RECENT DEVELOPMENTS IN THERMAL DRIVEN COOLING AND REFRIGERATION SYSTEMS

Roberto Best
Centro de Investigación en Energía
Universidad Nacional Autónoma de México
Privada Xochicalco s/n 6258 Temixco, Mor. Mexico
Tel: +52-5556229736, Fax: +52-5556229791, email: rbb@cie.unam.mx

ABSTRACT

A review of recent developments on thermal cooling systems is presented. Special interest is mentioned in cogeneration applications as well as in the use of renewable energy resources for cooling. Also research work recently carried out in the Centro de Investigación en Energía of the Universidad Nacional Autónoma de México concerning absorption cooling systems and ejector cooling systems is presented.

INTRODUCTION

There are many cooling and refrigeration applications that can be covered by thermal driven cooling systems. This has recently expanded to a series of new technologies available or in a stage of development that can be an option in the near future. Absorption, adsorption, desiccant systems, ejector-compressor systems are being developed for coupling with thermal heat sources, such as waste heat in cogeneration systems as well as renewable energy sources such as solar, geothermal and biomass. The search for new systems is directed to higher efficiency systems such as double effect or even triple effect systems and in the other hand the use of single stage systems that can operate at even lower firing temperatures than systems available ten years ago. A recent area of study is small capacity systems for air conditioning for small size commercial or domestic applications. Industrial

refrigeration as well as refrigeration for small size application such as ice making and food storage in less developed areas of the world are still applications that require more development.

ABSORPTION SYSTEMS

Absorption systems originally direct fired, operated with steam and hot water are now designed to operate with natural gas, biogas town gas, waste heat from industry and solar energy. Although the market is still dominated by single stage absorption chillers as the one shown in Fig.1, double effect have been produced for many years.

