Experimental Analysis on the Performance and Characteristics of Compact Solar Refrigeration System

M. Achuthan
Annamalai University, Annamalainagar, Tamil Nadu, India
A. Venkataraman
Rajiv Gandhi Engineering College, Pondicherry, India
R. Rathnasamy
Annamalai University, Annamalainagar, Tamil Nadu, India

ABSTRACT

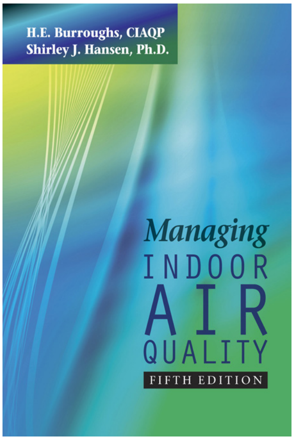
This article focuses on the experimental analysis of fabricated Compact Solar Refrigeration System (CSRS) for small capacity cooling applications operating with water as refrigerant and lithium bromide as absorbent. Micro nozzles are introduced in the evaporator and in the absorber to shower the operational fluids in the system with the objective of increasing the heat transfer with effective absorption in the evaporator and absorber respectively. Modelling and performance analysis of the CSRS has done the influence of source temperatures and other operating parameters on the performance of systems fitted with micro nozzles. It appears that the coefficient of performance in CSRS has been improved from 0.3 to 0.6, since the heat transfer rate is improved in evaporator.

Keywords: Compact Solar Refrigeration System, Li-Br, Micro nozzles.

INTRODUCTION

The energy demand on the cooling application is considerably increasing in domestic and industrial applications and also scarcities of non-renewable energy sources are increasing. The solution for meeting the demand is renewable energy sources like solar energy, bio-fuel, etc… and recovery of wasted heat. Lot of work have been initiated in using

MANAGING
INDOOR AIR QUALITY, 5th Edition



H.E. Burroughs, C.I.A.Q.P., and Shirley J. Hansen, Ph.D.

This newly revised and updated practical desk reference is structured to serve as a guide and information resource—both on treating existing indoor air problems effectively, and on preventing costly IAQ problems from occurring in the first place. Finding solutions to indoor air quality problems is often a complex, multi-disciplined endeavor. A single-discipline approach from the environmental engineer, the industrial hygienist, or the medical doctor, unfortunately tends to narrow both the control and the treatment options. This book cuts across these professions to offer those concerned with the total facility, a broader, more comprehensive approach to managing indoor air quality and mitigating indoor air quality problems. Topics covered also include updated ASHRAE standards and information, expanded discussion of greening and sustainability, building security and mold-related issues, current diagnostics and remediation practices, and the latest information on filtering.

ISBN: 0-88173-661-9

6 x 9, 360 pp., Illus.
Hardcover, $000

ORDER CODE: 0654

CONTENTS

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Carbon Reduction: Policies, Strategies and Technologies	**0654**	**$125.00**	

Applicable Discount	
Georgia Residents add 6% Sales Tax	
Shipping Fees	**10.00**
TOTAL	

② Indicate shipping address: **CODE: Journal 2010**

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order) EMAIL ADDRESS

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

MEMBER DISCOUNTS
A 15% discount is allowed to AEE members.
☐ **AEE Member (Member No.____________________)**

③ Select method of payment:
☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

CARD NO.

Expiration date *Signature*

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

④ Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.


WORLD ENERGY
ENGINEERING
CONGRESS
WEEC
2011

renewable energy for the cooling applications which is available in clean form and in plenty.

Solar energy is used in the refrigeration systems in two ways, one is by solar PV system which coverts solar energy to electric energy which can be used in Vapour Compression Refrigeration System and the second method is by using Solar Collecting system which converts solar energy to heat energy which can be used in Vapour Absorption Refrigeration System.

Solar Absorption Refrigeration System

In general, Vapour Absorption Refrigeration Systems (VARS) use low grade/temperature energy and the alternative option is using solar energy. VARS requires a robust construction compared to the Vapour Compression Refrigeration System for the same cooling load. The high capacity Vapour Absorption Refrigeration Systems uses fire wood, coal, diesel etc. [2]. A solar powered VARS operates by directly harnessing solar energy for the cooling purpose. Previous researchers have shown that the vapour absorption refrigeration systems generally offer smaller Coefficient of Performance (COP) and are commonly used for high capacity cooling loads [1] using coal or diesel etc.., that are non-renewable and emit harmful greenhouse effects.

