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SOLAR ENERGY FOR REFRIGERATION AND AIR CONDITIONING

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ABSTRACT

Solar refrigeration may have applications in both developed and developing countries. Applications in developing countries such as vaccine storage or large scale food preservation have been the subject of much research. In developed countries the main area of interest is air conditioning. Previous work on photo-voltaic and solar thermal systems is reviewed. Research at Warwick is underway on carbon - ammonia refrigerators driven by the heat of steam condensing in a thermosyphon heat pipe. The heat source can be solar energy, biomass, or some combination of the two. A new area of interest is the use of desiccant wheel technology for solar powered air conditioning. The basic principles are described and pastexperience assessed.

KEY WORDS: Refrigeration, Solar, Biomass, Carbon, Ammonia, Adsorption, Heat Transfer

There are several important reasons for considering solar energy as an energy resource to meet the needs of developing countries. First, most ofthe countries called developing are in or adjacent to the tropics and have good solar radiation available. Secondly, energy is a critical need of these countries but they do not have widely distributed readily available supplies of conventional energy resources. Thirdly, most of the developing countries are characterised by arid climates, dispersed and inaccessible populations and a lack of investment capital and are thus faced with practically insuperable obstacles to the provision of energy by conventional means, for example, by electrification. In contrast to this solar energy is readily available and is already distributed to the potential users, fourthly, because of the diffuse nature of solar energy the developments all over the world have been in smaller units which fits well into the pattern of rural economics [Bansal. N.K(1997)].Objectives of the Study. The present study is part of a project in solar energy utilization in AIT, aimed at the development of one or more prototype units demonstrating the usefulness and economic viability of solar energy for the designed purposes, The specific objective of the argument in this chapter is to identify an area of solar energy utilization useful to the developing countries of Asia, and further, to select: a suitable device for development and for a preliminary investigation [Critoph, R.E(1996)].

POSSIBILITIES FOR RESEARCH AND DEVELOPMENT

Solar energy research seems to have gathered momentum during the last two decades. Over this period there have been many publications, seminars and conferences dealing with solar energy. One of the most up to date and comprehensive surveys of solar energy applications is a report by an ad-hoc advisory panel of the Board on Science and Technology for International Development entitled 'Solar Energy for Developing Countries: Perspectives and Prospects', NATIONAL ACADEMY OF SCIENCES (1972). The conclusions of this report supersede those of earlier such serves and are summarised below.

The panel observes that solar evaporation has been a historical, traditional method of obtaining salt from sea water or brines; it remains important today on both a small and a large scale in many countries. The reappears to be little research that cannot as well be done by the industries using this process. Water heating technology is well established and the needed development is largely to adapt the technology to use materials and manufacturing capabilities of the country in question. Hot water for hospitals, schools another such institutions and families could become much more widely available with these developments [Henning.H.M (1995)]. The nature of the equipment is such that it can be manufactured in developing countries, and adapting it to their conditions seems to be straightforward. Solar distillation must still be regarded as experimental but small scale community stills are near to extensive commercial applications. Designs are now available for solar stills that are serviceable and can be used with a reasonable degree of confidence. Further research in this application would involve adaptation of existing technology to the specific needs of developing countries through design modifications to allow the use of locally available materials and locally manufactured components. A traditional and widespread use of solar energy test for drying, particularly, of agricultural products. The design and

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control of tiles for particular crops or other materials to be dried are areas of research that could lead to more practical applications in developing countries which could result in improved utilization of food supplies.