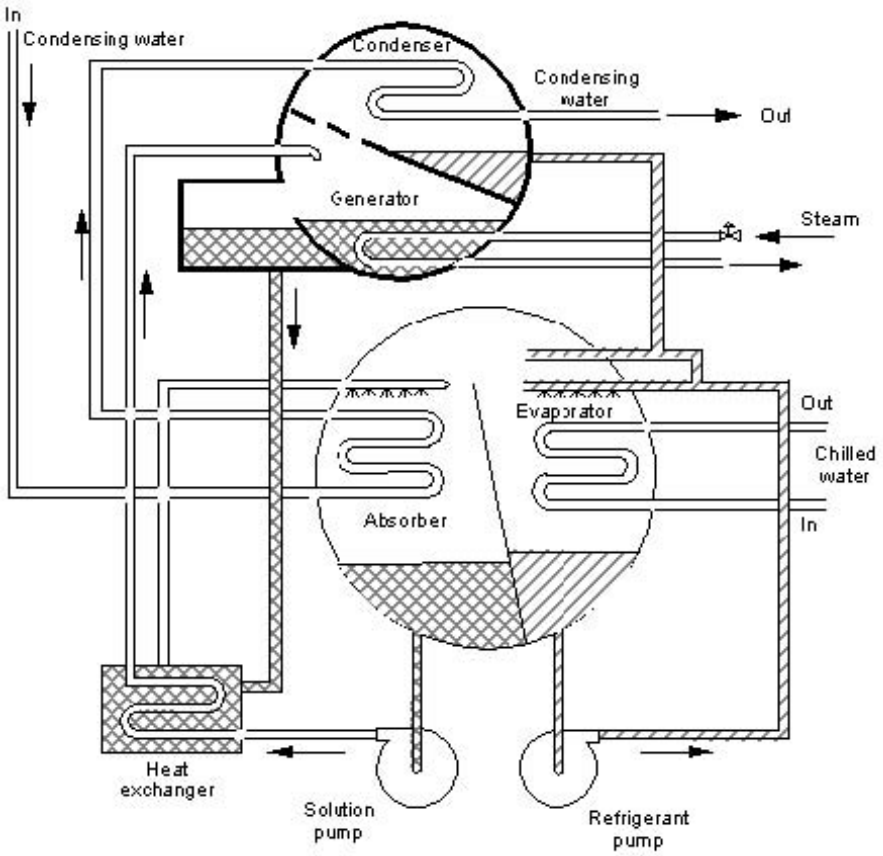

Figure 1. Schematic of single effect absorption chiller

The production of absorption chillers in the year 2005 was around 12,000 units of which China manufactured 6917 [1]. Most of the large systems produced are of the direct fired type. For cogeneration applications or for using solar or geothermal heat the hot water or steam fired units can be used directly, although specific systems have been developed and the heat in the cogeneration can be used directly. There has been a need to develop absorber chillers that operate at lower generator temperatures to operate in cogeneration and low temperature heat sources, as a result the chillers operating in the 75 to 90 °C range have to be oversized which increa ses the capital cost. Low water temperature driven LiBr-H20 chiller such as Mix Match units by York with a modified generator has been produced [2]. Double effect chillers have been adapted to waste heat sources, and some work has been done to design specific double effect chillers to this application. Reference [3] describes the development of a 563 kW double effect waste heat driven chiller that was operated with six 60 kW microturbines. A double effect 2,500 ton chiller system from Broad was installed in Austin Texas, where part of the chilled water was used to cool the turbine inlet air, as shown in Fig. 2, improving the electric efficiency [4].

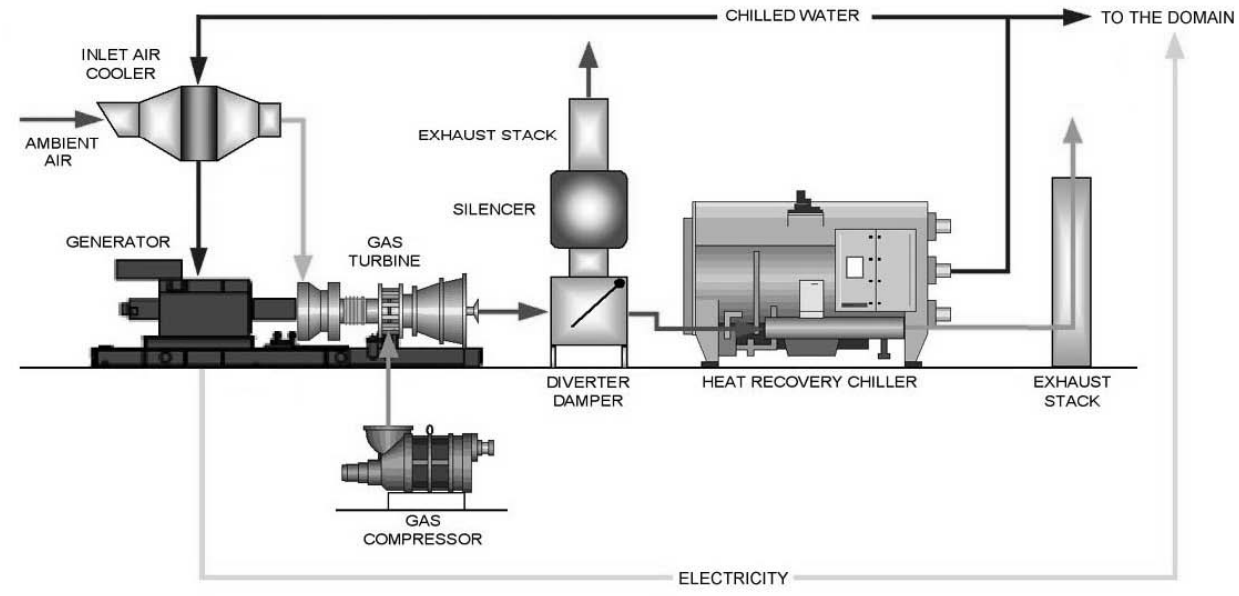

Fig. 2. Gas turbine cooling with absorption chiller [4]

Single and double stage absorption systems have been used in converting available high temperature waste heat into chilled water cooling [5]. The experience in trigeneration in México and Latin America is still very scarce. One case that is well documented is the Elcatex project in Honduras, where a trigeneration 15 MWe system was installed producing power, steam and chilled water through two York 500 ton York single stage systems [6]. With respect to triple effect systems, Japanese manufacturers are already working on a high efficiency 352 kW direct fired triple effect lithium bromidewater chiller as shown in Fig. 3, with a target COP of 1.6 and operating at the high generator temperature of 207 °C [7].