Compact Solar Refrigeration System

The absorption refrigeration systems utilising solar energy with smaller capacity are called Compact Solar Refrigeration Systems (CSRS). CSRS can be used in wide real life applications like cooling systems for travel, in rural areas and remote cold storages. CSRS receives the solar energy through the solar collectors for operation.

Performance Analysis of CSRS

The coefficient of performance (COP) of the solar refrigeration system generally depends on the performances of solar collector, generator, evaporator, and condenser and also depends on the pair of working fluid combinations which is used in the system. In the past five decades many efforts in these directions have been made and reports have been submitted on the performance analysis of solar refrigeration systems [3, 4]. Generator performance of the system is purely reliant on the heat source supplied to it [5].The heat source for the SARS is solar energy through the solar collector. This solar collector converts the solar energy to heat energy which is then input into the SARS in the form of hot water. The temperature of the hot water depends on the performance of the solar collector. The review on the solar collector shows that the performance of the solar collectors mainly depends on the shape of the collector [6]. The different types and shapes of solar collector give the different heat outputs. The COP of the SARS also depends on the condenser performance and the review indicates that the higher the effectiveness of the condenser the correspondingly higher the performance of the system [7].

Working Fluids in CSRS

The other important factor to be considered for the performance of the SARS system is the pair of refrigerant and absorbent working fluids. The working fluid pairs which are used in the SARS should be carefully planned for an eco-friendly and good thermo mechanical properties. The study on the performance of various pairs of refrigerant and absorbent indicates that a water and lithium bromide combination suits for small capacity applications and the pair has the advantage of utilizing the low level heat energy and is also considered eco-friendly [9, 10]. Also, various studies show that absorption refrigeration systems perform well for higher capacities outputs compared to the smaller capacities [11, 12].

CSRS with Micro Nozzles

This review provides a need for further studies on small capacity absorption refrigeration systems with better performance [8]. In this work copper tubes are attached with micro nozzles for spraying working fluids on the overheat exchanger coils available in the CSRS. This results in the increase of heat transfer in the evaporator and absorber by 20% which influences the COP of the system from 0.1 to 0.5. The performance of the system was analysed with different temperatures of hot water supplied to the generator. Temperature variation happened due to the solar insolation.

CONSTRUCTION OF CSRS

Construction of the CSRS is shown in the Figure 1. It contains two vessels connected by tubes. The upper vessel is divided into two compartments by a short wall where the right side compartment a strong solution sprayed over the hot water tubes receiving the heat energy from the solar collector. The strong solution will absorb heat from the hot water, thereby the refrigerant in the strong solution evaporates and will pass over the condenser tubes which are in the left side compartment of the same vessel. The cold water circulated in the condenser coil takes off the heat from the refrigerant vapour, thus condensing the vapour into liquid.

In the lower vessel, the condensed refrigerant will be sprayed on evaporator coils. As the refrigerant evaporates, it takes the heat from the fluid circulated in the evaporator coils and the cooling effect is obtained. The evaporated refrigerant vapour will be absorbed by the absorbent which is available in the next compartment of the same vessel and forms the strong solution. Pumps are used to circulate the fluids between the upper and lower vessels. The performance of the CSRS is obtained by evaluating the coefficient of performance, which is the ratio of the cooling obtained in the evaporator to the heat supplied to the generator. The power input for the pumps is negligible relative to the heat input at the generator, therefore the working of the pump is often neglected during analysis.

