Biomass Stimulated Absorption Refrigerator for Food Storage in Papua New Guinea

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ABSTRACT

A medium capacity (140 litre) water-ammonia absorption refrigerator, thermally stimulated by a charcoal-stove is being developed to store food in remote locations and island communities of Papua New Guinea. This low initial cost system has no moving parts, so there are not likely to be excessive maintenance costs.

The paper describes a prototype charcoal/or biomass-stove thermal refrigerator in which the absorption cycle and the thermo-syphonic cycle of a heating liquid has been coupled in a novel and straightforward approach.

The system consisted of a heat-exchanger, in the form of a jacket surrounding the generator tube of a water-ammonia absorption cycle refrigerator and was connected in a close-pipe work loop to a heat exchanger placed in a charcoal-stove. A heat-transfer oil flowed due to thermo-syphonic forces between the heat exchanger and the jacket. The commercially manufactured (but modified) refrigerator employed required a heat input of 200 W and had an evaporator capacity of 22 W in the freezer cabinet at a generator temperature of 200°C. The working pressure of the aqua-ammonia system was reduced from 2.6 MPa to 1.75 MPa in order that the evaporator could operate at a lower generator temperature of between 170°–180°C.

According to initial tests it took 4 hours for the system to warm up, and took another 7 hours for water in the freezer cabinet to approach 0°C from the initial 25°C. The cooling capacity of the evaporator was roughly 70% of the cooling capacity of the original system with electric heating. For the twelve hour test the stove consumed 2.5 kg of charcoal with air port opening between 3 to 5 millimeters. Initial results show that fluctuations in the heating oil temperatures did not have a corresponding effect on evaporator temperature due to the thermal inertia. This cycle of operation is being extended at present to allow larger heat flux through the jacket. However, food below +5°C could be maintained over a 24 hour cycle, using coconut husks and other biomass material commonly available in the island communities.

The need for the systems to be developed in this project will be greatest in coastal fishing villages and island communities around Papua New Guinea, where large amounts of fish and marine produce are lost or their value depreciated by spoilage. Preliminary estimates indicate that the prototype absorption unit stimulated by wood/coconut husk stove (rather than electricity/kerosene), when manufactured commercially, will cost less than K 1500 at 1991 prices.

INTRODUCTION AND BACKGROUND

In tropical countries like Papua New Guinea vast amounts of fresh fruit, vegetables and fish are lost or their value depreciated by spoilage. This spoilage could be prevented partially at the local village level by medium size, i.e. 300-400 litres capacity, cooling units capable of providing temperatures in the range of 0° to 5°C for short-term food preservation. The refrigerator for the purpose must be simple to operate, long lasting, and have the ability to be used without conventional fuel in remote areas, coastal villages and island communities, devoid of conventional power.

The application of refrigeration to vaccine storage has to date focussed on photovoltaic powered units. They are inherently expensive and have not achieved performance expectations in the rural areas of Papua New Guinea because of the lack of infrastructure and know-how. These units are not economical for short-term preservation of fish and food storage [1,2].

The work on the development of a proto-type thermal operated absorption refrigerator for food storage was started in the Mechanical Engineering Department, University of Technology, PNG, in 1988 with the financial assistance of UNESCO channelled through the Regional Network for Alternative Energy Sources in South East Asia and the Pacific [3].

The aim was to develop experimentally a thermal absorption refrigerator for food storage, by suitably altering the water-ammonia solution concentration and operation pressures of a commercial unit in order to energise the modified system with heat, supplied by evacuated-tube solar collectors, at temperatures in the range of 140°–150°C, in the ambient conditions of 32°C. An absorption cycle and solar-technology were coupled in a normal straightforward approach to produce a reliable, low cost and effective refrigeration unit for food storage in the Third World.

A major breakthrough last year was achieved in the Mechanical Engineering Department by operating a commercial absorption refrigerator (Electrolux) with the help of a charcoal/wood stove. It was shown experimentally that from now on refrigerators for food storage in the remote areas of Papua New Guinea can be run without being dependent on electricity, gas/kerosene oil or photovoltaics [4].