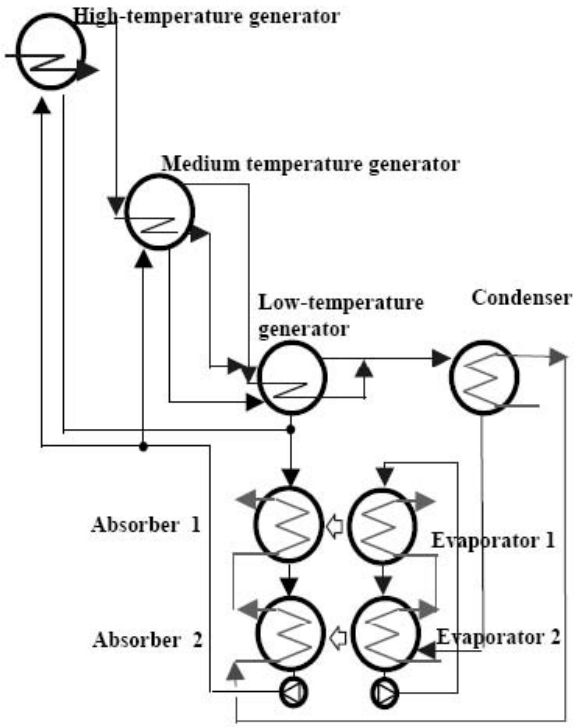

Fig. 3. Schematic diagram of a triple effect absorption system [7]

Air cooled lithium bromide-water systems. This is a long time objective, that has partially been solved with the systems such as the indirectly air cooled system such as in Rotartica, shown in Fig. 4 [8].

Fig. 4. Air-cooled Rotartica absorption cooling system [8]

F. Kakushiji et al [9] reported the development of an air cooled absorption chiller and heater employing a two stage evaporation absorption cycle and employing a ternary solution of LiBr-LiI and water to increase the solubility of the solution. The operation of a GAX ammonia-water cooling system, as shown in Fig. 5, coupled to a selected MGT has been simulated. Two configurations were analyzed as shown in Fig. 6, firstly the configuration where the exhaust gases enter directly to the generator heat exchanger. Secondly, the configuration where the hot gases exiting the MGT enter a recuperator heat exchanger to heat the thermal oil that will then enter the generator of the GAX absorption system [10].

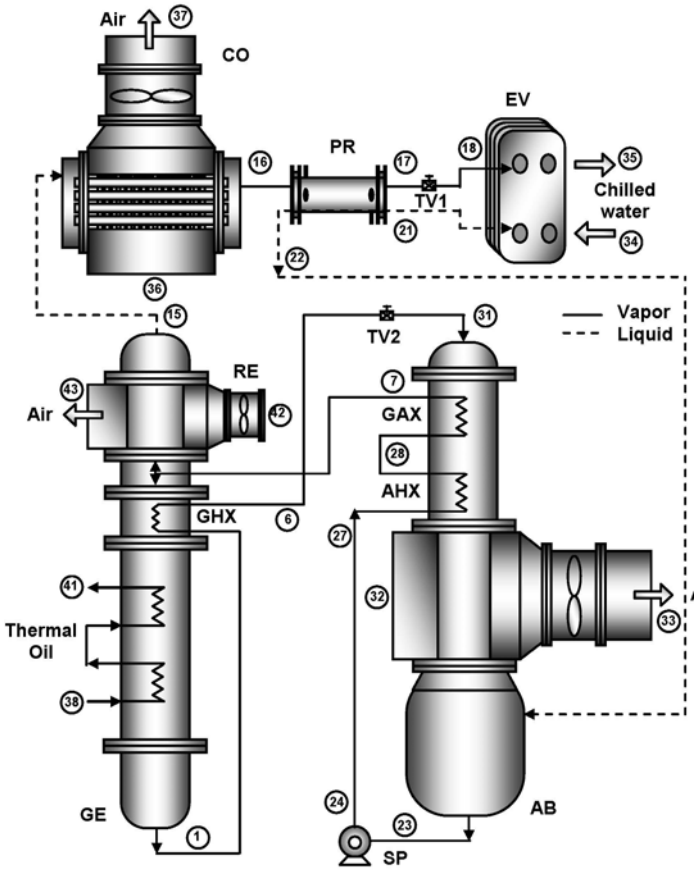

Fig. 5. Diagram of an indirect fired GAX cooling system [10]

POTENTIAL OF SOLAR COOLING TECHNOLOGIES

For solar applications a very complete work was presented by Munguier [11], where it presents the technologies being developed. In adsorption there are two well known commercial systems by Nishiyodo shown in Fig. 7 and Mayekawa with systems in the 50 to 70 kW range, new systems are now available such as Sortech with zeolite water and silica gel 10 kW systems. In absorption systems where apart from the well known Yazaki and thermal LiBr-water technology there are new products such as Sonnenklima ($LiBrH_20$), EAW ($LiBr-H_20$), Rotartica ($LiBr-H_20$), Klimatwell ($LiCl-H_20$), Pink (NH_3-H_20) all in the capacity range between 5 kW to 15 kW for ice production ammonia-water and other systems can produce ice for thermal

storage TES. More information on collaborative work on solar air conditioning and refrigeration can be found in [12, 13].