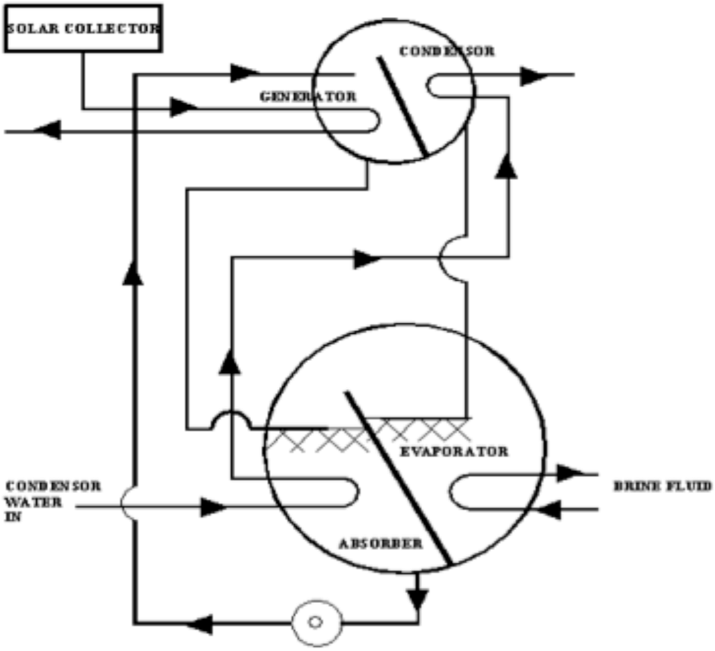


Figure 1. Layout of CSRS

PROBLEM FORMULATION

A mathematical model is used to analyse the performance of the CSRS. This model shows the relationship between the following parameters, namely:

- Heat removed in the evaporator
- Heat supplied in the generator
- Heat removed in the condenser
- Temperatures of the brine at inlet and outlet
- Temperatures of the generator fluid at inlet and outlet and
- Condenser fluid temperatures at inlet and outlet.

The mathematical model is formulated using the second law of thermodynamics along with heat, mass, and the energy balances. First, Equation 1 reveals the relationship between the heat generated in the generator, heat removed in the evaporator and with the absolute temperatures

$$\frac{Q_g}{T_g} + \frac{Q_e}{T_e} = \frac{Q_c}{T_c} \tag{1}$$

Next, Equation 2 is to find out the Coefficient of Performance (COP) using the relationship between the heat generated in the generator, heat removed in the evaporator and the absolute temperatures.

$$CPO = \left(\frac{T_e}{T_c - T_e}\right)\left(\frac{T_g - T_c}{T_g}\right) \tag{2}$$

Where,

Q_e = Heat removed in the brine evaporator in Watts

Q_g = Heat supplied to the generator in Watts

Q_c = Heat removed from the refrigerant at the condenser in Watts

T_g = Temperature at which heat (Q_g) is given to the generator in °C

T_c = Temperature at which heat (Q_c) is discharged to atmosphere in °C

T_e = Temperature at which heat (Q_e) is absorbed in the evaporator in °C

Equation 3 is used to find the experimental COP of the CSRS using the relationship between the heat removed from the brine and heat supplied at the generator.

$$\mathrm{COP} = \frac{Q_e}{Q_g} \tag{3}$$

$$Q_g = mc_p\,(T_{hi} - T_{ho}) \text{ in Watts} \tag{4}$$

$$Q_c = mc_p\,(T_{ei} - T_{eo}) \text{ in Watts} \tag{5}$$

Where,

m = Mass flow of hot water from the solar collector in Kg/Sec

c_p = Specific heat of the hot water in W/kg°C

T_{hi} = Temperature of the hot water at inlet of the generator °C

T_{ho} = Temperature of the hot water at the outlet of the generator °C

T_{ei} = Temperature of the brine inlet in the evaporator °C

T_{eo} = Temperature of the brine at outlet of the evaporator °C

EXPERIMENTAL FACILITY

The CSRS is designed with the consideration of good mechanical and chemical behaviour with suitable piping and vessel materials fabricated with lot of care. All the heat transfer equipment like evaporator, condenser, and generator cooling coils in the absorber were carefully tested and proved for the leak proof. Micro nozzles are introduced in the spray pipes to enhance the heat transfer rate in the evaporator and effective absorption in the absorber. Care is taken much in fabricating and evacuating the setup. After fabricating the equipment the charging of the working fluids is done. Then leak test is performed on the system followed by load test for mechanical and chemical stability. The fabricated experimental setup is shown in the Figure 2.

