A Novel Concept for Refrigeration using Solar Parabolic Concentrator

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Abstract **- If one considers domestic scale refrigeration what remains among the available options as the most appropriate for solar refrigeration are only two which are 1. Electrolux refrigeration, and 2. Icy ball refrigeration. Both the above options have the advantage of accepting not only solar radiant thermal energy, but also if needed, biomass thermal energy with appropriate interfaces. Both the above types of processes are proven one, yet they have been traditionally run with conventional energy sources. The novelty of the present work is that for the first time, it has recognized the appropriate match of these known processes with concentrating solar collectors for application to small size refrigeration and ventured to look into interfacing issues of these prospective combinations.**

Key words **- Refrigeration, Concentrator**

I. INTRODUCTION

Solar energy can be used for refrigeration in three ways for domestic application, solar PV run vapour compression refrigeration would be the most expensive at current market prices of solar photo voltaic electricity, ammonia vapour absorption refrigeration system being suited for large scale application is too complex to match the small size of household refrigeration [1, 2].

One strategy which is overlooked mostly is that even with intermittent solar energy input one can achieve continuous refrigerating effect if emphasis is to be provided to solar refrigeration at the user end.

II. CLASSIFICATION OF SOLAR REFRIGERATION SYSTEMS

Solar energy may be used for refrigeration in several ways as follows.

2.1 Based on the type of energy input to the process

a) **Solar photo voltaic electricity**, as seen with conventional vapour compression refrigeration process, or thermo electric cooling process, or with 3 in 1 type Camping fridge which can accept 220V AC or 12V DC electric heating or gas flame heating and which is used in vehicles or at camps.
b) **Solar thermal energy**, as used in ammonia vapour absorption refrigeration system and in Electrolux type of refrigeration [3].

2.2 Based on the continuity of refrigeration

a) Continuous refrigeration as it is with conventional vapour compression refrigeration, ammonia vapour absorption refrigeration system and electrolux type of refrigeration
b) Intermittent refrigeration which, for example, is used in Icyball type of refrigeration system

Considering the intermittent nature of sunshine it may be seen that intermittent type of refrigeration is the most appropriate for coupling to solar parabolic dish concentrator.

III. STRATEGY FOR USING INTERMITTENT SUNSHINE FOR CONTINUOUS REFRIGERATION

A. Continuous solar refrigeration 1st strategy

In solar photo voltaic refrigeration, store solar energy in batteries and use associated power conditioning equipment to provide backup power during non-sunshine period. This is more expensive due to these extra equipment and more so, if one considers that non-sunshine hours form nearly 2/3rd of one day.

B. Continuous solar refrigeration 2nd strategy

Be it solar photo voltaic or solar thermal refrigeration, oversize the system and over produce and store solar energy in the form of ice and then use this ice during non-sunshine period. In this case no batteries and no associated power conditioning equipment are required and just the conventional refrigeration equipment needs to be sized appropriately larger. Ice is far better environment friendly energy storage as compared to batteries.

Among these options for domestic application,

1. Solar photo voltaic run vapour compression refrigeration would be the most expensive at current market prices of solar photo voltaic electricity,

2. Ammonia vapour absorption refrigeration system being suited for large scale application is too complex to match the small size of household refrigeration.

To understand and appreciate the relative advantages and disadvantages of Electrolux refrigeration, and Icy ball refrigeration, it is appropriate to look briefly into conventional refrigeration techniques and their limitations for intended applications.

IV. Conventional Refrigeration Processes

4.1 Vapour compression refrigeration system

The vapour-compression refrigeration uses a liquid refrigerant as the medium which while circulating in the machine absorbs and removes heat from the space to be cooled and then rejects that heat into atmosphere. This system has four main components: a compressor, a condenser, a thermal expansion valve known as throttle valve or metering device, and an evaporator.

Many systems continue to use HCFC refrigerants, which aggravate depletion of the Earth's ozone layer. Ammonia (NH_3) has a long history of usage as a refrigerant with excellent performance and non-polluting features. However, ammonia has two practical limitations: it is toxic and is incompatible with copper tubing.

4.2 Icy ball refrigeration system

The Icyball is an intermittent heat absorption type of refrigerator. In such case water-ammonia mixture is taken as the refrigerant. Water and ammonia dissolve on one another easily. So, they combine in the hot ball at room temperature.

When the hot ball is heated, evaporation of the ammonia first because it has a lower boiling point compared to water. The other cylinder is in water to help condense the ammonia in the cold ball. The cold ball is placed in the insulated box when the balls are fully charged, when the ammonia evaporates by absorbing heat from the refrigerated space and to dissolve in water in the hot ball. A hole in the cold ball is provided for a special ice cube tray.

Advantages of icy ball refrigeration are 1. The unit can operate on a relatively small energy input, 2. It can yield subzero temperatures for 24 hours from a single 20-minute application of heat, 3. Any heat energy source — candle, oil, gas, electric, solar or wood , etc. can power the refrigerator 4. The refrigerator unit is simple and self-circulating, and 5.Except having to clean its flue from time to time, the cooler requires little or almost no maintenance.