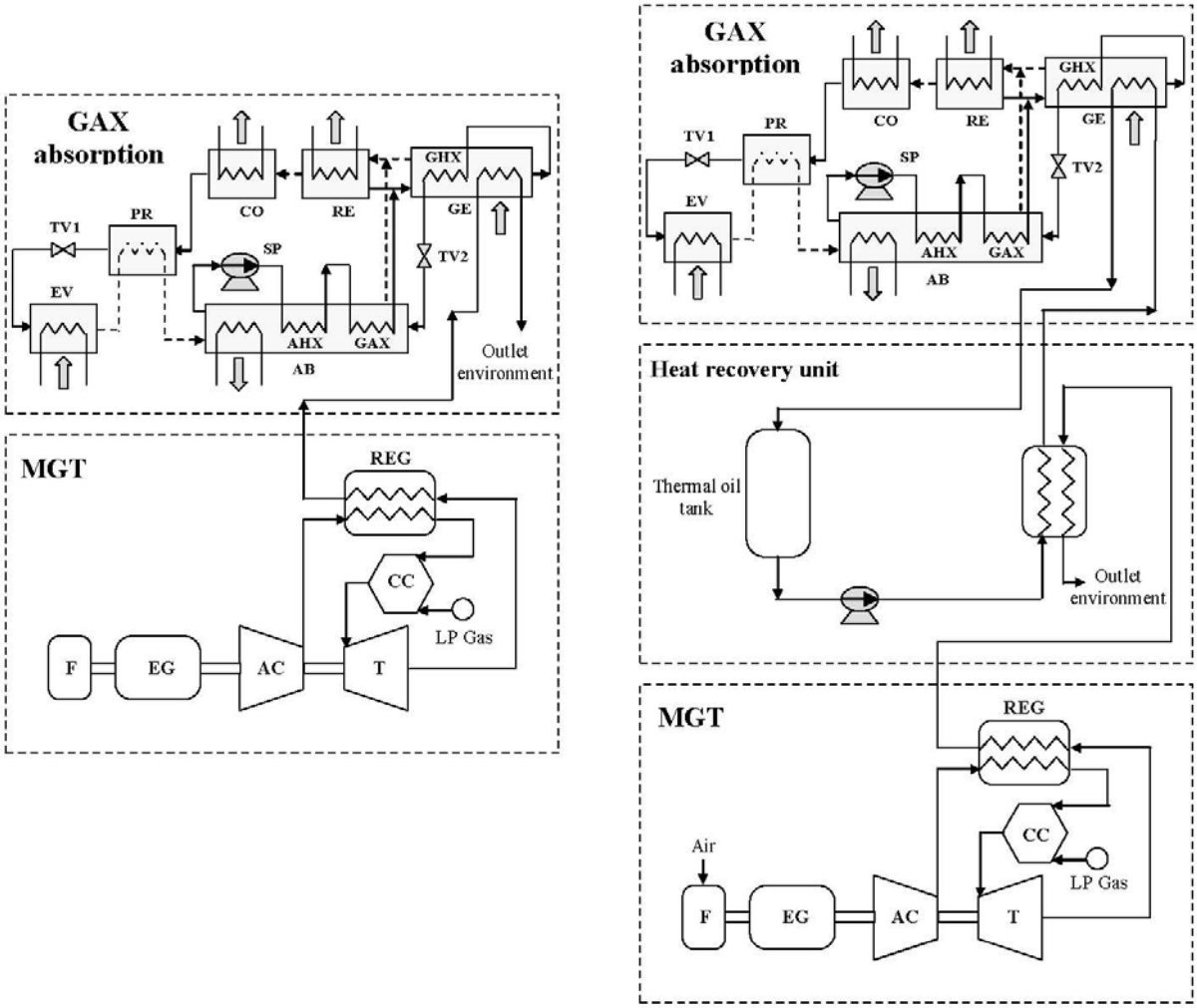

Fig. 6. Coupling of a GAX cooling system with a microturbine [10]

