

Design and performance evaluation of solar-biogas powered hybrid vapour absorption refrigeration system operating with temperatures from solar and biogas flame heating

Vijayendra Singh Sankhla, Deepak Sharma, Mahesh Kothari, Chitranjan Agarwal, Kapil Samar

Abstract: This paper represents design and performance evaluation with experiments tests of solar-biogas powered hybrid vapour absorption refrigeration system. The system designed for 40 liter capacity with 0.05 TR for cooling Amonia- water mixtures. This refrigerator system was designed 140°C temperature for generator by heating source like solar energy and biogas flame. Biogas flame as heat source was produced more than 140°C temperature and COP of the system achieved 0.134 individually. When system whole day working with biogas flame. Solar energy which was used 4 to 5 hours daily when solar radiation was available. In this case when solar thermal as heat source was produced only 70°C temperature but in the case of solar panel direct current supply to heater, heater as a heat source was produced approximately 150°C temperature. In case hybrid powered when 18 hours using biogas flame as heat source and 4 to 6 hours hour solar energy in the form of solar panel DC supply, COP had achieved 0.1.

I. INTRODUCTION:

Refrigeration systems are a unit necessary unit for dairy farm farmers. Energy is one in all the crucial input for manufacturing refrigeration result. Refrigeration method is typically affected in overseas or villages because of uninterrupted offer of electricity. During this regard, a thought is projected during this article that ultimately uses energy from star further as organic waste out there at dairy farm centers (i.e. cattle dug, room waste, agricultural waste etc.) and solar energy from sun. At the time of independence the total milk production in India was approximately 17 million tonnes per year. With the span of time, today India has become the second largest producer of milk, producing 127 million tonnes of milk per year, out of which only 20% of the total milk production is handled by the organized sectors. The village level co-operative societies collect milk from the dairy farmers, which is then transported to cooling centers. These cooling centres consist of refrigerating systems operating on conventional electric supply. In case of unavailability of electric supply, diesel generator sets are utilized to power the refrigeration systems.

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These conventional refrigeration systems operating on grid electric supply, performs milk processing operations, room conditioning for milk products, their packaging & cold storage of dairy products. Since refrigeration is highly energy consuming process, the problem of peak load penalty can be overcome by using solar-biogas hybrid vapour absorption system & the part load can be shared by this system.

The renewable sources of energy such as solar & biogas in dairy applications is generally used for hot water supply from boiler, hot water generator for milk processing or for CIP cleaning. The field level applications of solar-biogas based refrigeration systems for preservation of milk as well as commercial applications of solar-biogas based refrigeration system for preservation of milk, milk related cooling operations, room conditioning for cold storage & packing rooms for milk & dairy products are found to be minimum. Owing to this, there is an utmost requirement of development of commercially feasible solar-biogas based refrigeration system that can meet the refrigeration requirements dairy food industry. The existing knowledge of refrigeration & air conditioning systems based on continuous supply of electricity as well as diesel generator sets, will be applied to design & develop energy efficient solar-biogas based refrigeration systems for cooling of milk & its products at rural level. Application of solar energy & energy obtained from biogas, being renewable in nature has a great scope for its commercial use in processing of dairy products, leading to design & development of solar-biogas based refrigeration systems for dairy farmers.

Dairy and food industries are fast growing industries and day-by-day newer technologies are being introduced to get better quality of foods. Use of conventional energy is common practice for major processing of milk. At present all most all dairy operations are performed using grid supply with diesel gen-set as backup. Milk procurement system has changed in India and now milk is being procured by maintaining cold chain to improve its microbial quality. The proposed solar-biogas refrigeration system will help dairy farmers to reduce their dependency on grid electricity supply, thereby saving considerable amount of energy used for refrigeration systems in dairy farming.

