International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 04 | Apr -2017 www.irjet.net p-ISSN: 2395-0072

"SIMULATION MODELING FOR THE PERFORMANCE OF VAPOR ABSORPTION REFRIGERATION SYSTEM USING EVACUATED TUBE COLLECTOR AND PARABOLIC DISC COLLECTOR WORKING IN CONJUGATE SYSTEM"

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Abstract – *For converting solar energy for the purpose of water heating, the theoretical performance of vapor absorption refrigeration system using evacuated tube collector and parabolic disc collector working as a conjugate collector system is introduced. A simulation model is developed to determine the theoretical COP of the system and the effect of atmospheric conditions on the performance is presented in this work. A comprehensive set of theoretical tests and detailed analysis of system model are presented. Here in this project the combined performance of evacuated tube collector and parabolic disc collector is introduced. Performance of vapour absorption system using conjugate system of collector been done. Vapor absorption refrigeration system is presented using both the collectors when combined in series and form a conjugate system of collectors. Both collectors are combined to form conjugate system for the purpose of heating water, used for solar vapor absorption refrigeration system. In this research work the setup of system is theoretically examined and the results are found.*

Keywords—Evacuated Tube Collector, Parabolic solar collector, Conjugate System of Collectors, COP, Vapor absorption refrigeration system, Simulation model.

1 INTRODUCTION

Almost all the non-renewable energy sources will be depleted in the near future. These sources also cause environmental hazards. Thus the dependence on such sources has to be reduced. Thus the only viable option to meet the future energy requirement is to use the renewable energy sources. Based on the way of solar collection, the solar collectors are classified into non concentrated and concentrated type. A non-concentrated solar collector has the same area for intercepting and absorbing solar radiation, while concentrated type will have a concave shaped reflective surface for intercepting radiation and it will be focused to a small area and thus increases radiation flux.

In the present work, the effect of two different collectors like evacuated tube and parabolic disc collectors are connected in series for the purpose of heating water used in solar vapor absorption refrigeration system are theoretically studied and compare the maximum COP of the conjugate system with separate collectors used [1]. The conjugate system of collector for vapor absorption refrigeration system is introduced, by calculating the various performance parameters, and the comparison of these performance parameters are presented. This project work has involved a detailed theoretical analysis of the system and investigate the actual max COP of the solar vapor absorption refrigeration system during the period of time.

2 LITERATURE SURVEY

C. A. Estrada-Gasca et al. determined the theoretical efficiencies (r/) and thermal behaviour of all-glass evacuated tube solar collectors with an internal absorber film (ETCIAF), i.e. the absorber film deposited in the inner surface of the inner tube, are compared and contrasted with the traditional design of all-glass evacuated tube solar collectors with an external absorber film (ETCEAF), using the absorber film on the external surface of the inner tube.

Siddharth Arora designed a evacuated tube collectors is enumerated followed by the thermal network analysis of this collector. The temperature of each component is determined empirically. Numerical analysis is applied to find the coefficient of heat transfer across the air gap from absorber plate to the copper tubes. The performance characteristics of these collectors are analyzed and compared with commercially available brands to test their capability to power the generator of an absorption chiller.

C. J. Saltiel investigated the optical efficiency of the collector is found by following incident rays onto the collector cover, calculating the amount of energy absorbed by the receiver for each ray, and then integrating the energy for all rays. Absorption and reflection losses in the collector materials are considered, as well as the formation of ray cascades. The collector overall efficiency was found for the case of a selective surface coating on the inner receiver cylinder and for the case of an absorbing fluid contained within a semi-transparent inner cylinder. The addition of a highly reflective thermal radiation coating of the inner surface of the cover, in order to suppress thermal radiation losses, was also evaluated.

N. K. Saikhedkar et al observed that the solar energy is good option for that it is in use also. The daily average solar energy incident over India varies from 4 to 7 kWh/m^2 having approximately 2,300–3,200 sunny hours per year, depending upon location. Raipur is located in the sunny belt of the country and receives a good amount of solar radiation over the year. It has been observed that the daily global solar radiation over the Raipur's region is 4.58 kwh/m^2, while the daily diffuse radiation is 1.72 kWh/ m^2.

