Proceedings of the IASTED International Conference
POWER, ENERGY, AND APPLICATIONS
September 11–13, 2006, Gaborone, Botswana
ISBN Hardcopy: 0-88986-614-7 / CD: 0-88986-616-3

DESIGN OF SOLAR-AQUA-AMMONIA ABSORPTION REFRIGERATION FOR RURAL AREAS OF BOTSWANA

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ABSTRACT
Botswana lies within the highest solar radiation belt in the Southern Africa region with mean annual total radiation of 8000 – 8500 MJ/m^2. In 2002 in an attempt to bring grid electricity to rural areas, the government of Botswana completed a 72 villages' rural electrification project, bringing the proportion of the national population having access to grid power to about 30 percent [1]. The larger proportion of the population, that is about 70%, however, still remain not connected to the grid system. As a complimentary effort to addressing this situation, this paper proposes widening the application of solar technology, especially in the villages; in particular the paper proposes the design and development of a Solar-Thermal Aqua-Ammonia Absorption Refrigerator system to be used by the rural dwellers for cold storage. Firstly, a small test model of 50 litres capacity will be designed, manufactured and tested in the laboratory. This will, then, be followed by a prototype test model that will be investigated in the field using Campbell Scientific CR510 data-loggers to automatically record required data onto Digital Storage Modules (DSMs). Periodic visits will be undertaken to the test site for data uploading as well as observatory investigations, and equipment inspection and servicing. The manufactured solar cooling system would be useful to the rural dwellers for storage of medicines and vaccines at rural health clinics as well as storage of perishable agricultural produce.

KEY WORDS
Aqua-Ammonia Absorption Refrigerator, Rural Application

1. Introduction

Refrigeration is a well-developed field that is widely used, both in domestic and commercial set-ups. Unfortunately, however, several factors ranging from cost to non-availability of grid power mean that many rural communities still do not have access to refrigeration facilities.

The application of solar thermal powered refrigeration was first investigated about 1962. However, it is considered a relatively new technology, whose performance has not been completely evaluated. Also from 1982 when depletion of the stratospheric ozone layer was first noticed, there have been concerns about the continued use of Chlorofluorocarbons (CFCs), culminating in the 1987 Montreal Protocol. Use of solar energy, a renewable resource, is one of the proposed measures for mitigating global warming and climate change. The solar thermal powered refrigeration is suitable for remote areas, which enjoy a high level of solar insolation but have no access to grid electric power.

Solar energy is a very significant and major renewable energy source in Botswana. Botswana lies within the highest solar radiation belt in the region, with the following values obtained from radiation isolines maps. The radiation figures are presented in table 1.

Table 1 – Global Radiation for Botswana

Mean Annual Total MJ/m^2	**Mean Daily MJ/m^2/day**			
	Jan	Apr	Jul	Oct
8500	24-30	≤20	15-19	24-26

The government of Botswana through its Ministry of Minerals, Energy and Water Affairs and the Botswana Power Cooperation completed its 72 villages' rural electrification scheme costing BWP 183 million in 2002 bringing the proportion of the population having access to grid power to 30%. There is still about 70% of the population, mainly rural and peri-urban, without electricity in Botswana. This project therefore will help to preserve item and perishable goods that need cool storage, especially in the rural areas of Botswana with no access to grid connection.

2. Methodology

This development work will be carried out in three phases: laboratory investigations on site, field investigations, and commercialisation of research findings.

2.1 Phase 1 Laboratory Investigations

A small test model of a solar thermal refrigerator will be designed and manufactured based on the aqua-ammonia absorption cooling system. The size of the model will be 50 litres. The model will be tested in the laboratory. A datalogger will be installed to automatically record test data. Key parameters to be investigated will include:

- Time series data of heat capacities for absorber, evaporator, generator (boiler) and condenser.
- Time series data of heat exchange coefficients for absorber, evaporator, condenser, generator and heat exchanger.
- Time series temperature measurements for the storage space versus the ambient space.
- Time series refrigerant-temperature measurements in absorber, evaporator, condenser and generator.
- Time series temperature measurements for solar collector inlet and outlet.
- Time series temperature measurements for heat exchanger inlet and outlet.
- Solution circulation flow rates.
- Solar radiation parameters.
- Solution concentration.
- Refrigerant pressures.
- Usage of backup heat.