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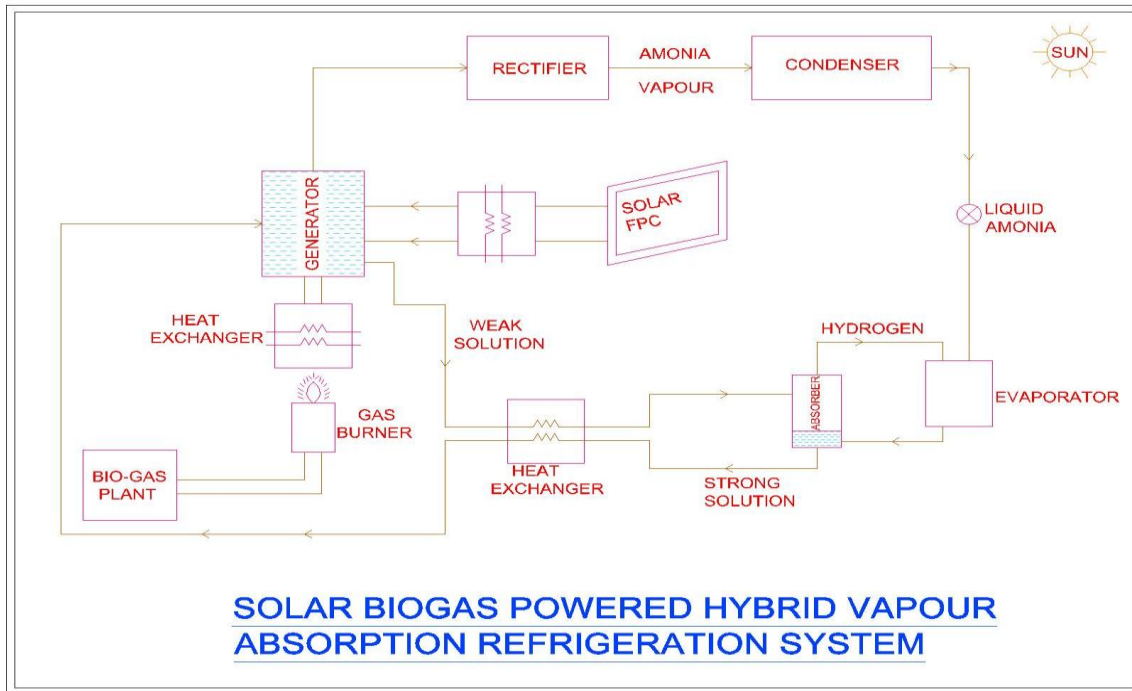


Figure 1: Block diagram of solar-biogas hybrid vapour absorption refrigeration

II. Methodology:

Design of the VARS

Vapour absorption refrigeration system mainly consists of generator tube, absorber unit, and evaporator and condenser unit. In this case 40 L capacity absorption refrigerator of each part was designed and dimensions were determined. For design of the VARS following parameters were calculated;

$$QE = m_p \times C_p \times \Delta T$$

m_p = weight of the product to be cooled (kg)

C_p = specific heat of the product (kJ/kg K)

Mass flow rate of solution in the evaporator (m_1)

Mass flow rate of liquid ammonia in the evaporator was calculated using formula given below

$$m_1 = 210 * Q_E / (h_1 - h_5)$$

h_1 = Enthalpy of vapour ammonia leaving evaporator (h_1)

h_5 = Enthalpy of liquid ammonia leaving condenser (h_5)

Q_E = Heat absorbed by the refrigerant in the evaporator

$$m_1 + m_3 = m_2$$

m_1 = Mass flow rate of solution in the evaporator

m_2 = Mass flow rate of strong aqua- ammonia solution leaving absorber m_3 = Mass flow rate of weak aqua- ammonia solution leaving generator

$$m_1 x_1 + m_3 x_3 = m_2 x_2 = (m_1 + m_3) x_2$$

x_1 = Concentration of ammonia in vapour leaving generator

x_2 = Concentration of ammonia in strong solution leaving absorber

x_3 = Concentration of ammonia in weak solution leaving generator

Design of evaporator

$$Q_E = [U \times A_E \times LMTD]$$

Q_E = Heat absorbed by the refrigerant in the evaporator (KJ/min)