SOLAR APPROACH AND LIMITATIONS

A medium capacity commercially available aqua-ammonia absorption refrigerator was modified by optimising both the solution concentration of ammonia from 35% to 50% and the working pressures from 2.6 MPa to 1.5 MPa to match with the lower generator temperatures of between 140° to 150°C available with heat-pipe evacuated tube solar collectors during sunny periods [5].

The original electric heating element of the absorption refrigerator was replaced by a heat-exchanger in the form of a jacket surrounding the generator tube and was connected in a close-pipe work loop to two manifolds (Fig. 1). These manifolds enclosed heat-exchangers, which constitute the fluid-condensing ends of 30 heat-pipe evacuated tube solar-energy collectors, each collector having an absorber area of 0.1 m^2. A heat-transfer oil flowed due to thermosyphonic forces between the manifolds and the jacket. The modified refrigerator required a thermal heat input of 200 W which was supplied by the heat-transfer fluid heated by the sun. According to initial tests the minimum temperature recorded at the evaporator coil was –14.5°C. The temperature remained below –8°C for almost six hours of the day; at an ambient temperature of approximately 32°C. The maximum temperatures obtained by the solar collectors ranged between 152°–160°C when insolation peaked 980 W/m^2 (Fig. 2).

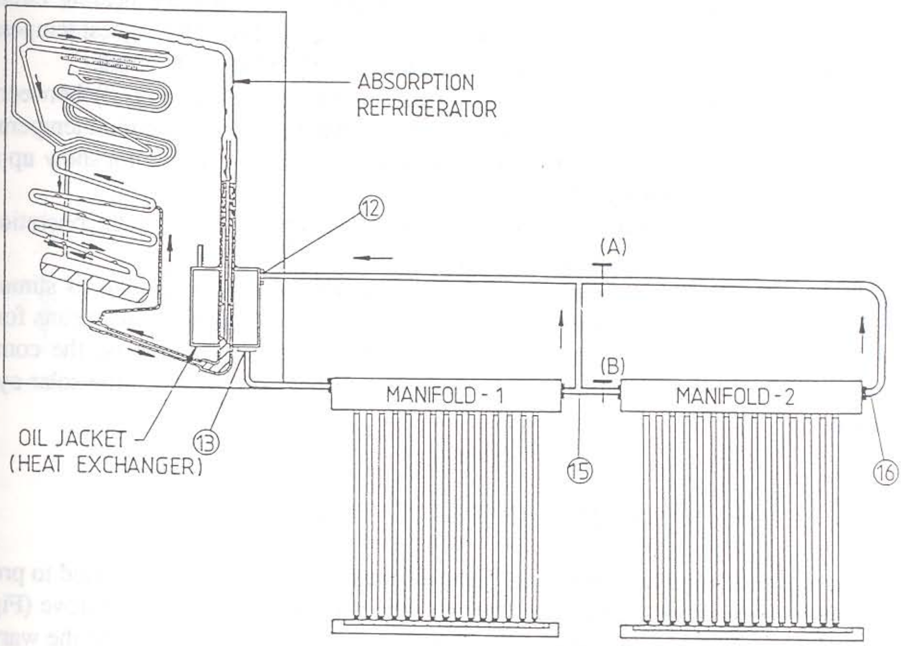

Fig. 1. Schematic link-up between heat pipe collectors and refrigerator.