Composition of Working Fluids in CSRS

The working fluids used in the CSRS are Lithium Bromide (LiBr) as absorbent and the properties of the LiBr are as follows:

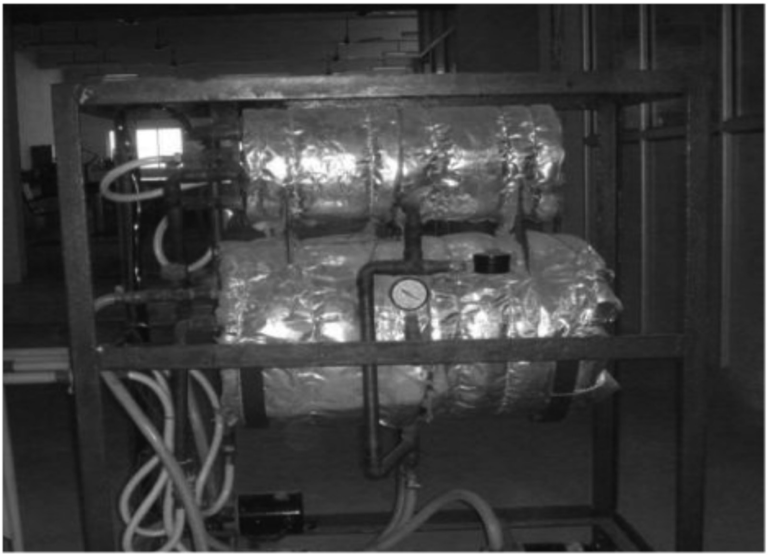


Figure 2. Experimental set up of the compact solar refrigeration system

Molecular Weight: 86.85
Composition: lithium 7.99% bromide 92%
Specific Gravity: 3.46 at 25^{o}C
Melting Point: 549^{o}C and
Boiling Point: 1265^{o}C at atmospheric pressure conditions

Water (H_2O) is taken as refrigerant. This is pure and free of contaminants. LiBr is corrosive in the presence of air so, corrosion inhibitors, such as Lithium Chromate, are charged into the system to retard corrosion. Octyl Alcohol (2-Ethyl 1-Hexanol) is added as additive to increase absorption effect of the absorbent.

Specification of the Compact Solar Refrigerator

The operating parameters of the compact solar refrigeration system for the performance analysis ratings are listed in Table 1.

The experiment was conducted with different generator inputs at different time intervals. The parameter data related to generator condenser and evaporator performance during the experiment are given in Table 2.

Table 1. Specification of CSRS

Serial No.	Description	Rating
1	Mass flow in generator	0.00467 kg/s
2	Generator inlet temperature	75 – 93 ^{0}C
3	Mass flow in Condenser	0.006 kg/s
4	Condenser inlet temperature	25 – 35 ^{0}C
5	Mass flow in Evaporator	0.005 kg/s
6	Evaporator outlet temperature	19 – 22 ^{0}C

Table 2. Parameters obtained in the experiment

Serial No	Time (min)	Generator			Condenser		Evaporator			
		Temperature (^{o}C)		FlowRate (ml/min)	Temperature (^{o}C)		FlowRate (ml/min)	Temperature (^{o}C)		
		Inlet	Outlet		Inlet	Outlet		Inlet	Outlet	Out let (after fitting Nozzle)
1	90	75	50.0	280	25	36.0	360	32.0	22.0	17.0
2	105	78	53.0	280	25	36.0	360	33.0	21.0	16.5
3	120	80	55.0	280	25	36.5	360	33.0	20.5	17.5
4	135	83	56.0	280	26	36.5	360	33.5	20.0	17.5
5	150	85	57.0	280	28	37.0	360	33.5	20.0	15.5
6	165	87	58.0	280	29	37.0	360	34.0	20.0	15.5
7	180	88	58.5	280	29	37.5	360	34.5	20.0	15.5
8	195	89	59.0	280	30	37.5	360	34.5	19.5	16.0
9	210	92	61.0	280	33	37.5	360	34.0	19.0	16.0
10	225	93	63.0	280	35	37.5	360	34.0	19.0	16.5

RESULTS AND DISCUSSION

The recorded experimental values are used in formulated models to analyse the performance of CSRS. The temperature variations with respect to time for the different components of the CSRS are given in Figure 3. It is indicated that the generator input temperature is found to be increased with respect to time, condenser outlet temperature and evaporator inlet. Temperature is not having significant variation with respect to time. Also, it is identified that the expected cooling temperature is obtained constantly with respect to time in the experimental system.