H. P. Garg find out an overall heat loss coefficient in the case of an evacuated tubular collector has been developed for all possible range of variables and values compared with the analytically calculated values.

R. R. Arakerimath presented the importance of a need to develop more strategies for trapping of all non-conventional energy sources. Out of all resources one of the best and effective sources of energy is the solar energy. The usage of solar water heating system is high in winter and rainy seasons. Also the solar energy collection efficiency is more in summer. Therefore in the present work an attempt has been made to produce the refrigeration effect by obtaining the energy from parabolic dish collector, with the help of vapour absorption refrigeration technique. In this way a commercial parabolic dish collector water heating system can be used for heating purpose in winter and rainy seasons and cooling effect during summer.

Hamza Hijazi designed a low cost parabolic solar dish concentrator with small-to moderate size for direct electricity generation. Such model can be installed in rural areas which are not connected to governmental grid. Three diameters of the dish; 5, 10 and 20 m are investigated and the focal point to dish diameter ratio is set to be 0.3 in all studied cases. The dimensions of the ribs and rings which support the reflecting surface are optimized in order to minimize the entire weight of the dish while providing the minimum possible total deflection and stresses in the beams. The methodology presented is robust and can be extended to larger dish diameters.

N.D. Kaushika, presents viability aspects of paraboloidal dish solar collector systems. The basic geometrical optics equations for multifaceted paraboloidal dish solar collectors are presented in the form helpful for engineering design. Performance data for experimental dish collectors of 5 m diameter, involving undemanding accuracy of optical profile and short focal length (1.8 m), are presented

N.D. Kaushika et al. presents the design, development and performance characteristics of a low cost solar steam generating system which incorporates recent design and materials innovations of parabolic dish technology. The concentrator is a deep dish of rather imperfect optics, made of silvered polymer reactors setted in the aluminum frame of a satellite communication dish.

3 PLAN OF RESEARCH WORK

In this paper work has and theoretical analysis of different performance parameters like evaporator temperature, generator temperature and COP of the solar vapour absorption refrigeration system using conjugate system of collectors. A simulation model in MATLAB is developed via mathematical modelling to compare the theoretical result. In this research work absorption cooling systems are made using single-effect absorption cycle with a NH_3/H_2O pair.

The experiments were performed in winter and summer climatic conditions of 2015 in Raipur, Chhattisgarh, India. The Latitude is 21°15'4.98"N and the Longitude is 81°37'46.71"E. May is usually the hottest month of the year in this region and typical results during the period have been reported here. The experiments were carried out on alternate days from 10:00 am to 4:00 pm using conjugate collector system for vapour absorption refrigeration system. Readings were taken to calculate the performance parameters, during experiment from January to May for vapor absorption refrigeration system.

Experiment duration is 6 hrs, starting at 10:00 am. It is done to increase the accuracy of the experiments. The evacuated tube collector inclination is 45° are fixed for all experiments and disc type collector is adjusted manually according to sun tracking to focus the maximum radiations on receiver.

The experiments were conducted in both collector were combined in series for working as a conjugate system for the purpose of water heating. The parameters, viz, outer glass temperature of collector, water temperature, ambient temperature, incident radiation on glass cover of, inlet and outlet temperatures of water from collector/collectors are measured on 6 hrs basis for all the three phase experiments. Water, glass, vapor and collector inlet outlet temperatures were recorded with the help of K type constant thermocouples. The ambient temperature and outer glass temperature were measured by mercury thermometer.

Fig 1: Experimental Setup of control valve and thermocouple or conjugate system of Collector

4 METHODOLOGY

Water in atmospheric conditions is stored in a storage tank which is placed at some height. The outlet of this storage tank is connected with the inlet of the evacuated tube with the help of a pipe. A control valve is connected between inlet of evacuated collector and outlet of storage tank to control the flow of liquid. The temperature of the water which is flowing through the evacuated tube collector is increased due to solar energy.

This evacuated tube collector is used for preheating of water. This preheated water is now allow to enter in a absorber pot (receiver) which is placed at the focus of the Disc type focusing solar collector for further heating so the temperature of the water in the receiver is further increased up to the required temperature of the generator. The storage tank, evacuated tube collector and disc type solar collector is so placed that the water from storage tank to the out let of the receiver circulates naturally [4].