A_E = Area of the evaporator coil

LMTD = Logarithmic Mean Temperature Difference

Logarithmic Mean Temperature Difference was calculated by using the equation

$$LMTD = \left[\frac{(\Delta T_1 - \Delta T_2)}{\ln \left(\frac{\Delta T_1}{\Delta T_2} \right)} \right]$$

$$\Delta T_1 = T_{hi} - T_{co}$$

$$\Delta T_2 = T_{hi} - T_{ci}$$

T_{hi} = Temperature of air surrounding evaporator

T_{ho} = Temperature of air after 1min

T_{ci} = Temperature of NH3 liquid entering evaporator

T_{co} = Temperature of NH3 liquid

A_E = Area of the evaporator coil

$$A_E = NE \pi DE LE$$

DE = Diameter of the evaporator coil

LE = Length of the evaporator coil

NE = Number of

evaporator coil

Design of condenser

$$Q_C = [U \times A_C \times \text{LMTD}]$$

QC = Heat rejected from the condenser

AC = Area of the condenser

LMTD = Logarithmic Mean Temperature Difference

$$\text{LMTD} = \left[\frac{(\Delta T_1 - \Delta T_2)}{\ln \frac{(\Delta T_1)}{\Delta T_2}} \right]$$

$$\Delta T_1 = T_{hi} - T_{co}$$

$$\Delta T_2 = T_{hi} - T_{ci}$$

Thi = Temperature of NH3 vapor at inlet

Tho = Temperature of NH3 liquid at outlet

Tci = Inlet temperature of air

Tco = Outlet temperature of air

AC = Area of the condenser coil

$$AC = \pi DC LC$$

DC = Diameter of the evaporator coil

LC = Length of the evaporator coil

NC = Number of evaporator coil

Design of Absorber unit

$$V_{AV} = \frac{\pi}{4} \times D_{AV}^2 \times L_{AV}$$

VAV = Volume of the absorber vessel

DAV = Diameter of the absorber vessel

LAV = Length of Absorber vessel

Generator design

Therefore dimensions of the generator tube were calculated by using equation;

$$V_G = \frac{\pi}{4} D_G^2 L_G$$

VG = Volume of the generator tube

DG = Diameter of the generator tube

LG = Length of the generator tube

Theoretical Coefficient of Performance of Vapour absorption refrigeration system

The net refrigerating effect is the heat absorbed (QE) by the refrigerant in the evaporator. The total energy supplied to the system is the sum of work done by pump (Wp) and the heat supplied (QG) in the generator. Therefore, the coefficient of performance of the system is given by:

$$COP_{cooling} = \frac{\dot{Q}_E}{(\dot{Q}_G + \dot{W}_P)}$$

Required Capacity of Biogas Plant

Required energy from biogas plant

$$Q_B = Q_G / \eta_b \eta_G$$

QB = Required energy from biogas plant in KJ for 24 hours

QG = Heat required to generator in KJ for 24 hours

ηb = Efficiency of biogas burner

ηG = Efficiency of generator

Capacity of Biogas plant for 24 hours = Required energy from biogas plant in KJ (QB) / calorific value of biogas in MJ/cubic meter

1 cubic meter biogas = 1000 liter biogas = 20 MJ energy

Required Capacity of Biogas burner

Capacity of biogas burner Qb = QG/ηG

QG = Heat required to generator in KJ

ηG = Efficiency of generator

Required Capacity ETC solar water heater

Capacity of solar ETC collector

$$Q_{ETC} = Q_G / \eta_A \eta_w \eta_G$$

QETC = Actual heat required by ETC solar collector in KJ for 8 hours

QG = Heat required to generator in KJ for 8 hours

ηA = Efficiency of heat absorbing capacity insulating material

ηw = Efficiency of heat absorbing capacity of water tank

ηG = Efficiency of generator

Now calculation for required area for solar collector

AETC = ETC solar collector area in m²

IS = Average solar intensity in KW/ m²

$$AETC = Q_{ETC} / IS$$

Number of evacuated tube required (n) = AETC/aETC

n = Number of Evacuated tube required

aETC = Area of each evacuated tube in m²

Required Capacity of Solar Photovoltaic (Solar Panel)

