

Presentation of a Novel Solar Air Conditioning System Using a Hybrid Ejector/Exchanger Unit

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ABSTRACT: A novel solar air conditioning system under development in the framework of a research project is presented. It uses high efficiency evacuated tube solar collectors and an ejector cooling cycle. The ejector has the feature of combining motive and heat exchanger functions, as it also acts as the cycle evaporator and condenser. The system will also have a heat storage unit using a microencapsulated phase change material. A prototype will be assembled for testing and demonstration.

Keywords: solar air conditioning, ejector, evacuated tubes, system prototype.

1. INTRODUCTION

Solar cooling systems are increasingly used due to increasing needs for cooling and due to the fact that cooling demands in Summer are associated with high solar energy availability, which allows operation with maximum solar collector efficiencies. In recent years, small capacity thermally-driven cooling machines (starting at about 5 kW cooling capacity) have entered the market, specially using absorption cooling technology.

Among different available solar cooling technologies, [1], ejector cycles present an interesting option, as they are simple and reliable. At the heart of the ejector (or jet) cooling cycle is the ejector, that replaces the compressor of the vapour compression system. A typical ejector is shown in Fig.1. There are 2 inlets, the main one for vapour flow at high pressure and velocity and the

secondary one for refrigerant from the evaporator. The vapour is accelerated through a nozzle (to a Mach number above 2) creating a low pressure in the mixing chamber that drives refrigerant vapour from the evaporator (by Venturi effect). The mixture is then fed to the condenser – see Fig.2 for a typical cycle. Different refrigerants, both natural and organic, can be used in an ejector cooling cycle. This system is adequate for air conditioning applications – see examples in [2, 3]. Ejector cooling COP is usually between 0.3 and 0.6, for a driving temperature of 80 to 150°C. The cost of the cooling system itself is rather low, as the ejector is simple to manufacture. However, the temperature level requires the use of high efficiency solar collectors, such as evacuated tube types. The system is very reliable, as there are no moving parts and no special maintenance is required.

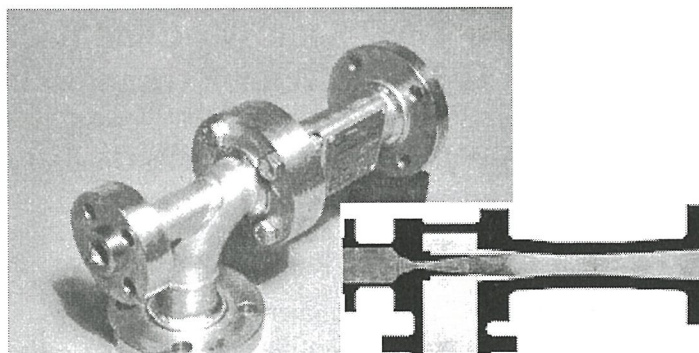


Figure 1: View and cross-section of an ejector.

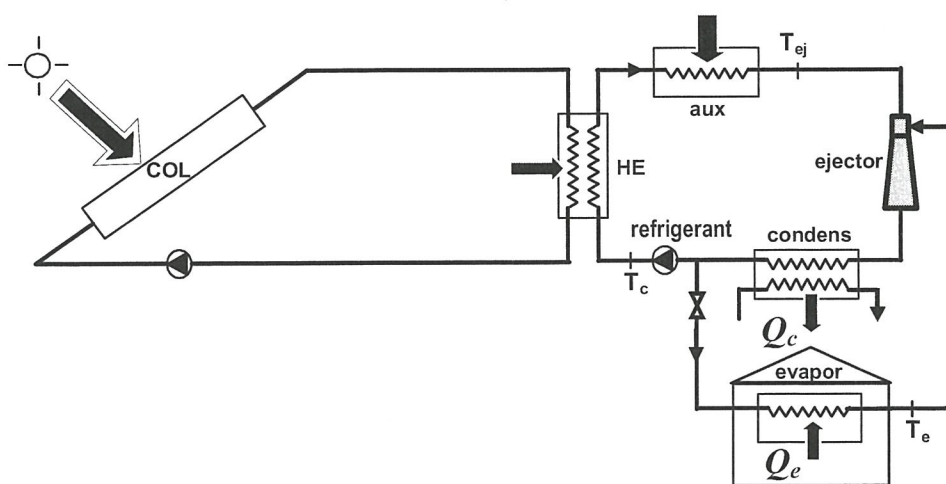


Figure 2: Representation of a solar air conditioning ejector system.