The main limitation of Icy Ball refrigeration is that nobody is building such a unit now, and hence can't be bought in the market. A second limitation is the fact that, although heat has to be applied to the unit just only once a day that heat *does* must be applied every 24 hours [4].

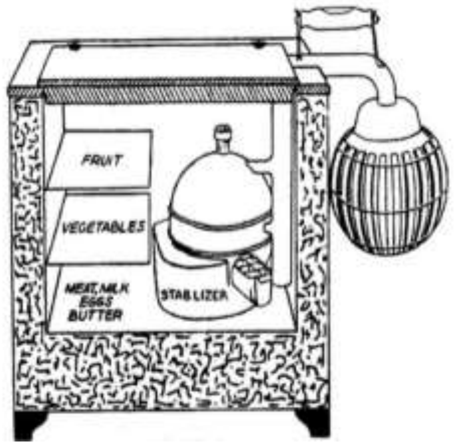

Figure 1 Placement of stabilizer and cold ball in Icyball refrigerator [4]

4.3 VAR system

Absorption refrigeration system uses solar radiant heat energy, heat from a fossil-fuel, waste heat from factories, or district heating systems. Such a system is used to air-condition buildings using the waste heat from a water heater or gas turbine. This is a very efficient energy use since the gas turbine produces electrical power, and hot water, and air-conditioning as co-products in a technical scheme called cogeneration/regeneration.

Now we consider two schemes which are the most appropriate for small scale refrigeration using solar concentrators.

V. Electrolux refrigeration system

The absorption cycle refrigerator uses ammonia as refrigerant, water as absorber, and hydrogen for pressurization. Hence there is no valve in the working fluid circuit. Three fluid circuits are distinguishable here: ammonia, water and hydrogen. The gas which would be on the high pressure side of a conventional refrigerator is usually ammonia, hence the ammonia is at high pressure in this scheme too. It is also hot, and is cooled to the ambient temperature in the conventional way, upon which it liquefies. The liquid flows into the evaporator, which is also at a high total pressure, but now the dominating pressure is that of hydrogen. The ammonia pressure is maintained at low level due to absorption in water. The liquid ammonia then evaporates, producing cooling as usual. The ammonia-water solution moves to a generator, where it is heated by a small flame or an electric heater. This releases ammonia, which due to a percolator action lifts water to a vapor-liquid separator. This lift generates the pressure difference to keep the water flowing. The ammonia replaces the hydrogen on this side, and gets condensed in the condenser as liquid ammonia [5].

VI. DESIGN ASPECTS OF COUPLING PARABOLOIDAL DISH CONCENTRATOR WITH CAMPING FRIDGE

From the point of view of matching solar energy collection device with application device, coupling paraboloidal dish concentrator to a camp fridge is one of the most desirable and required technical solution for extended use of solar collection device and also providing a renewable energy source to the camping fridge that uses ammonia absorption refrigeration system called as Electrolux refrigeration and as described earlier.

Two routes to solar refrigeration exist:

1. Solar photovoltaic electricity operated conventional refrigerator
2. Solar thermal energy drivable Electrolux refrigerator(camping fridge).

Now we consider the design issues of coupling paraboloidal dish concentrator with camping fridge.

1. To resolve the problem of enabling continuous refrigeration using intermittently available solar energy stored solar thermal energy is to be used run the fridge. A scheme to realize this indicated in figure 2 where one thermic oil filled overhead tank is used to supply oil to the concentrator for heating. The hot oil is then collected in another tank below concentrator level. The outlet of heating spiral coil at the focal plane of the concentrator has to have a check valve that opens only when the oil reaches pre-set temperature, say 250ºC. Thus even if sunshine is interrupted due to any reason like cloud cover, dust blown by winds etc, hot oil is collected in batches in the collection tank.

   Main features of both the options are briefly listed in the table 1 below.

Sr. No.	Feature	Solar thermal camping fridge	Solar PV fridge
1	Energy supply form	Heat	Electricity
2	Refrigeration scheme	Ammonia absorption	Ammonia vapour compression
3	Size	Limited to small sizes	Can be as that of conventional domestic refrigerators
4	Energy source	Any heat source	Any electrical energy source
5	Energy conditioning	Heat supply at >110ºC	Power supply at 12V/24V/220V
6	Backup	Cold stored in the form of ice, or heat stored in the form of sensible heat in heat transfer oil	Rectifier and/or inverter attached battery for solar PV or grid powered unit
7	Common	Tracker essential to maximize solar thermal or photo voltaic energy collection	
8	Disadvantage	Only small sizes available since thermo siphon effect is used	Comparatively more expensive During monsoon has to shut down or needs grid supply
9	Advantage	Any renewable thermal energy from biomass or oil can be used	Larger sizes permissible

Table 1 Comparison of solar thermal and solar PV refrigerators

2. The three-in-one camping fridge such as Dometic Model RM 123E can run on LPG, 12V/220V electric supply. Here energy input in any form is finally converted into heat to run the absorption refrigeration system. For LPG use there is a flue tube through which heat from gas flame is transferred to the refrigerant. A scheme to use solar heat without any major modification of the camping fridge is shown in figure 3.