2.2 Phase 2 Field Investigations

A prototype test model of a solar cold room will be designed and manufactured based on the aqua-ammonia absorption cooling system and improved based on the findings of phase 1 of the project. A suitable rural area will be identified for installation of the solar cold room; it is preferred that such a site be in a community set-up where a small scale retailer such as a bottle store or butchery could be engaged to use and monitor the cold room on behalf of the project. A set of data measuring equipment will be installed while a solar-powered datalogger such as the Campbell Scientific CR510 datalogger, will automatically record required data onto Digital Storage Modules (DSMs). Researchers will visit the field site periodically for data uploading as well as observatory investigations and equipment inspection and servicing.

2.3 Phase 3 Commercialisation

Phase 3 will depend on the successful completion of phase 2. Positive findings will provide a basis for commercialisation of the project. A local manufacturer will be invited to enter a joint venture for manufacture of solar cold rooms for selling to interested parties; other stakeholders in rural development such as local government and small scale retailers would also be involved.

3. Theory of Absorption Refrigeration System

Two common types of refrigeration can be identified: compression-type refrigeration and generator-type refrigeration.

Vapour compression systems use compressors to compress the refrigerant vapour. Compression systems require electrical power as energy input to drive the compressor; this is usually supplied from the mains or from photovoltaic panels for areas that do not have mains grid electricity supply. Several government and aid-funded institutions such as schools and clinics located in remote areas normally opt for PV-powered refrigeration. However, the cost of such systems is normally beyond the reach of individual households thus making absorption the favoured option.

3.1 Compression Type Cooling Systems

The vapour compression chiller is the most common cooling system and its process is represented in the Duhring diagram below.

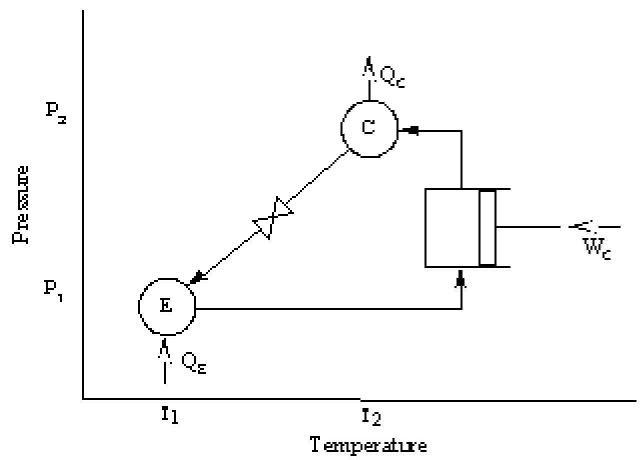

Figure 1: A Duhring diagram for a Vapour Compression Cooling System

A refrigerant is vapourised in an evaporator (E), drawing heat (QE) from an external source. The vapour is compressed, requiring work (WC), to a pressure where the saturation temperature is higher than the heat sink temperature (T2), and then condensed (C), rejecting the heat (QC) to the heat sink.

3.2 Absorption Type Cooling Systems

Absorption type systems use a generator to compress the refrigerant. The absorption type cooling system is represented in the following Duhring diagram:

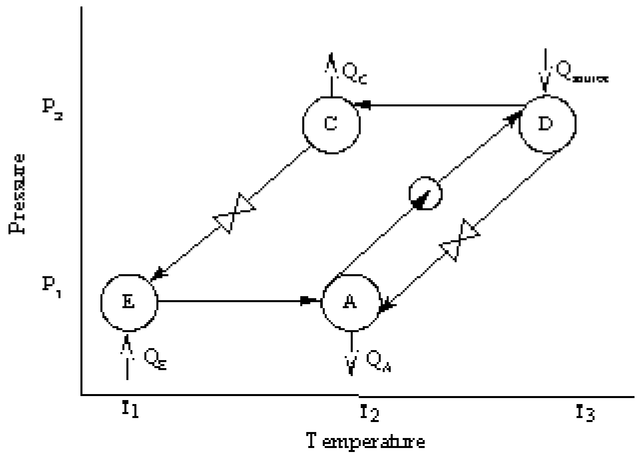

Figure 2: A Duhring diagram for an Absorption Cooling System

The compressor is replaced with a solution circuit that absorbs the vapour at the low pressure and desorbs it at the higher pressure. Superheated vapour coming out of the precooler is absorbed into solution (A), rejecting heat to the same heat sink as the condenser. The solution is pumped to the condenser pressure (D) and vapour is desorbed using heat supplied by a high temperature source. The low concentration solution is reduced to the evaporator pressure through a throttling valve and returned to the absorber. The concentration change in the absorber and desorber are accompanied by a change in the saturation temperature.