Required capacity of solar panel

$$Q_{SP} = Q_G / \eta_{SP} \eta_H \eta_G$$

QSP = Power required by solar panel in KW for duty hours

QG = Heat required to generator in KW

ηSP = Efficiency of heat absorbing capacity of solar panel

ηH = Efficiency of DC heater

ηG = Efficiency of generator

Required Capacity of DC heater

Required capacity for DC heater

$$Q_{DCH} = Q_G / \eta_G$$

QDCH = Capacity of power required DC heater in KW

QG = Heat required to generator in KW

ηG = Efficiency of generator

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III. Results and Discussion

Table 4.1: Designed dimensions of the components of the VARS

Components		Dimensions				
		Volume, m ³	Diameter, m		Length, m	
Heat exchanger copper coil		4.24 × 10 ⁻⁵	0.006		1.5	
		No. of turns = 28				
Generator tube		7.85 × 10 ⁻⁵	0.02		0.25	
Absorber unit	Absorber vessel	3.30 × 10 ⁻⁴	0.06		0.125	
	Absorber tube	2.5 × 10 ⁻³	0.03		3.6	
Evaporator		4.6 × 10 ⁻⁵	0.014		0.30	
Condenser unit	Condenser tube	4.9 × 10 ⁻⁵	0.014		0.32	
	Condenser fins	3.5 × 10 ⁻⁶	Length, M	Width, M	Thickness, m	No. of fins
			0.07	0.05	0.001	35

Table 4.2 Required capacity of various renewable energy based heat source

S.No.	Various renewable energy based heat source	Required Capacity
1	Biogas Plant	3 cubic meter
2	Biogas Burner	0.4 KW
3	Solar water heater	100 liter.7 ETC solar water heater
4	Solar Photovoltaic system	1 KW Solar panel
5	DC heater	0.4 KW