The variation of experimental COP with respect to the brine outlet temperature is represented in Figure 4. COP is 0.6 at low temperatures and is not varying for small increase in the outlet temperature of the brine solution.

The heat removed in the evaporator with respect to the brine out let temperature is shown in the Figure 5. The heat removal rate is considerably decreasing with respect to the increase in the brine outlet temperature. It clearly indicates that if the load on the system increases the performance is decreasing.

The variation in theoretical COP and the experimental COP with respect to the brine outlet temperature is given in Figure 6. The theoretical performance and experimental performance of the system have negligible deviation for the low brine outlet temperature and there is significant variation for the increase in the temperature of the brine outlet temperature. The maximum variation is 0.15 is indicating that the theoretical COP is increasing and the experimental value is decreasing with respect to the rise in the brine outlet temperature.

The effect of nozzles with respect to the performance is indicated in the Figure 7. It shows the performance of the CSRS system is improved by increasing the heat transfer rate in the evaporator, raising the COP from 0.3 to 0.6.

CONCLUSION

The experimental results and analysis show that the compact solar refrigeration system performs well for the low cooling load and is well suited for the small capacities. The hot water inlet temperature in the generator influences the CSRS performance and the optimum hot water inlet temperature of the generator is 95°C. The temperature reduction achieved in the brine of the evaporator is from 10°C to 15°C. Introduction of nozzles in the evaporator improves the performance of the system. In future this system with nozzles can be used with the heat resources like bio-gas in domestic plants and burning of sugar cane bagasse.