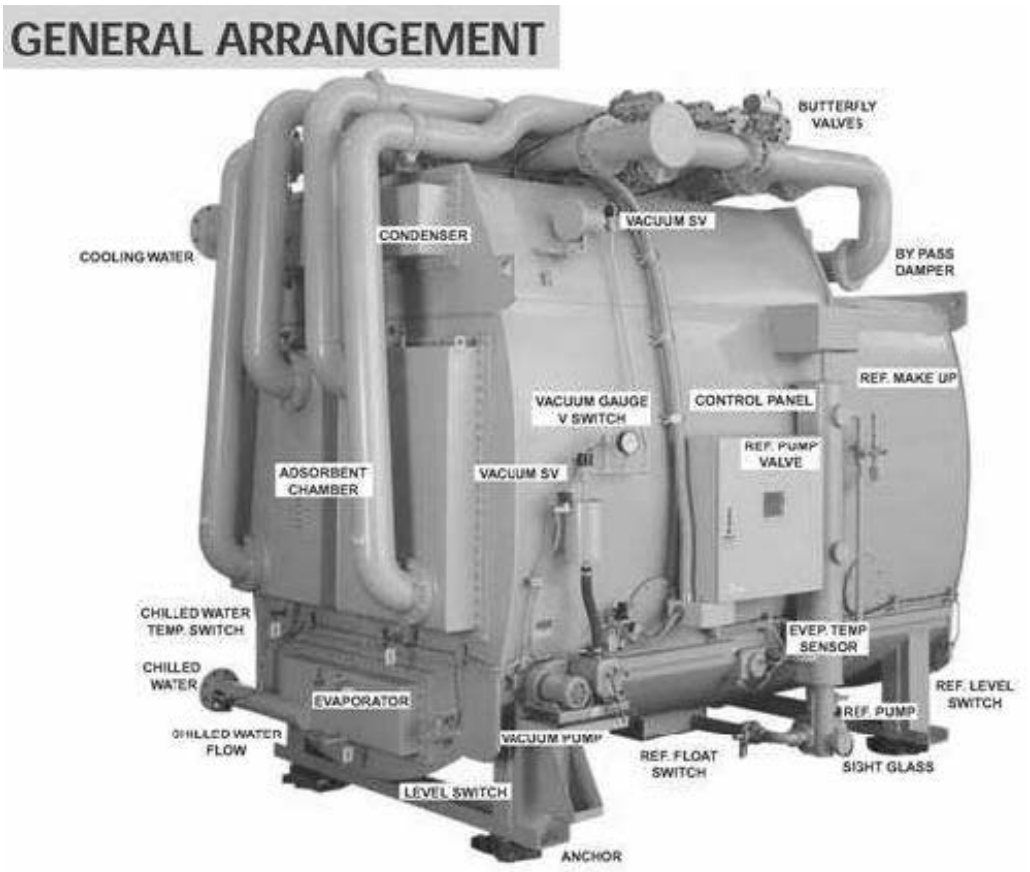

Fig. 7. Nishiyodo adsorption chiller [14]

ADSORPTION

Wang and Oliveira [14] published a very comprehensive revision of adsorption cooling and refrigeration from ice making to air conditioning. Solar adsorption ice making machines can have a production of between 4 and 7 kg of ice per m^2 of solar collector and a COP value between 0.10 and 0.15. Air conditioning can be powered by water as low as 55 °C with COP values between 0.2 and 0.6. In a recent work [15] Wang et al studied a micro-CCHP system and test facility equipped with a small LPG & natural gas engine and a new adsorption chiller. The tests conducted provided a comprehensive database of the operating parameters for the micro-CCHP system. The system can supply electricity load of 12 kW and heat load of 28 kW or cooling load of 10 kW simultaneously. Critoph et al [16] studied the coupling of

a 5 kW ammonia activated carbon adsorption cooling system to an engine´s exhaust.