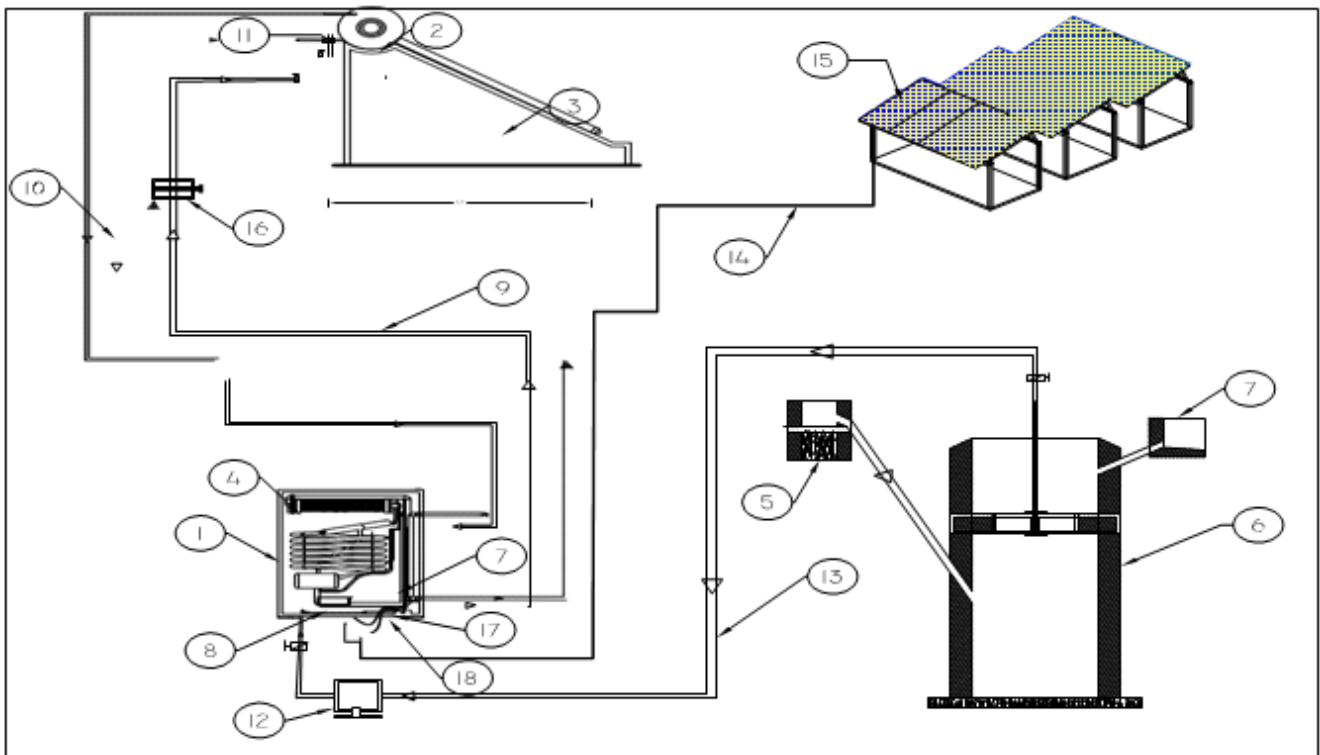


Figure 2: Schematic diagram of developed solar-biogas hybrid vapour absorption refrigeration system

Table 4.10: List of components of solar-biogas-hybrid power vapour absorption refrigeration system

S.no.	Figure description	S.no.	Figure description
1	Vapour absorption refrigeration cycle	10	Hot water pipe
2	Solar water storage	11	Valve
3	Solar water tube	12	Biogas flow meter
4	Evaporator fins	13	Biogas pipe
5	Biogas slurry tank	14	Electrical connection
6	Biogas tank	15	Solar panel
7	Sludge tank	16	Centrifugal water pump
8	Drain water tub	17	Electrical heat exchanger
9	Cold water pipe	18	Biogas burner

Figure 3: shows the variation of generator temperature and variation of COP over a time period of 24 hours in full load condition. In this duration the refrigerator is powered by biogas during first four hours of operation and then shifted on DC power source for next 6 hours provided by solar photovoltaic. In the 11th hour of operation the refrigerator is again powered by biogas and is kept on biogas for remaining time of operation. The following observations were made: The initial temperature of generator is found to be 140°C, which decreases slightly during first hour of operation. In the second hour of operation generator temperature remains constant at 140°C which increase slightly after the fourth hour of operation, when refrigeration is powered by solar panel supplying DC power. When solar

panel in the form DC supply as power source the generator temperature almost remains constant during entire period of operation. During the 12th hour of operation a sudden decrease in the generator temperature is observed. The generator temperature further increases sharply & attains a value of 140°C again, when the refrigerator is powered by biogas. This temperature of 140°C is maintained constant for the remaining hours of operation. It can be concluded from the above discussion that the generator temperature lies in the range of 135°C - 140°C.

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The variation of COP is discussed as follows: Initially the COP is found to be 0.45, which decreases rapidly during first four hours of operation. During this time period the refrigerator is powered by biogas at full load condition. At the end of the fourth hour COP attains a value of 0.23 followed by a rapid increase when the refrigerator is shifted to DC power source. The value of COP as observed in the 12th hour of operation under full load condition is found to be 0.16. As discussed earlier while using solar thermal

power the maximum attainable temperature is obtained resulting in COP of 0.12. During the 13th hour of operation the refrigerator is again powered by biogas and is kept as biogas for the remaining time of operation as heat source to generator of the refrigerator. It can be observed from figure 4.38 that there is gradual decrease in COP followed by gradual increase in the 15th hour of operation a gradual decrease in COP is obtained followed by slight fluctuations the refrigerator maintain a COP of 0.104 approximately.