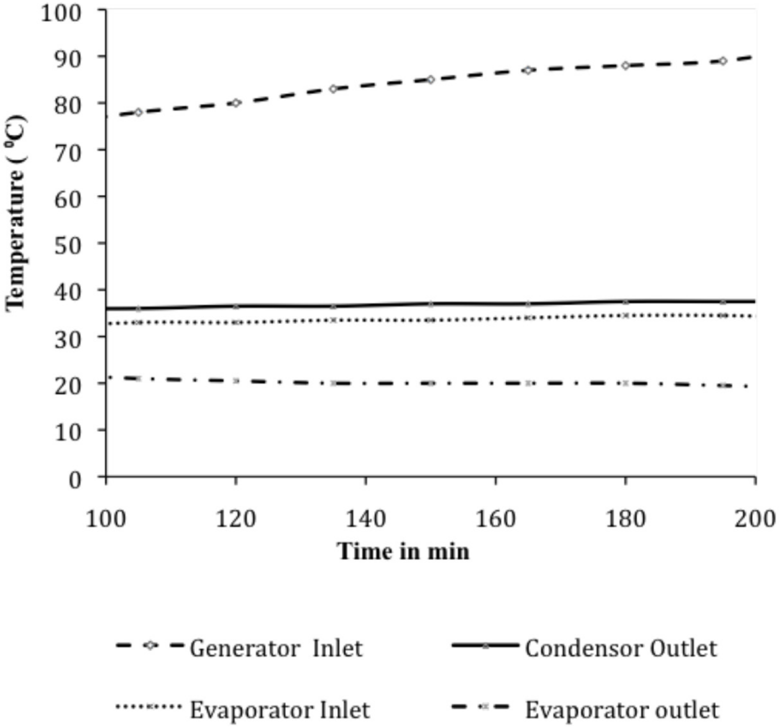


Figure 3. Variation of temperatures of different components against time

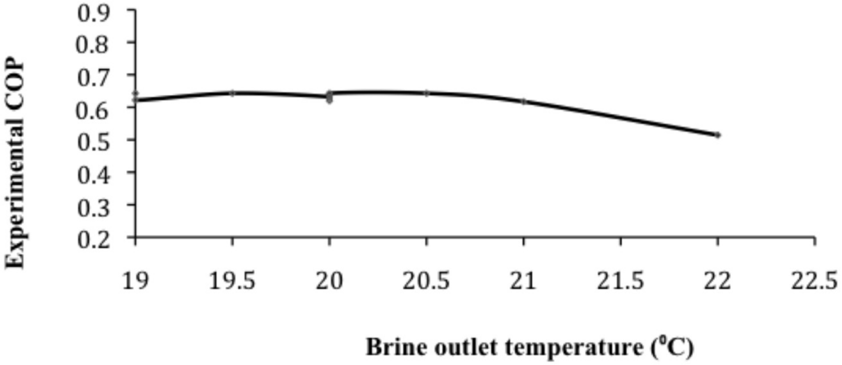


Figure 4. Variation of the experimental COP against brine outlet temperature

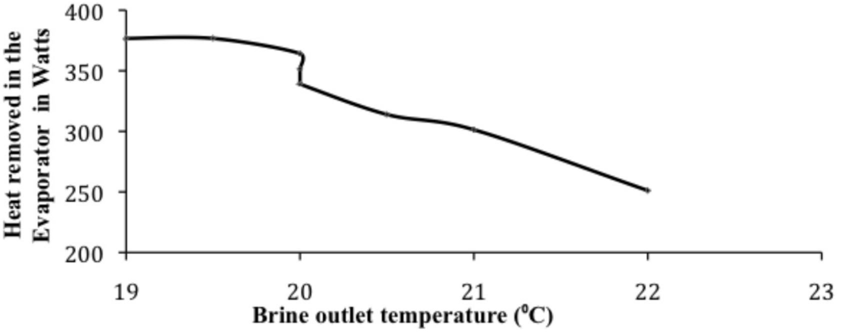


Figure 5. Variation of the heat removed in the evaporator against brine outlet temperature

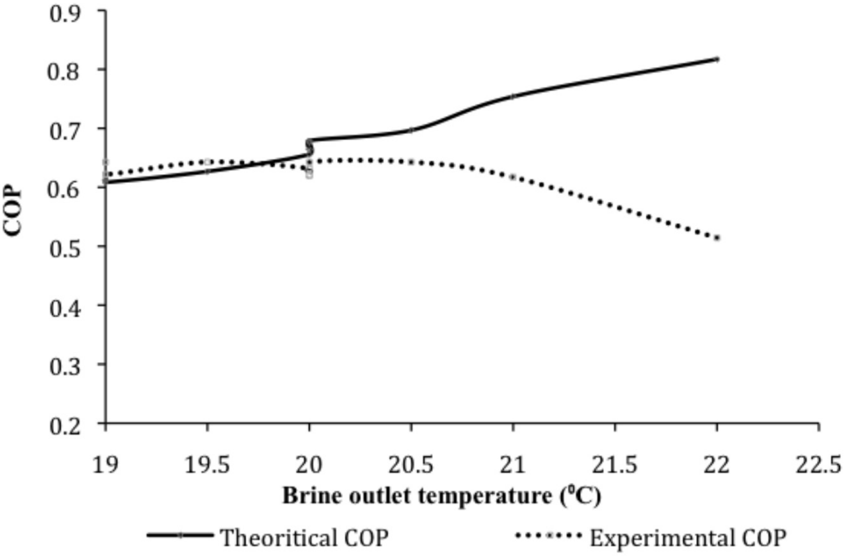


Figure 6. Experimental and theoretical COP against brine outlet temperature

References

All mansoori Gand Vinodpatel, "Thermodynamic basis for the choice of Working fluids for solar absorption Cooling systems,"Solar energy1979vol. 22, pp. 483-491.

Antonio De Lucas, Marina Donate, Carolina Molero, Jose Villasenor, Juan F. Rodrı´guez "Performance evaluation and simulation of a new absorbent for an absorption refrigeration system" International Journal of Refrigeration, 2004, pp. 324–330

Fathi R and S. Ouaskit, "Performance of a solar libr - water absorption refrigerating systems,"Rev. Energ. Ren.:journées de thermique, 2001, pp. 73-78

Florides GA, Kalogirou SA, Tassou SA, Wrobell C, "A design and construction of a

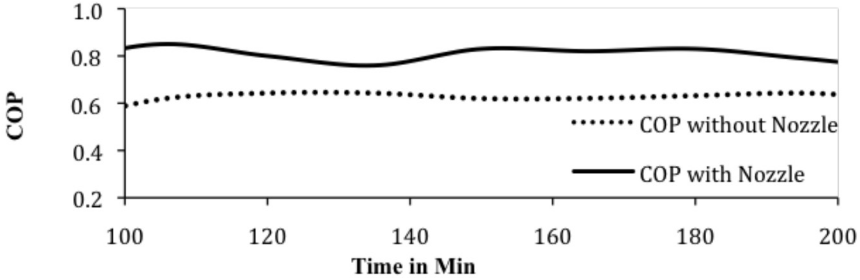


Figure 7. Effect of COP in CSRS With and Without Nozzle

LiBr–water absorption machine," Energy Conversion and Management, 2003, pp. 2483–2508