Research and development in solar heating have been aimed almost entirely at applications in the temperate climates of industrialised countries. The panel knows little of the real extent of needs for space heating in developing countries, or of the possible role of solar energy in meeting these needs. Studies in air conditioning aimed primarily at United States and Australian applications are still in early stages. Technological feasibility appears to be assured; economic feasibility is now under study. The best methods of obtaining cooling with solar energy in developing countries are far from clear at this time and the immediacy and extent of needs for airconditioning are not known. There are many refrigeration cycles and systems that can be considered for solar refrigeration. It has yet to be established what may be the best scale on which to operate solar refrigerators in developing countries. There are a substantial number of open questions regarding refrigeration, and the application has the attractive possibility of better utilization of available foodstuffs if refrigeration could be successfully provided,

APPLICATIONS IN DEVELOPING COUNTRIES

There is a demand for cooling in many parts of the world where there is no firm electricity supply and conventional fuels are difficult or expensive to obtain. Requirements tend to be either for medical uses where a high capital cost per kW of cooling is acceptable, or for food (especially fish) preservation where the cooling power required is muc

lower. Vaccine storage refrigerators have been sold at a cost of £60-170 /W cooling [Critoph, R.E(1990)], the lower cost being for a solar thermal system sold by the French Company BLM and the larger for a typical photovoltaic system. These high costs are considered acceptable since the application is related to medical provision. [Harvey(1990)] has shown that in the case of a fish storage ice-maker for Zambia, the required capital cost was £8.5/W and he concluded that a 1 tonne ice/day solar thermal refrigerator could be built to this price. There is little possibility that the higher costs per watt of the smaller units could be justified in larger plant.

POSSIBLE REFRIGERATION CYCLES

There are five classes of cycle that can be used for renewable powered refrigeration systems. (Desiccant wheel technology for air conditioning is dealt with later)

- A standard mechanical vapour compression cycle, requiring an electrical input to a hermetically sealed compressor. The electricity is generated by photovoltaic panels. This has the advantage of using of the-shelf technology, but the disadvantages of high cost and the probable need for an electricity storage sub-system.

- **Intermittent adsorption cycles.**

Adsorption refrigeration cycles rely on the adsorption of a refrigerant gas into an adsorbent at low pressure and subsequent desorption by heating. The adsorbent acts as a ‘chemical compressor’ driven by heat. In its simplest form an adsorption refrigerator consists of two linked vessels, one of which.

contains adsorbent and both of which contain refrigerant as shown in Fig. 1 below.

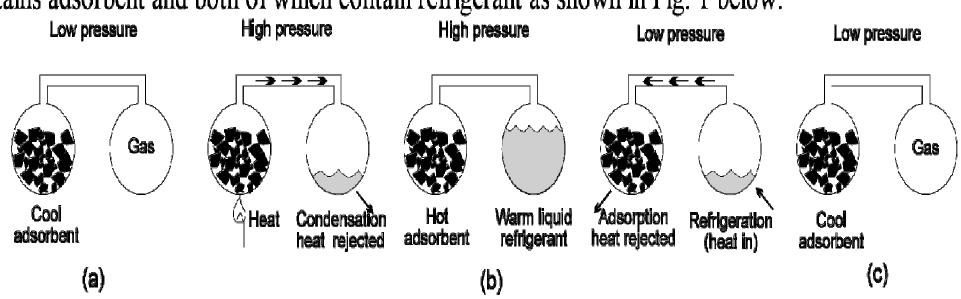


Figure 4.1: Vessels contains refrigerant gases

Initially the whole assembly is at low pressure and temperature, the adsorbent contains a large concentration of refrigerant within it and the other vessel contains refrigerant gas (a). The adsorbent vessel (generator) is then heated, driving out the refrigerant and raising the system pressure. The desorbed refrigerant condenses as a liquid in the second vessel, rejecting heat (b). Finally the generator is cooled back to ambient temperature, re-adsorbing the refrigerant and reducing the pressure. Because the liquid in the second vessel is depressurised and boils, it takes in heat and produces the required refrigeration effect. The cycle is discontinuous since useful cooling only occurs for one half of the cycle. Two such systems can be operated out of phase to provide continuous cooling. Such an arrangement has a comparatively low Coefficient of Performance (COP = Cooling / Heat Input). Also, the thermal conductivity of the bed is generally poor so the time taken for a cycle could be an hour or more and the cooling power per mass of adsorbent could be as low as 10 W/kg. This is not a problem with solar powered vaccine refrigerators which produce a few kg of ice each day and operate on a diurnal cycle [Critoph, R.E(1994)].