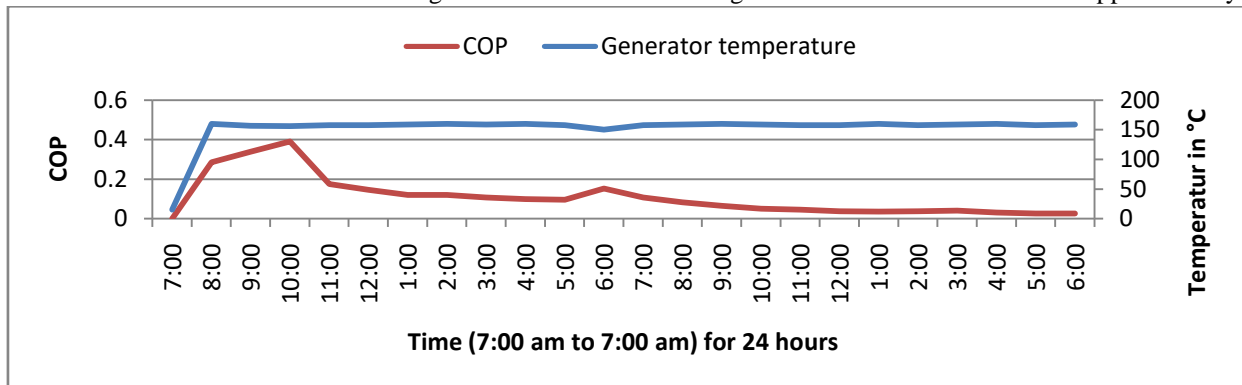


Figure 3: Variations of generator temperature and COP of the system with time

Figure 4.3 shows the variation of evaporator temperature and variation of COP over a time period of 24 hours in full load condition. In this duration the refrigerator is powered by biogas during first four hours of operation and then shifted on DC power source for next 6 hours provided by solar photovoltaic. In the 11th hour of operation the refrigerator is again powered by biogas and is kept on biogas for remaining time of operation. The following observations were made: The initial temperature of evaporator (cabinet) is found to be 16°C, which decreases slightly during first hour of operation. In the second hour of operation evaporator (cabinet) temperature remains constant at 2°C which increase slightly after the fourth hour of operation, when refrigerator is powered by solar panel. The evaporator temperature further decreases sharply attaining a value of 2°C again, when the refrigerator is powered by biogas. This temperature of 2°C is maintained constant for the remaining hour of operation. It can be concluded from the above discussion that the evaporator temperature lies in the range of 2°C - 4°C.

The variation of COP is as follows: Initially the COP is found to be 0.45, which decreases rapidly during first four hours of operation. During this time period the refrigeration is powered by biogas at full load condition. At the end of the fourth hour COP attains a 0.23 followed by a rapid increase when the refrigerator is shifted to DC power source. The value of COP is observed in the 12th hour of operation under full load condition is found to be 0.16. As discussed earlier while using solar thermal power the maximum attainable temperature is obtained resulting in COP of 0.12 . During the 13th hour of operation the refrigerator is again powered by biogas and is kept as biogas for the remaining time of operation as heat source to generator of the refrigerator. It can be observed from figure 4.38 that there is gradual decrease in COP followed by gradual increase in the 15th hour of operation a gradual decrease in COP is obtained followed by slight fluctuations the refrigerator maintain a COP of 0.104 approximately.