The figure below shows the circuit diagram for an absorption cooling system.

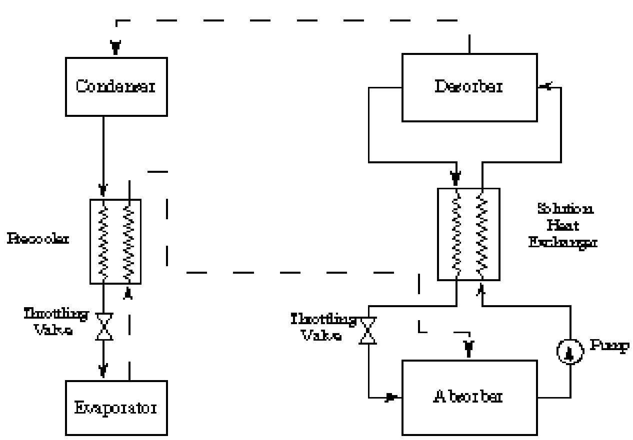

Figure 3: A Circuit diagram for a Vapour Compression Cooling System

3.3 Aqua-Ammonia Absorption Refrigeration Model

The project proposal is for design and development of a continuous absorption cooling system that uses a generator charged with water, ammonia and hydrogen; a solar heating system will be employed to heat the solution either directly or through a heat exchanger and a heating liquid such as water or oil.

3.3.1 Dalton's Law and the Continuous Absorption Cooling Cycle

The continuous cycle absorption cycle is based on Dalton's Law of Partial Pressure, which states [6]:

> ***"The total pressure of a confined mixture of gases is the sum of the partial pressures of each of the individual gases in the mixture"***

thus: $$P_t = P_1 + P_2 + P_3 + \ldots + P_n$$

where: P_t is the total pressure of the gas mixture, and P_1, P_2, P_3, …… and P_n are the partial pressures of the gases 1, 2, 3, ….n respectively.

Dalton's Law of partial pressures is the foundation of the principle of operation of one of the absorption type refrigerating systems. The law further explains that each gas behaves as if it occupies the space alone.

To illustrate, the absorption refrigerator uses two gases, ammonia and hydrogen. The ammonia, at room temperature, is absorbed by the water in the closed system.
Heating this solution drives out the ammonia. (The hydrogen is not absorbed by the water and remains as a gas.) Due to the pressure it is under, the ammonia condenses into a liquid in the condenser. The pressure is uniform throughout the system. Total pressure in the system is the sum of the vapour pressure of the ammonia plus the hydrogen pressure. When the pressure of the ammonia vapour is below the pressure corresponding to the vapour pressure for ammonia alone, the ammonia continues to evaporate. It tries to reach a vapour pressure corresponding to the temperature in the absorber.

The continuous absorption cooling system will be operated by application of heat from a solar flat collector. The unit will consist of four main parts - the boiler, condenser, evaporator and absorber. The solar water heat exchanger will be inserted in pocket (B). Central tube (A) has been incorporated for use of backup heat such as a kerosene or gas burner.

The unit charge will consist of a quantity of ammonia, water and hydrogen at a sufficient pressure to condense ammonia at the room temperature for which the unit is designed.

When heat is supplied to the boiler system, bubbles of ammonia gas are produced which rise and carry with them quantities of weak ammonia solution through the siphon pump (C). This weak solution passes into the tube (D), whilst the ammonia vapor passes into the vapor pipe (E) and on to the water separator. Here any water vapor is condensed and runs back into the boiler system leaving the dry ammonia vapor to pass to the condenser.

Air circulating over the fins of the condenser removes heat from the ammonia vapor to cause it to condense to liquid ammonia in which state it flows into the evaporator.

The evaporator is supplied with hydrogen. The hydrogen passes across the surface of the ammonia and lowers the ammonia vapor pressure sufficiently to allow the liquid ammonia to evaporate. The evaporation of the ammonia extracts heat from the food storage space, as described above, thereby lowering the temperature inside the refrigerator.

The mixture of ammonia and hydrogen vapor passes from the evaporator to the absorber.