However, a refrigerator producing one tonne of ice in a diurnal cycle would need 5 tonnes of carbon and contain 1.5 tonnes of ammonia. When contemplating larger icemakers it is obviously necessary to use a much faster acting cycle in order to reduce the mass of adsorbent and the cost of the system. Two beds, similar to the one shown above, can be heated and cooled out of phase to provide continuous cooling Good heat transfer is required to reduce the cycle time to a few minutes and thereby increase the power density of the adsorbent to the order of 1 kW/kg. We can also achieve a higher COP by maximising the quantity of heat regenerated. The heat rejected by one bed when adsorbing can provide a large part of the heat required for desorbing in other bed. This also requires good heat transfer.

- Intermittent absorption cycles are thermodynamically identical to adsorption systems but use liquid absorbents rather than solid adsorbents. Typically the pair used is ammonia-water, but ammonia-NaSCN, methanol-LiBr and other pairs have been used experimentally.
- A continuous absorption cycle with an electrically driven feed pump eliminates the problems of bulk, but if electricity is available to drive a solution feed pump then it could be argued that it would be better to use a conventional vapour compression cycle. The use of a small amount of photovoltaic electricity to drive a feed pump might be justified.
- The Platen-Munters diffusion absorption cycle is continuous and does not use a mechanical pump. It is used successfully in small gas or kerosene refrigerators and freezers but has proved difficult to adapt to larger sizes and to irregular heat sources such as solar energy.

Experimental Rig

The layout of the experimental rig is shown in Fig. 4.1.1 the main components are the generator, the boiler, the condensers (two) and the receiver-evaporator.

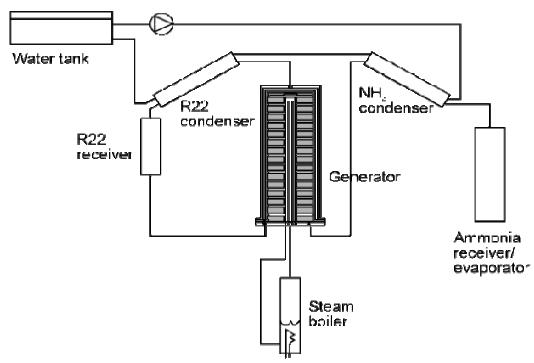


Figure 4.1.1: Schematic of heat transfer test rig

The generator (Fig. 4.1.2) is made of aluminium and contains three enclosed cylindrical volumes. It is formed by a hollowed inner shell (outside diameter of 25 mm with a thickness of 6 mm) and two outer vessels. The outside surface of the inner shell has fins between which are placed 15 monolithic carbon discs. The fins are approximately 5 mm thick, 32 mm long, 18 mm apart and 90 mm in diameter. They have slots to allow the distribution of ammonia between all the carbon discs in the generator. Each disc is cut radially in two equal parts before being inserting between two fins. The total mass of carbon is about 800 g. During the operating cycle, each of the three volumes contains a different working fluid. These fluids are steam, ammonia and R22 respectively. In the heating phase the carbon is heated by steam supplied to the centre hollow, whilst in the cooling phase the carbon is cooled by boiling refrigerant R22 in the outer shell.

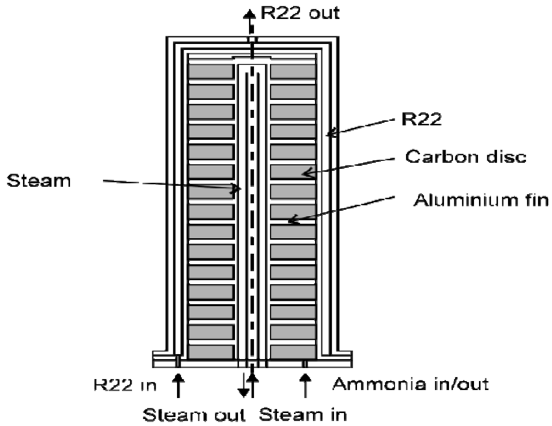


Figure 4.1.2: Cross section through generator

The steam boiler is made out of copper tube. An electrical heating coil, which is inserted at the base the boiler, can produce steam ranging from 100º C to 150º C. The steam circuit has a pressure gauge and a pressure release valve to relieve any excess pressure. The heating power is controlled by a variable supply unit and its maximum value is 2 kW.

