dai. Parametric analysis of a new combined cooling, heating and power system with transcritical CO_2 driven by solar energy. Applied Energy, 94, 2012, 58-64.

[2] PA Pilavachi. Mini-and micro-gas turbines for combined heat and power, Applied Thermal Engineering, 22, 2002, 2003-2014.

[3] F Sun, M Yitai. Thermodynamic analysis of transcritical CO_2 refrigeration cycle with an ejector. Applied Thermal Engineering, 31, 2011, 1184-1189.

[4] Y Hwang. Potential energy benefits of integrated refrigeration system with microturbine and absorption chiller, Int. J. Refrigeration, 27(8), 2004, 816-829.

[5] WE Khattam, MMA Salma. Distributed generation technologies, definition and benefits, Electric Power System Research, 71, 2004, 119-128.

[6] T Sung, D Lee, HS Kim, J Kim. Development of a novel meso-scale vapor compression refrigeration system (mVCRS), Applied Thermal Engineering, 66, 2014, 453-463.

[7] C Invernizzi, P Iora. Heat recovery from a micro-gas turbine by a vapour jet refrigeration systems. Applied Thermal Engineering, 25, 2005, 1233-1246.

[8] JC Burno, A Valero, A Coronas. Performance analysis of combined microgas turbines and gas filled water/LiBr absorption chillers with post-combustion, Applied Thermal Engineering, 25, 2005, 87-89.

[9] PA Pilavachi. Mini-and micro-gas turbines for combined heat and power, Applied Thermal Engineering, 22, 2002, 2003-2004.

[10] MC Cameretti, R Tuccillo. Combustion features of a bio-fuelled micro-gas turbine, Applied Thermal Engineering, 89, 2015, 280-290.

[11] JC Burno, VO Lopez, A Coronas. Integration of absorption cooling systems into micro gas turbine trigeneration systems using biogas: case study of a sewage treatment plant. Applied Energy, 86, 2009, 837-847.

[12] JC Ho, KJ Chua, SK Chou. Performance study of a microturbine system for cogeneration application, Renewable Energy, 29, 2004, 1121-1133.

[13] S Garimella, AM Brown, A Krishna, AK Nagavarapu. Waste heat driven absorption/vapour-compression cascade refrigeration system for megawatt scale. High flux low-temperature cooling, Int. J. Refrigeration, 34, 2011, 1776-1785.

[14] FL Lansing. Computer modelling of a single-stage lithium bromide/water absorption refrigeration unit, JPL Deep Space Netw. Prog. Rep., 42(32), 1977, 247-257.

[15] A Bejan, G Tsatsaronis, MX Moran. Thermal Design and Optimization book. John Wiley & Sons, Inc., USA, 1996.

[16] SA Klein, F Alvarado. Engineering Equation Solver. F Chart Software, Middleton, WI. Version 9, 2012, 224-3D.

[17] EW Lemmon, ML Huber, MO Mclinden. NIST REFPROP Refence fluid thermodynamic and transport properties, NIST Standard Reference Database, USA, 23,version 9.0, 2010.

[18] SK Kalla, BB Arora, JA Usmani. Performance analysis of R22 and its substitutes in Air-conditioner. J. Thermal Engg., 4(1), 2018, 1724-1736.

[19] SK Kalla, BB Arora, JA Usmani. Alternative refrigerants for HCFC- A review. J. Thermal Engg., 4(3), 2018, 1998-2017.

[20] M Dixit, SC Kaushik, A Arora. Energy and exergy analysis of absoption-compression cascade refrigeration system. J. Thermal Eng., 3(5), 2017, 1466-1477.

[21] M Dixit, A Arora, SC Kaushik. Enery and exergy analysis of a waste heat driven cycle for triple effect refrigeration. J. Thermal Eng., 2(5), 2016, 954-961.

[22] A Arora, SC Kaushik. T,heoretical analysis of a vapour compression refrigeration system with R502, R404A and R507A, Int. J. Refrigeration 31, 2008, 998-1005.

[23] A Arora, BB Arora, BD Pathak, HL Sachdev. Exergy analysis of a Vapour Compression Refrigeration system with R-22, R-407C and R-410A, Int. J. Exergy, 4, 2007, 441-454.

[24] A Arora, M Dixit, SC Kaushik. Computation of optimum parameters of a half effect water-lithium bromide vapour absorption refrigeration system, J. Thermal Eng., 2(2), 2016, 683-692.

[25] A Arora, M Dixit, SC Kaushik. Energy and exergy analysis of a double effect parallel flow $LiBr/H_2O$ absorption refrigeration system, J. Thermal Eng., 2(2), 2016, 541-549.