The ammonia vapor from the generator is now allow to enter inside a condenser for condensation process. A closed type vapor cooler called rectifier or dehydrator is used between the generator and condenser is a water cooled which further cools the ammonia vapor leaving the analyzer placed at the top of the generator, by this arrangement only dry and anhydrous ammonia vapor flows to the condenser [6]. The condensed liquid ammonia is not collected and this liquid ammonia is now allowed to passed to the expansion valve and finally this low pressure liquid ammonia enter inside the evaporation for further evaporation process. Absorber is provided between the generator and evaporator. The low pressure ammonia vapor leaving the evaporator enters the absorber where it is absorbed by the cold water in the absorber thus from aqua ammonia solution [9].

5 ANALYSIS OF VAPOR ABSORPTION REFRIGERATION SYSTEM

In this section various relations that are required in order to determine the COP of the vapor absorption refrigeration system using conjugate collectors and the interaction of the various constructional parameters on the performance of the system are presented [10].

5.1 Calculation of Theoretical COP of the System

In this system the total refrigerating effect in the system is dependent on the heat absorbed by the refrigerant (ammonia) in the evaporator. The total energy supplied to the system is the heat supplied in the generator [10].

Therefore, the Coefficient of performance (COP) of the system as theoretically known is given by

$$COP = \frac{Heat\ Absorbed\ in\ the\ Evaporator}{Heat\ Supplied\ in\ the\ Generator}$$

$$(COP)_{theoretical} = \frac{T_E}{T_G}\left(\frac{T_G - T_i}{T_i - T_E}\right)$$

6 MODELING AND SIMULATION

In this work simulation model of the conjugate system has been developed partying to satisfy the mathematical modeling of the system in MATLAB version 2012b. In this subsection a simulation model using mathematical modelling for useful energy of a conjugate collector is performed [11]. The theoretical useful energy equation for evacuated tube solar collector and parabolic disc collector has been has been calculated.

To calculate performance parameters of parabolic disc collector the model equations are expressed in the following steps [4].

To develop a mathematical model of the overall heat transfer coefficient.

$$U_l = h_w + h_{r,r-a}$$

To develop a mathematical model of the Heat removal factor

$$F_R = \frac{mC_P}{A_{r,\text{int}}U_l}\left[1-\exp\left(-\frac{A_{r,\text{int}}U_l F'}{MC_P}\right)\right]$$

To develop a mathematical model the Collector efficiency factor

$$F' = \frac{1/U_l}{\frac{1}{U_l}+\frac{D_{r,ext}}{h_{c,i}D_{r,\text{int}}}+\frac{D_{r,ext}\ln\left(D_{r,ext}/D_{r,\text{int}}\right)}{2k_r}}$$

To develop a mathematical model for Useful Energy for parabolic disc collector

$$Q_{u,th} = A_{ap}F_R\left[H_{ab}-\frac{A_{r,ext}}{A_{ap}}U_l\left(T_{f,i}-T_{amb}\right)\right]$$

To calculate performance parameters of evacuated tube collector the model equations are expressed in the following steps [4].

To develop a mathematical model of the overall heat transfer coefficient.

$$U_L = \left\{\frac{1}{h_{c,p-c}+h_{r,p-c}}+\frac{1}{h_w+h_{r,c-a}}\right\}^{-1}$$

To develop a mathematical model of Standard Fin Efficiency

$$F = \frac{\tanh\left\{\sqrt{\frac{U_L}{k\delta}}(W-D)/2\right\}}{\sqrt{\frac{U_L}{k\delta}}(W-D)/2}$$

To develop a mathematical model Collector Efficiency Factor

$$F' = \frac{1/U_L}{W\left[\frac{1}{U_L\{D+(W-D)\}F}+\frac{1}{C_b}+\frac{1}{\pi D_i h_{fi}}\right]}$$

To develop a mathematical model Heat Removal Factor

$$F_R = \frac{mc_p}{A_c U_L}\left[1-\exp\left\{\frac{-A_c U_L F'}{mc_p}\right\}\right]$$