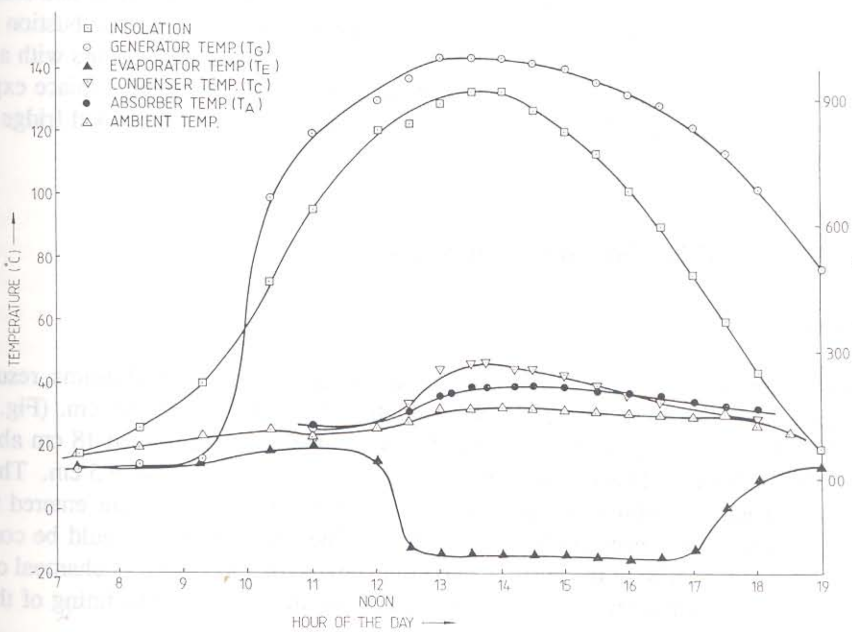

Fig. 2. System temperatures energised by solar collectors on a clear day.

Figures 3 and 4 show the temperature history of the system and the heating circuit on a partially cloudy day. Both manifolds were operational during the day. The highest temperature of the heating fluid from the collectors recorded a maximum of 152°C at 15 00 hours.

The interesting feature was a deep kink in the insolation pattern (Fig. 3) between 12 00 (noon) and 14 00 hours which resulted in a corresponding dip in the heating circuit temperatures in Fig. 4. This 'dip' was less pronounced in the generator temperature and did not show up at all in the evaporator temperature curve in Fig. 3.

This means that the thermal inertia of the system covers up any affect on the operation of the evaporator due to the irregularity in the radiation pattern.

The major short-coming of the system being that the solar-cycle is able to stimulate the evaporator for a period of 5 to 6 hours only, over a duration of 24 hours. This means for almost 18-hours the evaporator is non-operative. The insulation and door sealing on the commercial refrigerator unit was not sufficient to keep the temperature below +5°C when the solar-cycle was not operative.

CHARCOAL STOVE OPERATED REFRIGERATOR

In order to extend the evaporator cycle from 6 hours to 12 hours, it was decided to provide an auxilliary source of heat to the generator pipe with the help of a charcoal/wood stove (Fig. 5). It was estimated that 2 kilograms of charcoal will provide enough heat to accelerate the warming up period in the morning when the sun is low, from 4 hours to 2 hours. Similarly, the stove could extend the evaporator cycle in the afternoon when the sun begins to climb down.

Heating from the auxilliary stove would be imperative during cloudy days and the flexibility of fuel required for the stove, e.g. wood or coconut husks will make it acceptable and feasible in the under developed regions where such fuel is in abundance. By controlled combustion air, the stove would provide heat transfer oil between 150°–180°C over a period of six hours with a charge of 2 kilograms of charcoal. Initial tests showed that the stove could completely replace expensive heat-pipe evacuated tube solar-collectors, further lowering the cost of a future food fridge for the developing countries.

SYSTEM DESCRIPTION AND SPECIFICATION

Charcoal Stove

The prototype charcoal stove was fabricated from two disused 20 litre oil drums, resulting in overall dimensions of 29 cm in diameter, 57 cm high and a thickness of 3.5 cm. (Fig. 5). A cylindrical shape heat exchanger (20 cm high and 16 cm diameter) was located 18 cm above the grate made from mesh wire. This distance from the grate to the ash floor was 6.5 cm. The outlet of exhaust gases through a chimney 10 cm in diameter and 50 cm high. The air entered through the inlet port located in the lower portion of the stove. The combustion air could be controlled through a sliding gate provided at the port. A maximum charge of 1 kilogram of charcoal could be introduced into the stove through another door placed above the air port. The lining of the stove was done with 3 cm thick clay.