The ammonia condenser is a concentric tube counter-flow type. The water (coolant) flows in the annulus of the condenser whilst ammonia condenses in the tube part. The outer tube is made out of copper whilst stainless steel is used for the inner tube which contains the ammonia.

The R22 condenser, used when cooling the generator is of similar type but both tubes are copper with R22 condensing in the inner tube. For convenience and to limit the water used, the two condensers (ammonia and R22) use the same network of cooling water. The cooling water is stored in a tank that is temperature controlled by means of an immersion heater with a thermostat. A small pump is used to circulate the water.

The receiver - evaporator made out of stainless steel is a vessel of 300ml capacity. It collects the condensed refrigerant at up to 20 bar (50º C). A capacity probe is fitted to measure the amount of ammonia liquid collected. After the heating phase the receiver is inserted inside an ice bucket that contains water and that is well insulated. The ammonia cools and freezes water as it evaporates during the cooling phase of the system.

The temperature-time profile at a point within the bodies measured by stainless sheathed K-type thermocouple with a diameter of 1 mm. The steam and ice temperature profiles are measured with three thermocouples of the same type. Two pressure transducers are used to measure the ammonia pressure profiles respectively inside the bed and the receiver.

EXPERIMENTAL RESULTS

Experiments have been carried out in which the generator has been heated by steam condensing at 120º C and a heating time of 10 minutes. The experimental results are compared with a numerical simulation in Fig. 4. These tests correspond to cycles having a comparatively low COP of 0.10 because the carbon temperature is only raised to 110ºC. Later experiments will heat the carbon to 130º C, with expected COP's nearer to 0.3. The heat input to the carbon averaged 300 W/kg, but this could be increased by a factor of at least two if higher temperature steam were used. The carbon disc dimensions were not optimised for this application and so whilst the experiment has confirmed our heat transfer modelling assumptions it was not expected to reach much higher power densities.

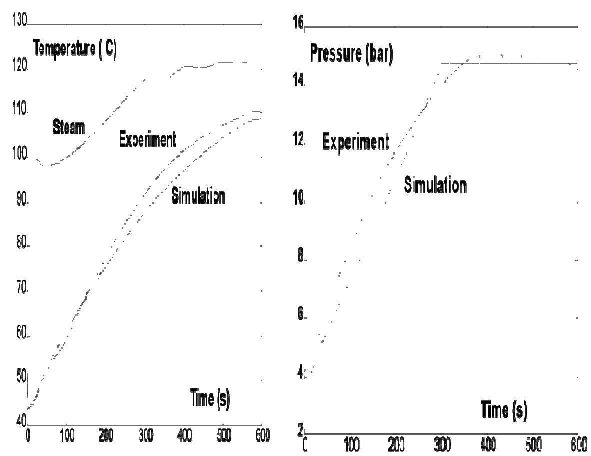


Figure 4.2.1: Experimental and simulated generator conditions

CURRENT DEVELOPMENTS

We have concluded that the best way to exploit the potential of the material is to experiment with the possibility of forming the carbon blocks integrally with the heat transfer surface or fin. In granular beds the gas space between the metal surface and adjoining grains has a high thermal resistance. Since grain packing near a wall is less dense than within the bed the effective bed conductivity is reduced near the wall. This is normally modelled by assuming a low heat transfer coefficient (or high thermal resistance) between wall and bed. The use of a monolithic block of carbon reduces the thickness of the gas space, but its thermal resistance still limits the heat transfer. If the monolith is actually formed around the heat transfer surface, the contact resistance between carbon and metal should become negligible. If consolidation of the bed around fins or tubes proves to be not feasible or uneconomic there are alternatives that will still reduce the gas space resistance significantly.