To develop a mathematical model for Useful Energy for evacuated tube collector

$$Q_{u_{th}} = A_c F_R\left[(\alpha\tau)I-\left\{\frac{A_p}{A_c}\right\}U_L(T_{fi}-T_a)\right]$$

Here the simulation model has been developed taking into consideration, that the combined performance of both the collectors is performing as a single conjugate collector system. The sum of useful energy determined for both the models results in the total useful energy of the conjugate collector system. Total useful heat of conjugate collector system is given by

$$Q_{u,(Total)th} = Q_{u,(ETC)th}+Q_{u,(Disc)th}$$

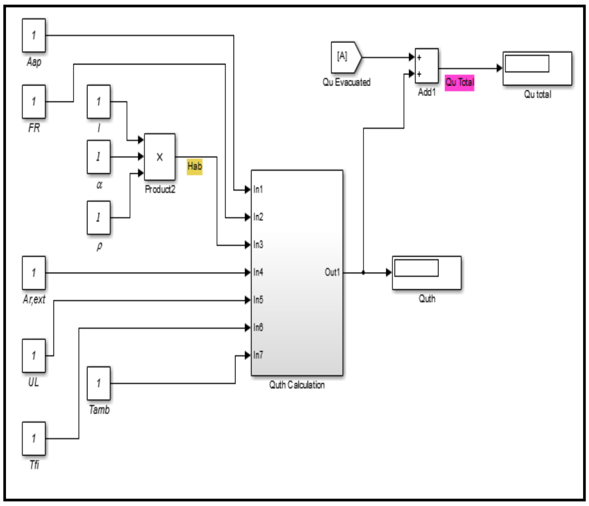

Fig 2 : Subsystem for the generation of Conjugate COP

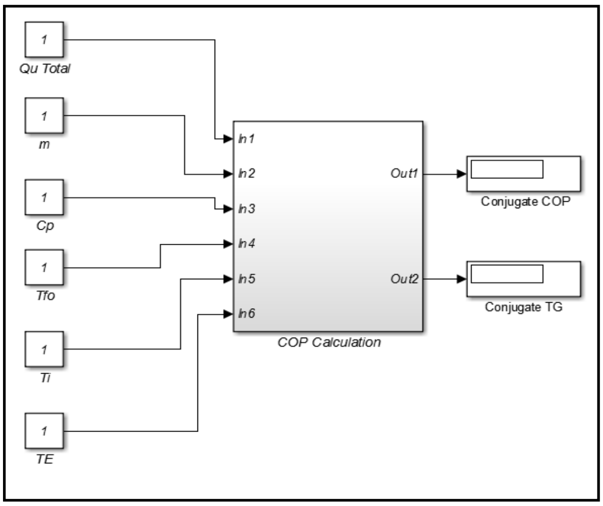

Fig 3 : Subsystem for the generation of total useful energy

Table 1 : Determination of theoretical performance parameters of parabolic disc collector from the month of Jan to May