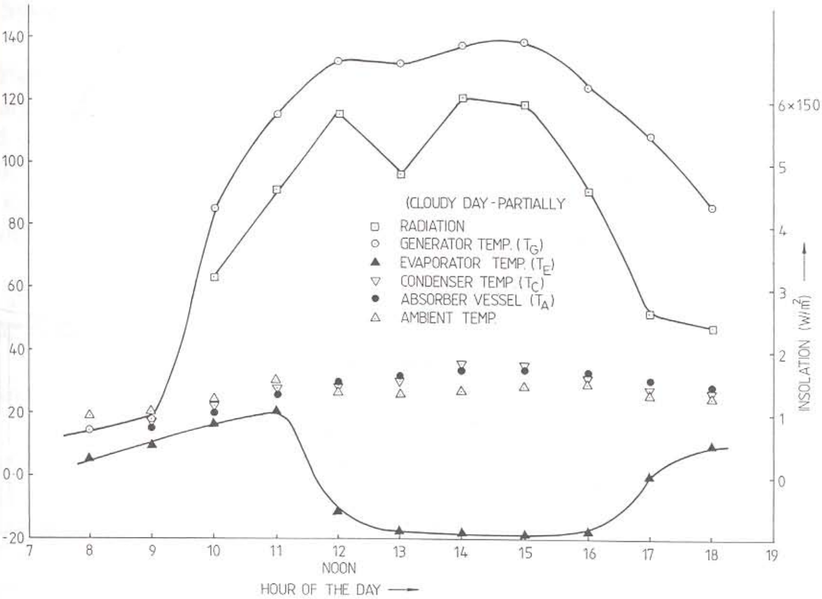

Fig. 3. Absorption system temperature energised by solar collectors.

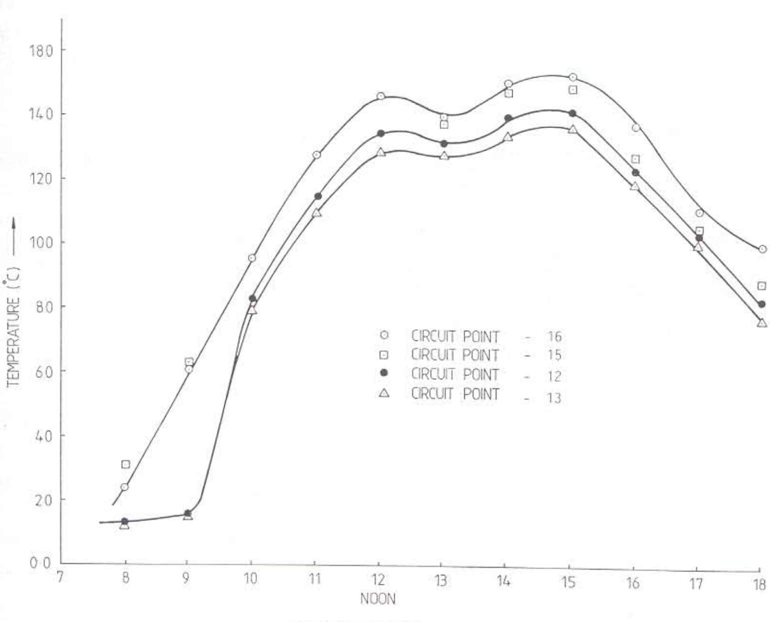

Fig. 4. Temperatures across heating oil circuit on a cloudy day.