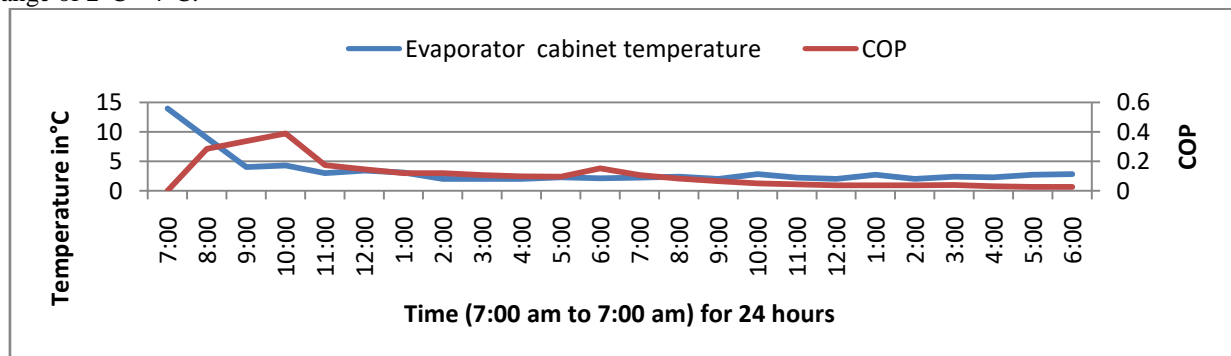


Figure 3 : Variations of evaporator cabinet temperatures and COP with time

Figure 4: Over a time period of 24 hours, the observations made are as follows: The graph predicts that during first 4 hours of operation the refrigerator cabinet temperature is maintained at a constant value of 2°C and for next five hours the system was shifted on solar panel as power source. Further the system was again shifted on biogas for remaining hours of operation. At this time heat extraction by water is reached its maximum value 3660 KJ by biogas powered system for first 4 hours after that system shifted on solar panel for next five hour and again system shifted on biogas powered for remaining hours and heat extraction is maintained around this value for 24 hours with respect to variation in room temperature and cabinet temperature so that average heat extraction value in 24 hours is 2000 KJ. For maintaining 2°C to 4°C cabinet temperature and heat extraction 2000 KJ, supply of heat continuously required in

KJ. Biogas consumption are 130 liter per hour for It produces 2600 KJ around energy per hours. Graph seems that around 2600 KJ heat energy should be required per hour for maintaining temperature and heat extraction but solar panel produces 1442 KJ energy per hour. After 24 hours evaluation total biogas is required is around 2000 liter. It produces approx 55000 KJ energy which is actual required for biogas operated refrigeration system.

In the graph seems that COP of the system initially reached at 0.45 and after that COP continuously decreased because heat supplied is increasing per hour and heat extraction is maintained with respect to cabinet temperature and room temperature. Over a time of 24 hours COP gradually is decreased. After the complete 24 hour operation we observed that average COP of the system is 0.106.

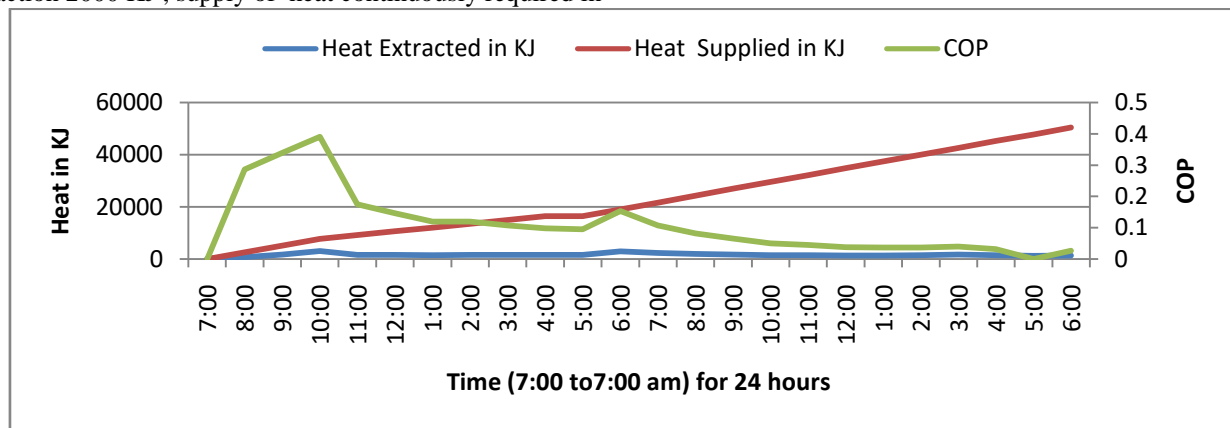


Figure 4: Variation of heat extraction and heat supplied with COP of system and time

IV. CONCLUSION:

A partial load of 3 Cubic meter biogas plant and 0.8 kW of solar panel with a COP value of 0.10 was obtained when operating the Solar-biogas powered vapour absorption refrigeration system at generator temperatures of 140°C when the design of the operating generator temperature was 120°C with a design capacity of 0.05 kW. The system was operated with a heat source temperature of around 120°C instead of 140°C. The heat required for these conditions can be obtained by biogas flame and solar panel direct current. The air cooled absorption system was operated at ambient temperatures above 25°C. Furthermore, at an ambient temperature of 28°C, 0.05kW cooling capacity was achieved, with a mass flow of ammonia of 0. kg/min and a water flow rate of 15 kg/min, with temperatures of the diluted solution at 140 ° C and under these conditions a COP of 0.1 to 0.13.

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