Days	Wind Speed (m/s)	Atm. Temp °C	Solar Intensity W/m²	Inlet Temp of Fluid °C	Outlet Temp of Fluid °C	Overall Heat Transfer Coeff. W/m	Collector Efficiency Factor	Heat Removal Factor	Theoretical Useful Energy W	Genetator Temp °C	Evaporator Temp °C	Theoretical COP of the System
Days	v	T_a	I	T_{in}	T_{out}	U_L	F'	F_R	$Q_{(u)th}$	T_G	T_E	COP
Day 1	0.72	29	965	36.5	49.5	3.31	0.729	0.728	2501.9	58.2	9.4	0.63
Day 2	1	29.4	972	37.0	50.0	3.56	0.704	0.693	2358.4	58.7	9.4	0.66
Day 3	1.4	28.3	963	37.2	50.3	3.68	0.695	0.685	2336.9	58.9	9.4	0.64
Day 4	0.98	29.7	973	35.8	48.7	3.78	0.691	0.681	2308.7	57.7	9.7	0.67
Day 5	0.75	28.9	965	36.4	49.4	3.33	0.716	0.706	2344.0	58.0	9.6	0.67
Day 6	0.62	31.4	980	39.0	52.1	3.41	0.711	0.700	2370.2	60.9	8.8	0.61
Day 7	0.64	29	971	35.6	48.6	3.48	0.710	0.700	2360.1	57.3	9.5	0.70
Day 8	0.97	28.5	967	36.3	49.3	3.42	0.711	0.700	2365.7	58.0	9.4	0.71
Day 9	0.84	26.2	954	33.1	45.8	3.49	0.706	0.695	2320.4	54.4	10.1	0.78
Day 10	1.2	26.1	952	34.0	46.8	3.69	0.696	0.685	2281.5	55.2	10.2	0.76
Day 11	1.1	32	987	38.9	52.1	3.94	0.681	0.670	2243.6	60.4	9.0	0.63
Day 12	1.4	35.5	1009	43.4	57.1	4.00	0.679	0.668	2412.1	65.9	8.0	0.53
Day 13	1.7	31.9	989	39.3	52.6	4.03	0.681	0.670	2358.9	61.2	8.9	0.62
Day 14	1.7	33.2	995	40.2	53.6	4.07	0.676	0.665	2361.6	62.3	8.7	0.61
Day 15	2.7	35.4	1009	42.5	26.1	4.65	0.645	0.633	2334.0	64.7	8.2	0.55
Day 16	3.2	34.6	1005	41.8	55.3	4.72	0.641	0.630	2317.2	63.8	8.3	0.57
Day 17	3.4	32.5	992	39.8	53.1	4.63	0.646	0.646	2296.2	61.6	8.7	0.60
Day 18	3.5	37.7	1022	44.5	58.2	4.87	0.634	0.623	2342.3	66.8	7.6	0.51
Day 19	1	38.1	1035	46.0	59.9	4.03	0.677	0.666	2427.9	68.9	7.1	0.49
Day 20	2.7	38.6	1030	45.7	59.6	4.69	0.643	0.631	2376.5	68.3	7.2	0.49
Day 21	0.9	37.8	1024	44.8	58.5	3.79	0.690	0.679	2448.1	67.5	7.5	0.51
Day 22	2.7	36.5	1019	44.1	57.8	4.61	0.646	0.635	2356.7	66.5	7.8	0.51
Day 23	1.7	38.8	1033	46.2	60.1	4.20	0.672	0.661	2440.2	69.1	7.4	0.49
Day 24	2.6	40.1	1041	47.5	61.5	4.79	0.638	0.627	2390.3	70.3	7.1	0.46
Day 25	0.6	40.6	1043	47.8	61.8	3.64	0.697	0.686	2507.6	71.1	7.0	0.47