DESICCANT SYSTEMS

The desiccant systems are based in the use of a rotary dehumidifier (desiccant wheel) in which air is dehumidified. The resulting air is cooled in a sensible heat exchanger and then cooled by an evaporative cooler. The resulting dry and cool air is directed into room. A heat supply is needed in order to regenerate the desiccant and low grade heat in the range 60-95 °C is required. The COP of actua l desiccant cooling systems is reported to be between 0.5 and 0.8 [17]. This is mainly due to the insufficient performance or low dehumidification effectiveness of the desiccant wheel. For this reason there are new developments as well as the proposal of two stage desiccant wheel [18, 19, 20]. Compared with a conventional one-stage desiccant wheel cooling system, the second wheel complements the first perfectly in a two stage desiccant wheel cooling system as shown in Fig. 8. Lower regeneration temperatures can be adopted compared with that of one stage system to achieve similar process air outlet state. It produces a broad application of low quality energy source such as waste heat or solar energy.

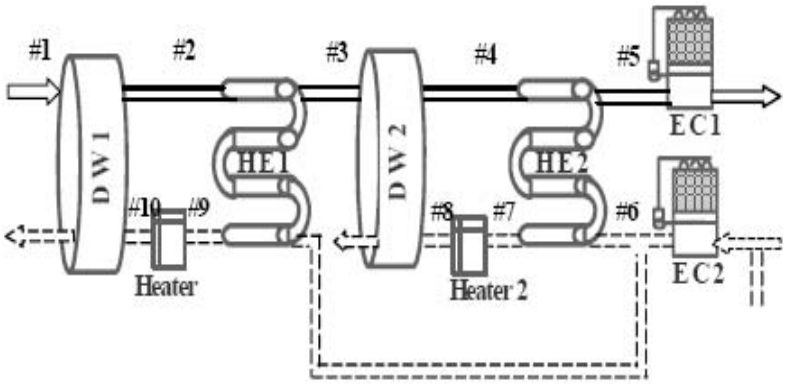

Fig. 8. Schematic diagram of a two stage desiccant cooling system [19]

EJECTORS

Vapour ejector refrigeration has become a topic of interest for research in recent years for the reasons that it is heat-operated utilizing low grade energy such as solar energy, waste heat from industrial processes; it could satisfactorily be operated at generator temperatures as low as 65 °C [21]. Figures 9 and 10 show the configuration of the ejector cooling system ECS and its corresponding thermodynamic states on a p-h diagram. The system consists of a generator, a condenser, an evaporator, an ejector, a pump as well as an expansion valve which belong to two loops. One corresponds to the power cycle, involving the primary fluid that is conformed by states 1, 3, 4 5r, 1 while the cooling cycle, comprising the secondary fluid is determined by states 2, 3, 4, 6, 2. The three pressure levels at which the system works are P_{GE}, P_{CO}, and P_{EV}, are also shown in Fig. 10.