In the framework of a new research project – Mediterranean-Aircon, partially funded by the European Commission – a novel ejector air conditioning system is being developed. Its main features and project objectives are described here.

2. DESCRIPTION OF THE SYSTEM

The project aims to develop an advanced solar-driven air conditioning system specially suited for hot climates. The system will be driven by solar energy and comprises modular evacuated solar tubes

coupled with an ejector-exchanger device, a cold storage booster and an air-handling unit.

The solar collector tubes will provide high-energy output and consistently high performance over the whole lifespan of the system. The tubes are suitable for applications where aesthetics as well as efficiency are important, and due to their modular nature, they are simple to install and allow for scale-up of system size.

Different types of evacuated tubes, with and without circular reflecting surface (see Figs.3 and 4) will be assessed for use in a

Mediterranean climate. In both cases, the outer tube is made of transparent borosilicate glass, which is able to resist impact and has excellent solar transmittance properties. The circular shape of the evacuated-tubes provides a superior absorption surface compared to flat plate collectors, and because the tube is

cylindrical, the sun's rays always strike the surface at right angles, thus minimizing reflection losses. The high-vacuum insulation of the collector tube, the key to its excellent efficiency, will be permanently maintained at less than 10⁻³ mbar with a getter.

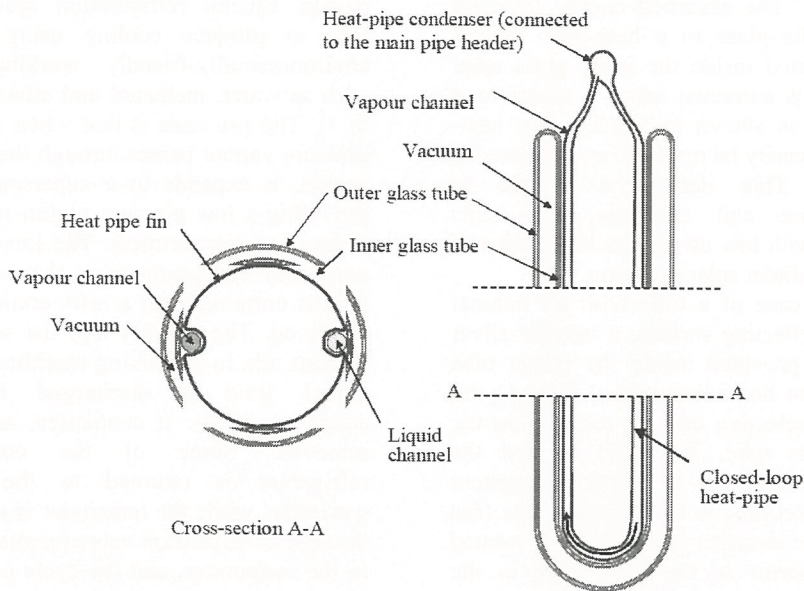


Figure 3: Schematic representation of a glass-glass evacuated-tube solar collector using a closed-loop heat pipe.