Mehrabian MA and Shahbeik AE, "Thermodynamic modelling of a single-effect LiBr–H2O absorption refrigeration cycle" Part E: J. Process Mechanical Engineering (IMechE), Year 2004 Vol. 219

Omer Kaynakli and RecepYamankaradeniz, "Thermodynamic analysis of absorption refrigeration system based on entropy generation," Current science, 2007 vol. 92, no. 4, pp. 472

Pongsidsrikhirin, Sathaaphornratana, Supachartchungpaibulpatana, "A review of absorption refrigeration technologies," Renewable and sustainable energy reviews, 2001, Vol. 5, pp. 343–372

Soteris A. Kalogirou, "Solar thermal collectors and applications," Progress in Energy and Combustion Science, 2004, pp. 231–295

Wang DC, Wang YJ, Zhang JP, Tian XL, Wu JY, "Experimental study of adsorption chiller driven by variable heat source" Energy conversion and management, 2008, pp. 1063–1073

Yijian He, Guangming Chen, "Experimental study on an absorption refrigeration system at low temperatures," International Journal of Thermal Sciences, 2007, pp. 294–299

Satha Aphornratana, Thanarath Sriveerakul, "Experimental studies of a single-effect absorption refrigerator using aqueous lithium–bromide: effect of operating condition to system performance,"Experimental thermal and fluid science, 2007, pp. 658–669

Mittal V, Kasana KS and Thakur NS, "Performance evaluation of solar absorption cooling system of Bahal (Haryana)," J. Indian Inst. Sci., sep- oct 2005, pp. 295–305

ABOUT THE AUTHORS

M. Achuthan received his B.E. in Mechanical Engineering from Madras University, Chennai, India in 1991 and M.E. in Refrigeration and Air-conditioning from Coimbatore Institute of Technology, presently affiliated to Anna University, Coimbatore, India in 1995. He is a research scholar in the Department of Mechanical Engineering, Annamalai university, Annamalainagar, Tamil Nadu, India. He has published 10 research papers in International and National conferences. His research focuses on Energy Engineering, Renewable Energy for cooling applications and IC Engines. He is having eighteen years of Engineering College Teaching experience. He is Active member in different professional bodies. Email: arunaiachuthan@gmail.com.

Prof. Rangasamygounder Rathnasamy obtained his B.E. (Hons.) and M. Tech. degree in Mechanical Engineering from Madras university and Indian Institute of Technology Madras, India respectively, in 1981 and 1983. Then he joined as PGET at thermal power station (Tata Electric Co. Bombay) before working as engineer at Coimbatore and as Associate lecturer at Allagappa College of Engg &Tech., Karaikudi. In 1988 he joined as a Lecturer in Mechanical Engineering at Annamalai University. He received his Ph.D. (flow and Heat transfer in micro-channel) from Indian Institute of Science, Bangalore in 2002. Presently he is a professor and supervises few Ph.D. scholars, since 2002. He also discharged duty as university representative for conduct of DDE examinations twice. In the meantime 2009-2010, on lien service he worked as Principal at Indira Gandhi College of Engg. & Tech. for women and A.C.T. College of Engg. & Tech. affiliated to Anna University Chennai. His research area includes heat transfer enhancement and non-conventional energy studies.

Prof. A. Venkatraman obtained his B.E. (Hons.) and M.E. degree in Mechanical Engineering from PSG Institute of Technology, Coimbatore, India respectively, in 1966 and 1972. He received his Ph.D. from Indian Institute of technology, Chennai in 1994. He has been in the faculty of Mechanical Engineering in different positions from 1966-2003and from2004 he worked as the principal of engineering colleges and currently principal of Rajiv Gandhi Engineering College, Pondicherry, India. His research area includes Engineering Design and Energy Technology. He is Fellow in the Institution of Engineers, Life member ISTE, Life member Solar Energy Society of India; Life member Indian Nuclear Society. He has guided several post graduate students, including Ph.D. scholars. He served in the academic committee, governing council member of different universities.