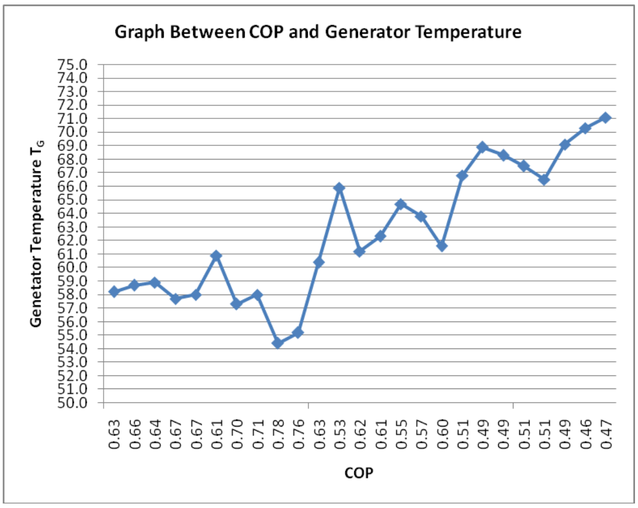

Fig 4 : Graph between generator and COP

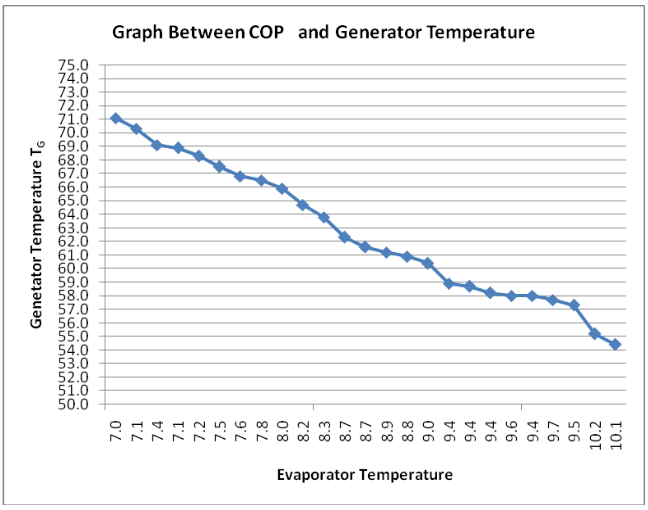

Fig 5 : Graph between generator and evaporator temp

7 RESULTS AND DISCUSSION

The theoretical generator temperature, evaporator temperature and results for COP of vapor absorption refrigeration system are tabulated and graphs are plotted respectively. The deviation in the value of COP of proposed system is very less as compared to value derived by developed simulation model which validates the proposed design. From table 1 and figure 4 it is observed that in the month of January to May the obtained COP of vapor absorption refrigeration system using conjugate collector system is maximum during the days of observation. The monthly maximum theoretical COP are found to be 0.67, 078, 0.63, 0.61, 0.51 respectively. From figure 5 by the use of conjugate collectors, the growth in generator temperature is observed which results in the increase in COP and decrease in evaporator temperature of the system is reported. This indicates the performance of vapor absorption refrigeration system. Evaporator temperature decreases as generator temperature increases. The COP attained is in the range of 0.46 to 0.78 for the generator temperature range of 54.4 ^oC to 71.1 ^oC.

8 CONCLUSION

The idea behind the work is to design a combination of collector system that exposes the maximum collector area of solar collectors for efficient heating of water, which can be further utilized for vapor absorption refrigeration system

For operation at lower refrigeration temperatures, advanced absorption cycles such as the double-stage cascade cycle, double-stage absorption and hybrid absorption cycle can be applied. In this research for the operation at lower refrigeration temperatures, different absorption refrigeration cycles have indicated and focus is given to improve the performance of solar vapor absorption refrigeration system working on a single effect based refrigeration cycle.

In this research there has been a major focus in improving the performance of vapor absorption refrigeration system, as the heat source temperature results in the increase in the system COP. In this work, the proposed design of conjugate collector system is very effective in increasing the generator temperature of vapor absorption and refrigeration system, which results in the improved performance of the whole system.

The research presents that the developed simulation model validates the physical model and the simulation results shown that the COP values of the cycle increases by increasing the generator temperature. This research opens the gateway to study and performance of different combinations of solar collector for water heating and other applications. The modeling will help in understanding the mathematical nature and working of the process and simulation will help in predicting the results with case.

Nomenclature

A_a = Aperture area [m^2]
A_o = External surface area of coverr [m^2]
A_i = internal surface area of absorber [m^2]
c_P = Specific heat of water [$J/kg.$ °C]
C = Concentration ratio [dimensionless]
D_o = External diameter of cover [m]
D_i = Internal diameter of cover [m]
W = Collector width [m]
L = Collector length [m]
F` =Efficiency factor of collector [dimensionless]
F_R = Heat removal factor of collector [dimensionless]
k_a = Conductivity of air [$W/m.$°C]
k_r = Conductivity of receiver [$W/m.$°C]
k_w conductivity of water [$W/m.$°C]
m = Mass flow rate [Kg/hr]
v = Wind velocity [m/s]
$h_{r,r\text{-}a}$=Radiation heat transfer coefficient between receiver and ambient [$W/m^2.$°C]
h_w = Convective heat transfer coefficient between receiver and ambient [$W/m^2.$°C]
U_l = Overall heat loss coefficient [$W/m^2.$°C]
I_b = Beam solar radiation [W/m^2]
$Q_{u,exp}$ = Experimental useful energy [W]
$Q_{u,th}$ = Theoretical useful energy [W]

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