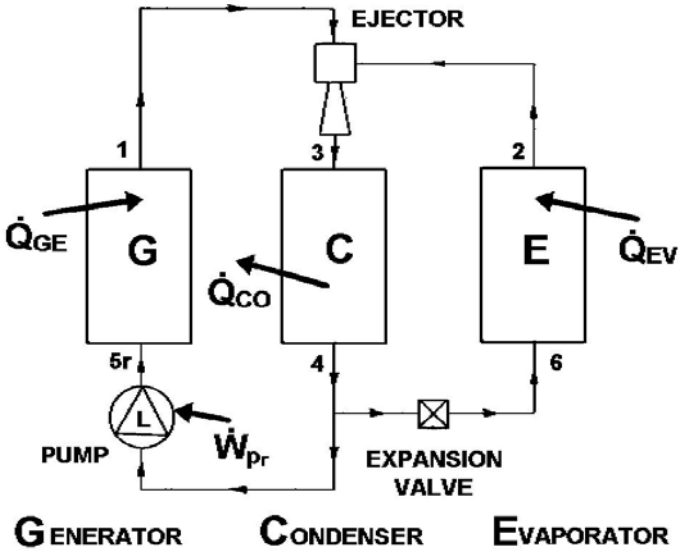

Fig. 9. Ejector cooling system

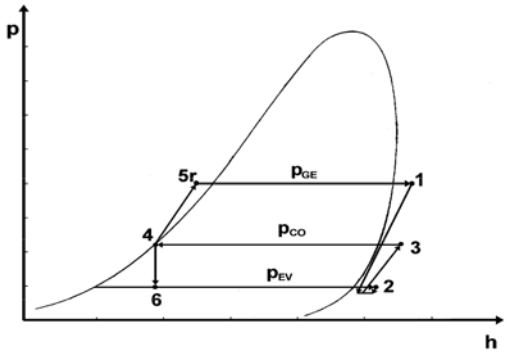

Fig.10. P-h diagram for ejector system

One interesting feature of the work carried out by Selvaraju [21] and Hernandez [22] is that refrigerant 134a has a potential for being utilised in applications for air conditioning, as it gives better performance and higher entrainment ratios (ratio of amount of secondary fluid to the primary fluid) in comparison with other refrigerants. This is important as it is commercially available in most all countries and off the shelf components could de used, such as heat exchangers, condensers and evaporators. The COP of these systems can be very interesting for applications where low evaporator temperatures are not required, such as radiant panel cooling, some applications in food processing, growing some agricultural products, cooling for fish farming. The typical COP values are in the range of 0.3 to 1.0 for a fixed condenser temperature of 30 °C evaporator temperatures between 4 and 16 °C and gen erator temperatures from 60 to 90 °C. With these values this technology could comp ete with single effect absorption and adsorption systems. The systems have to be developed to confirm these expectations.

BOOSTER ASSISTED EJECTOR REFRIGERATION SYSTEM

When there are applications where the pressure difference between the condenser and the evaporator is very high for example for refrigeration applications below 0 °C, the ejector performance is greatly reduced, so the incorporation of an

auxiliary booster has been proposed as shown in Fig. 11, that increases the efficiency [23].

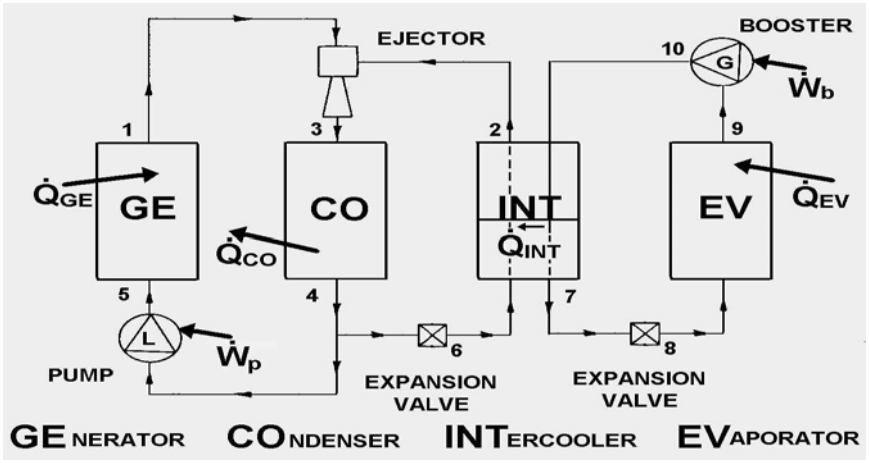

Fig. 11. Schematic diagram of a booster assisted ejector [22]

Recently a study has been presented for an ice production unit of a 2 kW system [24]. The system is design to operate powered with solar energy, producing 100 kg of ice in 6 h at a temperature of -10 °C, operates at generatio n temperature lower than 90 °C and employs refrigerant R134a. The study includes the criterion to select a design point, the methodology that determines the system behavioural maps and the criterion of system operation.

CONCLUSIONS

A review of solar thermal technologies was presented. New systems are being developed in order to use lower heat source temperatures or higher heat source temperatures with improved efficiencies for cogeneration purposes. The possibility of using ejectors with low temperature sources was also analysed.

ACKNOWLEDGEMENTS

The author would like to thank Mrs. Naghelli Ortega for helping in the edition of the manuscript. Part of the work carried out was carried with support from CONACYT project 44764-Y.

REFERENCES

1. G. Chen, Y. He, The latest progress of absorption refrigeration in China. Proceedings of the International Congress of Refrigeration, IIR Conference in Beijing, China, paper No. ICR07-174 (2007).
2. M. Oskam Roux, Design engineer absorption chillers, building efficiency, Johnson Controls, Durango, México. Personal Communication.
3. T. Wagner, S. Jung, M. Marler. Development of a waste-heat driven double effect absorption chiller, Proceedings of the International Sorption Heat Pump Conference, Denver, CO, paper No. ISHPC-100-2005 (2005).
4. J.B. Berry, R. Schwass, J. Teigen, R. Fiskum, K. Rhodes, Advanced absorption chiller converts turbine exhaust to air conditioning. Proceedings of the International Sorption Heat Pump Conference, Denver, CO, paper No. ISHPC-095-2005 (2005).
5. M. Meckler, L.B. Hyman, K. Landis, Designing sustainable on-site CHP Systems, ASHRAE TRANSACTIONS; paper No. DA-07-009 (2007).
6. J. Benitez, C.H. García, Aumento de competitividad de la industria centroamericana por implantación de sistemas de cogeneración de alta eficiencia, Proyecto ELCATEX
   - Honduras, www.enint.com.