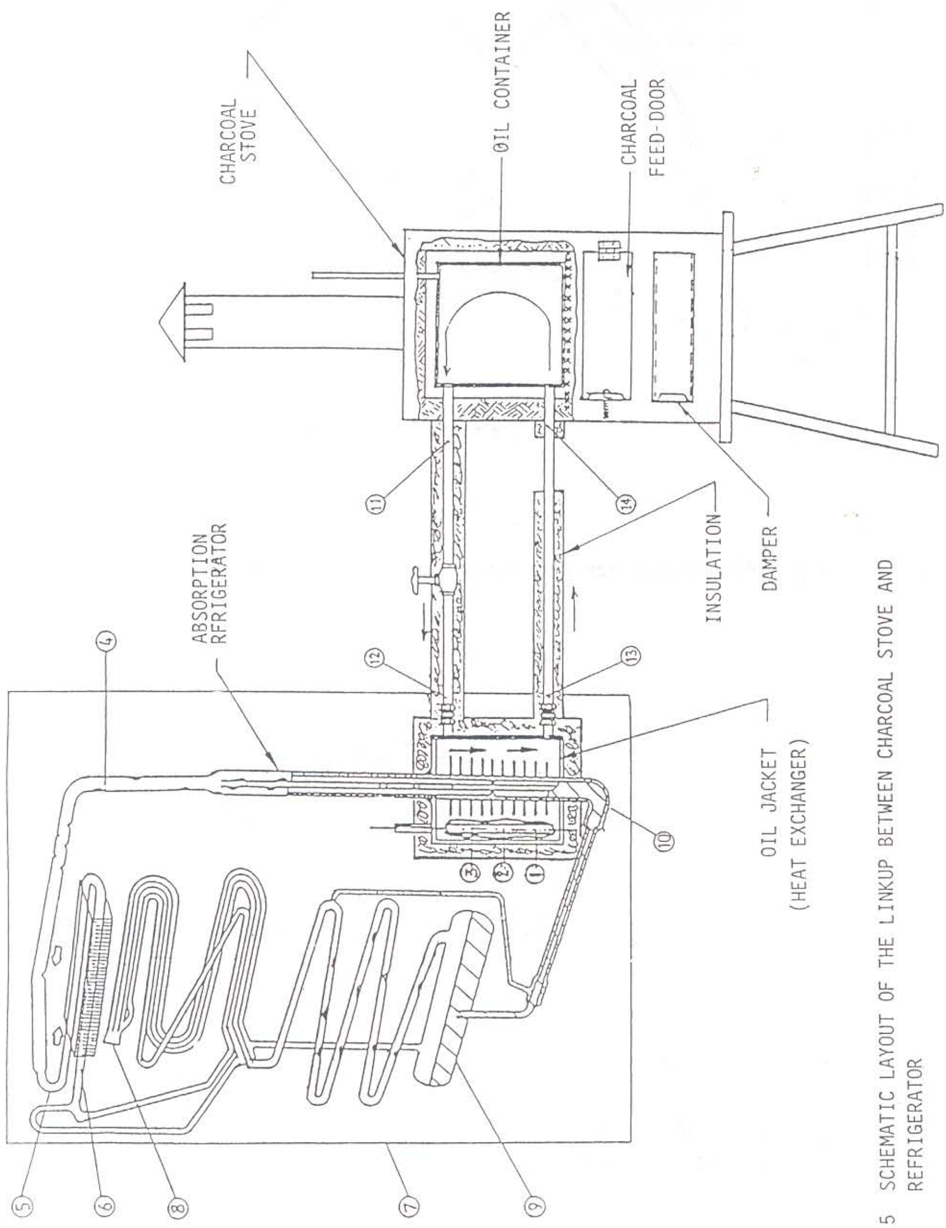

FIG.5 SCHEMATIC LAYOUT OF THE LINKUP BETWEEN CHARCOAL STOVE AND REFRIGERATOR

Fig. 5. Schematic layout of the link-up between charcoal stove and refrigerator.

Absorption System

The refrigerator avoids using either a motor or compressor, its operation is based on: (a) the ability of a large quantity of ammonia gas to be absorbed into cold water at a low pressure in the absorber, and subsequently to be driven out at a relatively high temperature and high pressure generator or boiler; and (b) the ammonia vapour being readily condensed at high pressure and high temperature in the condenser, and evaporating again at a lower temperature in the presence of hydrogen (which for present purposes remains inert) even though the total pressure remains invariant.

During this evaporation process, large quantities of heat can be extracted, i.e. refrigeration is achieved. The Platens-Munz cycle is employed in the system.

Charcoal Stove – Refrigerator Link Up

The prototype charcoal stove thermal refrigerator consists of an absorption cycle and thermo-syphonic cycle of a heating liquid which has been coupled in a normal and straightforward way (Fig. 5).

The system consisted of a heat-exchanger, in the form of a jacket surrounding the generator tube of a water-ammonia absorption cycle refrigerator and was connected in a close-pipe work loop to a second heat-exchanger placed in the charcoal stove. A heat-transfer oil flowed due to thermo-syphonic forces between the heat-exchanger and the jacket. The commercially-manufactured (but modified) refrigerator employed required a heat input of 200 W and has an evaporator capacity of 21 W in the freezer cabinet, at a generation temperature of 200°C.