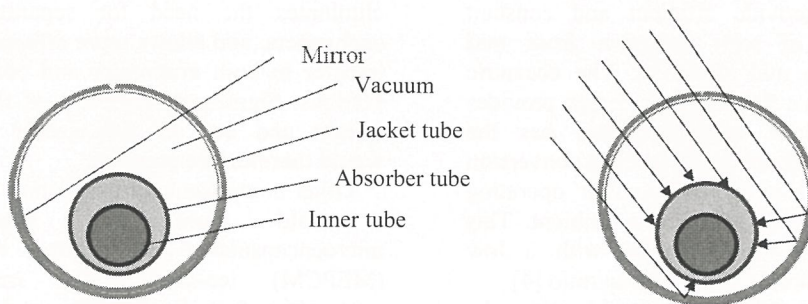


Figure 4: Schematic representation of a glass-glass evacuated-tube solar collector using an internal circular reflector with eccentric flow-through glass-tube.

In the case of a tube without an internal reflecting surface, a highly selective coating is directly applied onto the outer surface of the inner tube to provide the absorber. The two ends of the tubes are fused and therefore the absorbing surface is hermetically sealed between the two glass tubes. This provides permanent protection to the absorber surface from environmental influences. The absorbed energy transfers through the glass to a heat-pipe finned-plate inserted inside the inner glass tube. The heat is extracted using a closed-loop heat-pipe as shown in Fig.3. The heat-pipes can easily be removed and replaced if required. This design is simple to manufacture and assemble, and suits climates with low as well as high ratios of diffuse to direct solar radiation.

In the case of a tube with an internal circular reflecting surface, a circular silver mirror is provided inside the jacket tube (transparent borosilicate tube) by applying a highly selective coating directly on the inner glass tube. This will redirect the sunlight falling onto the sectional segment of the jacket tube to the absorber tube (see Fig.4). The absorber and mirror are located in the interior of the glass tube in the vacuum and therefore are permanently and completely protected from weather effects. The absorber tube is sealed off at one end and fused eccentrically with the envelope tube at the other open end. The tubes therefore provide efficient and constant collection of solar radiation from mid morning to mid afternoon. The eccentric tubing with a flow-through design provides optimum heat extraction, and has the ability to maintain solar thermal conversion efficiency above 60% even at operating temperatures 100 °C above ambient. This design best suits climates with a low diffuse to direct solar radiation ratio [4].

Other technologies could also be assessed and tested. Solar collectors for field evaluation will be selected depending on performance, robustness and cost. The units will be suitable for small to large-

scale installations for heating or solar air conditioning using a variety of heat-operated cooling devices, such as ejectors or absorption chillers.

The evacuated tubes are intended for installation on the roof of buildings to collect solar energy. The heat extracted from the tubes will be used to produce vapour to drive an ejector refrigeration device. Ejector refrigeration systems are able to produce cooling using natural, environmentally-friendly working fluids such as water, methanol and ethanol [2, 5, 6, 7]. The principle is that when the high-pressure vapour passes through the primary nozzle, it expands to a supersonic flow, providing a low pressure region inside the evaporator compartment. The low-pressure secondary refrigerant from the evaporator is thus entrained and a refrigeration effect produced. The primary and the secondary streams mix in the mixing chamber, and the mixed fluid is discharged into the condenser where it condenses, as heat is removed. Some of the condensing refrigerant is returned to the vapour generator, while the remainder is expanded through an expansion valve (capillary tube) to the evaporator, and the cycle continues. The proposed system uses a new, compact ejector configuration, which incorporates all the ejector components in a single "shell-and-tube-like" heat exchanger unit (Fig.5). The proposed ejector device eliminates the need for separate heat exchangers, and allows more effective heat transfer in both evaporator and condenser sections. Significant reduction of the size, weight and cost of the ejector system would therefore be possible.