7. H. Yabase, K. Kawabata, F. Yakushiji, T. Takigawa, Development of triple effect absorption chiller-heater, Proceedings of the International Sorption Heat Pump Conference, Denver, CO, paper No. ISHPC-048-2005 (2005).
8. Rotartica, www.rotartica.com.
9. F. Yakushiji, K. Kawabata, M. Kawai, N. Okuda, K. Tanimoto, Development of an aircooled absorption chiller heater employing two-stage evaporation/absorption cycle, Proceedings of the International Sorption Heat Pump Conference, Denver, CO, paper No. ISHPC-015-2005 (2005).
10. V.H. Gómez, A. Vidal, R. Best, O. García-Valladares, N. Velásquez, Theoretical and experimental evaluation of an indirect-fired GAX cycle cooling system, Applied Thermal Engineering (2007), doi:10.1016/j.applthermaleng.2007.06.027.
11. D. Munguier, Thermally driven water chillers-market status and new developments, Workshop Journée thématique SFT-IBSA Froid solaire et confort d´eté, Aix-les Bains (2007).
12. http://www.iea-shc.org/task38/index.html
13. H.M. Henning, (Ed). Solar assisted air-conditioning in buildings. A handbook for planners, Springer-Verlag/Wien (2004).
14. R.Z. Wang, R.G. Oliveira, Adsorption refrigeration-an efficient way to make good use of waste heat and solar energy, Proceedings of the International Sorption Heat Pump Conference, Denver, CO, USA, paper No. ISHPC-101K-2005 (2005).
15. R.Z. Wang, X.Q. Kong, J.Y. Wu, Y. Huangfu, D.W. Wu, Performance research of a micro CCHP system with adsorption chiller, Proceedings

of the International Sorption Heat Pump Conference, Denver, CO, paper no. ISHPC-044-2005 (2005).

16. R.E. Critoph, Z. Tamainot-Telto, Efficiency V. Cooling power in a modular carbon ammonia adsorption chiller: simulation and validation, Proceedings of the International Sorption Heat Pump Conference, Denver, CO, paper No. ISHPC-0542005 (2005).

17. N. Subramanyan, M.P. Maiya, S. Srinivasa Murthy, Application of desiccant wheel to control humidity in air-conditioning systems, Applied Thermal Engineering, (24), 2777-2788 (2004).

18. M. Motta, H. M. Henning, A novel high efficient sorption system for air dehumidification (ECOS), Proceedings of the International Sorption Heat Pump Conference, Denver, CO, paper No. ISHPC-038-2005 (2005).

19. T.S. Ge, Y. Li, R.Z. Wang, Y.J. Dai, Experimental study on a novel two-stage desiccant cooling systems, Proceedings of the International Congress of Refrigeration, Beijing, China, paper No. ICR07-E1-826 (2007).

20. Y. Dai, T.S. Ge, Y. Li, R.Z. Wang, Development of novel two-stage desiccant cooling system using composite silica gel material, Proceedings of the International Congress of Refrigeration, Beijing, China, paper No. ICR07-E1-1506 (2007).

21. A. Selvaraju, A. Mani, Analysis of an ejector with environment friendly refrigerants, Applied Thermal Engineering (24), 827-838 (2004).

22. J.I., Hernández, R.J. Dorantes, R. Best, C.A. Estrada, The behaviour of a hybrid compressor and ejector refrigeration system with refrigerants 134a and 142b, Applied Thermal Engineering (24), 1765-1783 (2004).

23. M. Sokolov, D. Hershgal, Enhanced ejector refrigeration cycles powered by low grade heat -Part 1: System characterisation, International Journal of Refrigeration (13), 351-356 (1990).

24. J. Hernández, R. Best, R.J. Dorantes, C.A. Estrada, Study of a solar booster assisted ejector refrigeration system with 134a, Journal of Solar Energy Engineering (127), 53-59 (2005).