The working pressure of the aqua-ammonia system was reduced from 2.6 MPa to 1.75 MPa in order that the evaporator could operate at a lower generator temperature of between 170° to 180°C.

INITIAL PERFORMANCE OF THE SYSTEM

Copper-constantan thermojunctions were placed around the absorption system (1-10) to indicate the temperatures at the generator, condenser, evaporator and absorber. Thermocouples were also fixed around the heating fluid circuit (11-14) shown in Fig. 5.

Figure 6 shows the history of the temperature taken at the inlet (T_{12}) and the exit (T_{13}) to the heat exchanger surrounding the generator pipe. The sharp rise in the temperature at (T_{13}) after one hour of the stove firing indicates the commencement of syphonic flow through the oil circuit and the heat exchanger. This was triggered by a minimum of 60°C temperature differential between the upper and lower oil paths of the thermal circuit. This had to be optimised by removing some insulation from the lower limb of the oil circuit (Fig. 5).

The average oil temperatures around the generator pipe attained a maximum after two hours (≈180°C) and then fluctuated ±20°C during the 12 hours test period. The fluctuation was caused by the irregular burning of charcoal in the stove and due to placing a fresh charge every four hours.

The cooling curve for one litre of water placed in the freezer cabinet (Fig. 7) shows that it took four hours for the system to warm up and then took another seven hours for the water to reach zero degree from the initial 27°C.

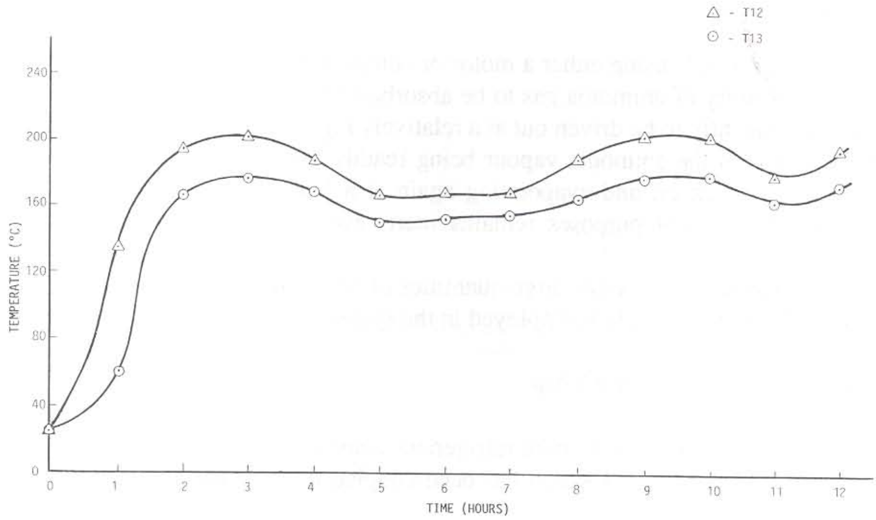

Fig. 6a. Temperatures generated across oil jacket with slow burning stove.