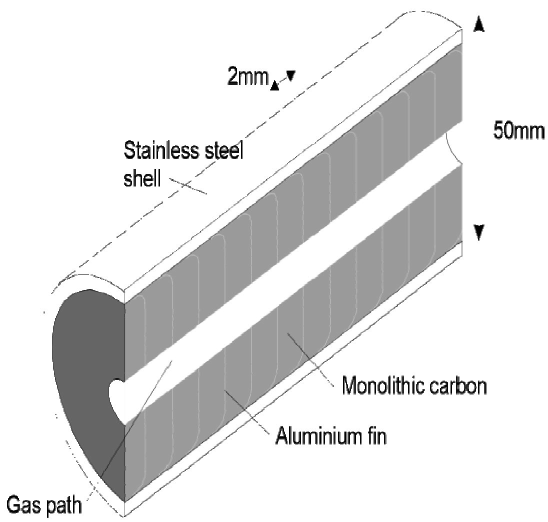


Figure 4.2.1: Generator design configuration

A number of design concepts exist. We are evaluating a thermosyphon heat pipe in a tubular design as shown in Figure 5. We have measured the effect of manufacturing process options on material properties, modelled the heat and mass transfer in a number of design options, and are constructing a 3 kW cooling generator. The estimated power density of the adsorption generator is close to 1 kW cooling / kg carbon which it is hoped will lead to final designs that are compact and have low manufacturing costs.

Applications in Developed Countries

In developed industrialised countries where there is grid electricity, there is no cost effective application for solar powered refrigeration of food, medicines etc. However, there may still be the possibility of cost effective solar air conditioning. The target cost per unit of cooling must be competitive with conventional systems, perhaps around £1 / Watt. None of the above mentioned systems are likely to achieve this figure. A few photovoltaic powered air conditioning systems have been built experimentally, but they are prohibitively expensive. Evacuated tube solar collectors have been used in conjunction with conventional Lithium Bromide - Water absorption air conditioners but are still far too costly and complex. The best possibility for cost effective solar powered air conditioning appears to be desiccant cooling.

Desiccant cooling has been known and available for many years but has become popular in recent years due to two factors. The first is that the damage to the ozone layer by conventional chlorofluorocarbon refrigerants has necessitated the search for alternatives to vapour compression refrigeration. Secondly, the need to replace the peak load demand for electricity for air conditioning applications coupled with the desire of gas utilities to balance their heating loads with a summer alternative has lead to the development of heat powered refrigeration cycles. The result has been research into improved desiccant materials and cycles to both improve performance and reduce costs.

Desiccants are substances that have a strong affinity for water and, because of this, can absorb moisture from an air stream. Desiccants can be solids such as lithium chloride, silica gel or molecular sieves, or liquids such as glycol, sulphuric acid or lithium bromide solution. There is a partial pressure of water vapour than can exist in equilibrium with a desiccant at a particular temperature. If the actual vapour pressure is above the equilibrium value, moisture will be absorbed, but if it is lower than moisture will evaporate from the desiccant. The process is therefore reversible.

The most common arrangement of desiccant system is the desiccant rotor. A desiccant rotor consists of a honeycomb support which has been impregnated with a finely divided desiccant. As air flows axially through the narrow honeycomb channels, moisture is absorbed by the desiccant. The design of the rotor gives a large surface area of contact between air and desiccant. As the air stream passes through the rotor, moisture is absorbed and the heat of absorption, almost equal to the latent heat of condensation, is released. The resulting air stream is therefore warmer but drier. The latent enthalpy contained in the moisture vapour is effectively exchanged for sensible enthalpy in the temperature of the resulting air.