Entering the upper portion of the absorber is a continuous trickle of weak ammonia solution fed by gravity from the tube (D). This weak solution, flowing down through the absorber comes into contact with the mixed ammonia and hydrogen gases which readily absorbs the ammonia from the mixture, leaving the hydrogen free to rise through the absorber coil and to return to the evaporator. The hydrogen thus circulates continuously between the absorber and the evaporator.

The strong ammonia solution produced in the absorber flows down to the absorber vessel and thence to the boiler system, thus completing the full cycle of operation.

The liquid circulation of the unit is purely gravitational.

Heat is generated in the absorber by the process of absorption. This heat must be dissipated into the surrounding air. Heat must also be dissipated from the condenser in order to cool the ammonia vapor sufficiently for it to liquefy. Free air circulation is therefore necessary over the absorber and condenser.

The whole unit operates by the heat applied to the boiler system and it is of paramount importance that this heat is kept within the necessary limits and is properly applied.

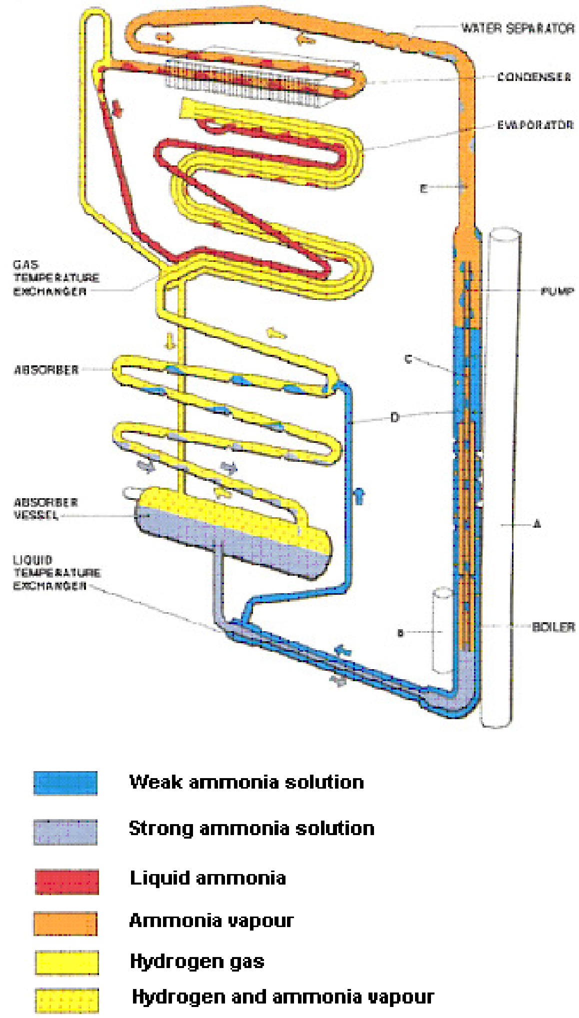

Figure 4: Ammonia Absorption Refrigerating System

3.3.2 Solar Heating System

The solar heater will be either of the flat plate collector type or of the concentrating collector type. A "flat plate collector" contains an absorber plate that uses solar radiation to heat a "carrier fluid," like oil or water, or air. Because these collectors can heat carrier fluids to around 80^o C, they are suited for residential applications.

Concentrating collectors are intended for larger-scale applications such as air conditioning, where more heating potential is required. The rays of the sun from a relatively wide area are focused into a small area by means of reflective mirrors, and thus the heat energy is concentrated. This method has the potential to heat liquids to a much higher temperature than flat plate collectors can alone. The heat from the concentrating collectors can be used to boil water. This is reflected in application of concentrating collectors for solar cooking as in figure 5.

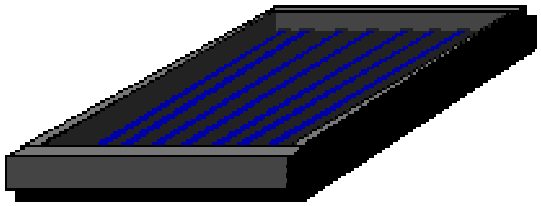

Figure 5: A Flat Plate Collector

Figure 6: Solar Cooker based on a Concentrating Collector
(Photo: courtesy of STC Consultants, Zambia)

4. Conclusion

Development funding for this proposal is currently being sourced. The project carries a good potential for success. Findings will be compiled, analysed and published.

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