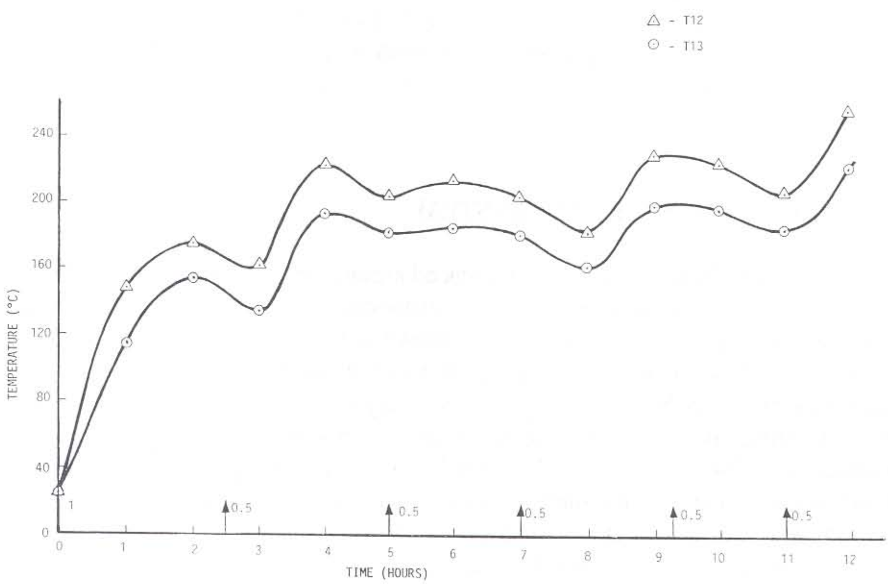

Fig. 6b. Temperatures generated across oil jacket with fast burning stove. (Arrows indicate the quantity of charge in kilograms placed in stove.)

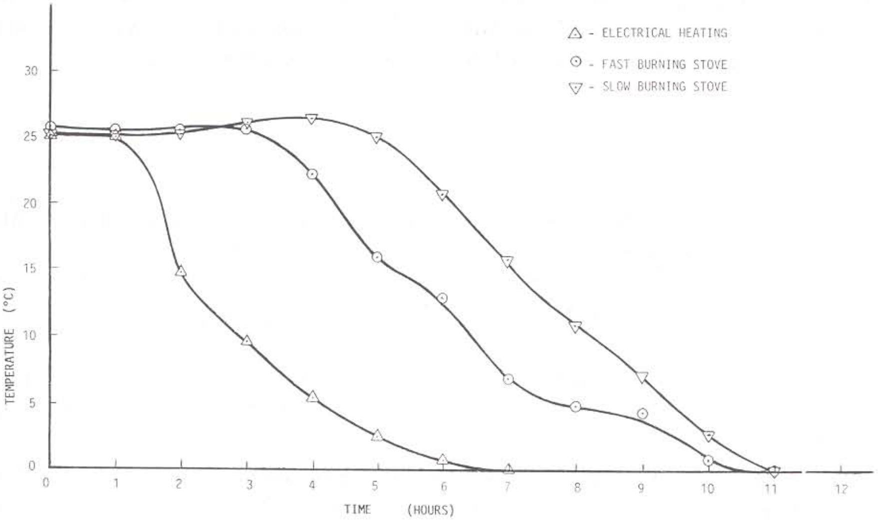

Fig. 7. Temperature of one litre of water in the freezer cabinet of the refrigerator.

The cooling curve is not as smooth as that obtained with electrical heating but depended on the slow or fast burning of the stove (Fig. 7). The reduced system temperatures recorded at the condenser (T_5, T_6) and at the absorber (T_9, T_{10}) indicated that the actual thermal energy getting into the system was about two-thirds of the total compared to the electric heating.

Fluctuation of generator temperature (T_1 – T_3) has a marked effect on the cooling curve. However, the evaporator appears to function steadily at a minimum generator temperature of 160°C.

For a twelve hour test the stove consumed 2.5 kilograms of charcoal with an air port opening of 5 mm at the start and then reducing to 3 mm at full combustion.

More tests are required to find the optimum combustion air for the charcoal stove to enable the system to perform with the minimum quantity of charcoal consumption over a 24-hour period.

This cycle of operation is being extended at present to allow larger heat flux through the jacket. However, food between 0°–5°C could be maintained by using coconut husks or other firewood material commonly available in the island communities.

ECONOMICS AND PROSPECTIVE APPLICATIONS

In tropical countries like Papua New Guinea and island communities in the Pacific, vast amounts of fresh fruits, vegetables and fish are lost or their value depreciated by spoilage. This spoilage could be prevented partially at the local village level by a medium size, i.e. 300-400 litres capacity wood stove – operated absorption cooling units capable of providing temperatures in the range of 0° to 5°C for short-term food preservation. The proposed system is simple and has no moving parts, so there are not likely to be any excessive maintenance costs or know-how required.

Preliminary estimates indicate that the described prototype absorption unit, stimulated by thermal energy from a wood/coconut husk stove (rather than electricity, gas/kerosene oil or photovoltaics) will cost less than US$ 1500/- at 1991 prices when manufactured locally.

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