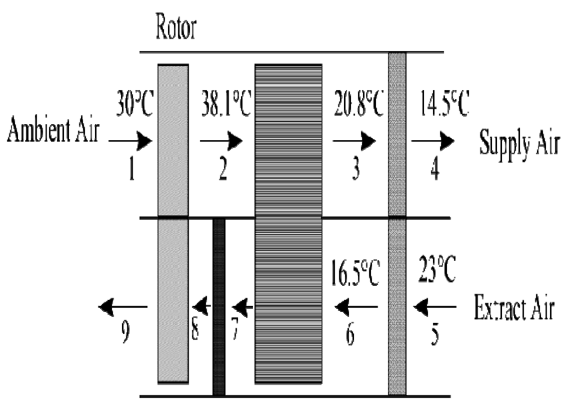
It is arranged that the rotor rotates slowly so that desiccant that has been exposed to moist process air moves into a separate sector. Here warm air, in which the vapour pressure is less than the equilibrium vapour pressure, carries away moisture that evaporates from the desiccant on the rotor

A schematic of a desiccant cooling system is shown in Figure 5.1. Latent heat contained in the fresh air (1) drawn into the building is exchanged on the desiccant rotor for sensible and the air temperature rises. This warm dry air (2) is then passed through a heat wheel.

The heat sink for the heat wheel is extract air (5) from the building that has been cooled by evaporative cooling (6). The resulting air stream (3) is therefore cool and dry. If moisture is added to this air stream, evaporative cooling takes place and cool air (4) is supplied to the building.

The warm moist extract air (6) after the heat wheel is heated further and the hot gas (7) passed through the desiccant rotor. Moisture leaves the rotor and so a warm moist air stream (8) is discharged to outside the building.

Desiccant Humidifier



Heater Humidifier

Thermal Wheel

Figure 5.1: Schematic desiccant cooling system

The benefit of a desiccant cooling system is that the air temperature required for reactivating the desiccant rotor needs only to be in the region of 50° to 80°C. Air in this range can readily be provided from an array of solar heating panels. Also, by the addition of a second heat exchanger in the supply air and by stopping the evaporative cooling, the system can be used to heat the building with excellent recuperation of the heat from the extract air.

A number of solar assisted air conditioning systems using desiccant wheels have been evaluated in Germany [28], Sweden [29] and in the USA where a system has been installed in a Kentucky Fried Chicken Restaurant in Florida [30]. These systems normally use solar energy together with a gas fired heater backup in order to provide a cost-effective solution.

ADVANTAGES AND DISADVANTAGES

Advantages of Solar Power

- Solar energy is a clean and renewable energy source.
- Once a solar panel is installed, solar energy can be produced free of charge.
- Solar energy will last forever whereas it is estimated that the world's oil reserves will last for 30 to 40 years.
- Solar energy causes no pollution.
- Solar cells make absolutely no noise at all. On the other hand, the giant machines utilized for pumping oil are extremely noisy and therefore very impractical.
- Very little maintenance is needed to keep solar cells running. There are no moving parts in a solar cell which makes it impossible to really damage them.
- In the long term, there can be a high return on investment due to the amount of free energy a solar panel can produce, it is estimated that the average household will see 50% of their energy coming in from solar panels.

Disadvantages of Solar Power

- Solar panels can be expensive to install resulting in a time-lag of many years for savings on energy bills to match initial investment.
- Electricity generation depends entirely on a countries exposure to sunlight; this could be limited by a countries climate.
- Solar power stations do not match the power output of similar sized conventional power stations; they can also be very expensive to build.
- Solar power is used to charge batteries so that solar powered devices can be used at night. The batteries can often be large and heavy, taking up space and needing to be replaced from time to time.

CONCLUSION

The capability of AIT in the design, construction, and operation of a solar powered refrigerator has been demonstrated. Furthermore, the operating conditions were found to be almost exactly in accordance with the design specifications. The theory of the system is therefore well understood. The new feature by which ammonia vapour from the evaporator is taken to the bottom header of the generator so that the heat of absorption during the refrigeration process is dissipated from the flat plate has been shown to remove the difficulty encountered by previous workers of obtaining sufficiently rapid absorption for satisfactory operation.

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