Other components of the system include a cold store unit employing microencapsulated phase change material (MEPCM) ice-slurries for improved continuity of cooling supply, and an air handling unit which could be integrated into the building air-conditioning system. MEPCM ice-slurries have the advantage that these could be used for heat transport

and storage simultaneously. While undergoing a phase change, i.e., from solid to liquid and vice versa, a MEPCM material absorbs or releases a large amount of heat with a small change in temperature. Phase change materials (PCMs) have two important advantages as storage media, namely they can offer an order-of-magnitude increase in heat capacity and for pure substances their energy discharge is almost isothermal. The use of ice as a phase change material is a popular method and this includes the use of ice balls, ice harvesting, ice-on-coil and ice slurries. An ice slurry is a mixture of water (in the form of ice and liquid water) and a glycol. The percentage of glycol determines the freezing point of the mixture (adding glycol depresses the freezing point) allowing the ice slurry to be used at various temperatures, e.g., for air conditioning or deep-freezing. Slurry ice in the form of a crystallised, water-based ice solution (slush) can be pumped as a secondary cooling medium directly into air handling units or stored for load shifting. The slurry flows like conventional chilled water whilst

providing 5-6 times the cooling capacity. The high energy content of the slurry allows significant reductions to be made in the size of pipes, pumps and storage tanks, and reduces pumping, air handling, and chilling costs compared with conventional chilled water systems.

3. RESEARCH WORK FORESEEN

Besides the specific development of individual components referred in the previous section, other project tasks include construction and experimental evaluation of a prototype system under real operating conditions (real building in a Mediterranean climate). The prototype system will have a cooling capacity of 5 kW. Comprehensive system monitoring will be carried out over a period of one year. Data will include temperature in the building, working fluid temperatures, vacuum level in the collector tubes, weather data, and cooling and thermal energy fluxes. An effective energy management and control strategy will also be developed.

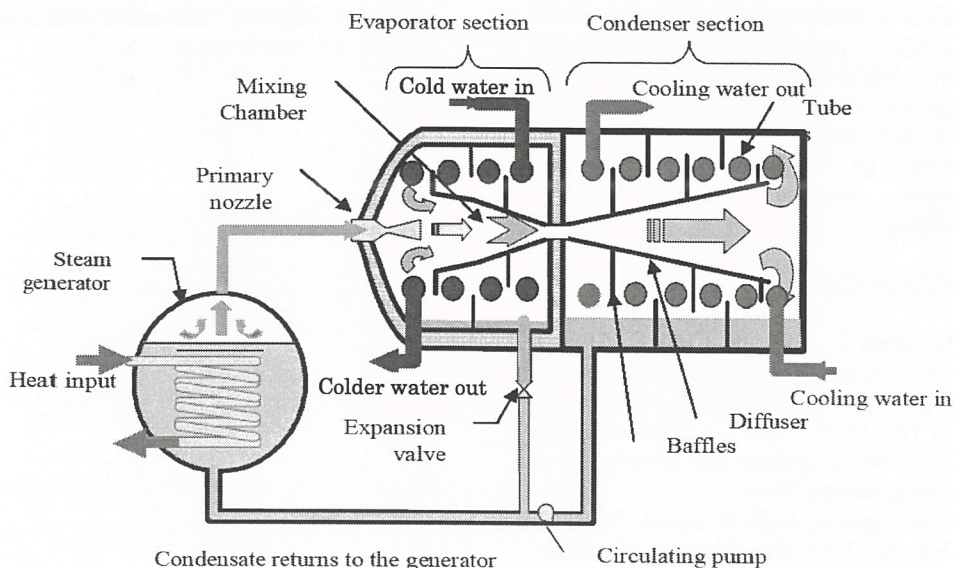


Figure 5: Schematic representation of compact hybrid ejector/heat exchanger unit and cycle.

The prototype will be used as a demonstrator of the novel technology.

Commercialisation of the system will follow, involving interested partners and manufacturers of HVAC equipment.

4. CONCLUSION

A novel solar air conditioning system using a compact and hybrid ejector/heat exchanger unit was presented. The system has the potential to have a low initial cost, as well as a low operating cost, contributing to the reduction of harmful emissions to the environment, when compared with electrically-driven air conditioning systems. The system shall be developed during the following months, and a 5 kW (cooling) prototype will be installed by 2009, in order to demonstrate its efficiency and feasibility.

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