6.1 Modification of camping fridge for solar thermal energy supply

The existing flue tube of the fridge is closed at the bottom after inserting a brass rod, say of 10mm diameter size and 100mm length through it such that part of it extends outside the flue tube. The brass rod is to conduct solar heat to the refrigerant via the flue tube. To improve heat transfer between the rod and flue tube, the annular gap is filled with heat transfer oil. A thermally insulated tank containing heat transfer oil is used to supply heat to the refrigerant via brass rod which remains immersed partly inside the storage tank when the tank is placed below. The tank is charged with solar heated oil as described earlier with reference to figure 2.

During working phase the heat from hot oil passes to the brass rod and gets relatively cooler after transferring heat to the brass rod. Having become lighter in density the oil sinks below making way for hotter oil. To regulate the thermo siphon caused oil circulation in the tank smoothly a partition is placed near the brass tube to streamline oil flow.

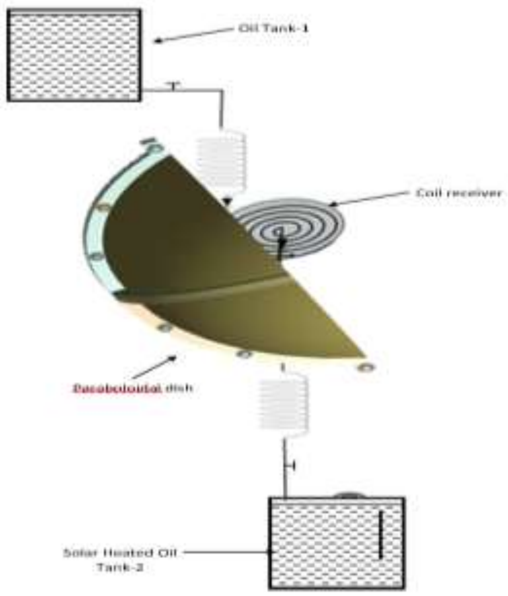

Figure 2Paraboloidal dish arrangement for charging solar heated oil

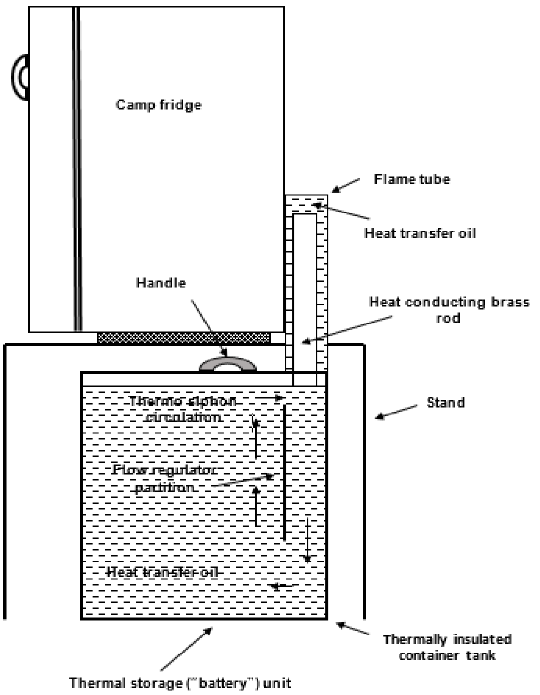

Figure 3 Scheme of continuous running of camping fridge with intermittently available solar energy

Now we check matching of components of the system.

At any time the heater of the fridge needs 75 W heat input. Let us check whether the tentatively sized brass rod is capable of conducting this much heat rate.

6.2 Heat transfer rate through brass conductor data for brass material and rod

The heat transfer rate

$$q_x = k\,A\,\frac{\Delta T}{\Delta x}$$

Where,

k, the thermal conductivity (W/m K),
ΔT, the temperature difference;
Δx, the rod length; and
A, the cross-sectional area.

Sr. No.	Feature	Detail
1.	Thermal conductivity, k [W/(m k)]	109
2.	Density of rolled & drawn brass [kg/m^3]	8580
3.	Specific heat of cast /rolled brass [kJ/kg K]	0.38
4.	Diameter of rod [m]	0.01
5.	Length of rod [m]	0.1
6.	Sectional area [m^2]	0.008
7.	Temperature drop across brass tube and surrounding heat transfer oil, assumed initially [^{0}C]	20

Table 2 Brass Conductor data for brass material and rod

$$q_x = 109 x 0.008 \frac{20}{0.1}$$

$$q_x = 171W$$

The heat transfer rate as computed = 171 W, which is more than the required 75 W (thermal). Thus sizing of brass rod is satisfactory.

6.3 Maximum daily energy need of camping fridge

Maximum daily energy can be calculated with the help of required thermal energy. Maximum daily energy need 0.13 to 0.2 kg/day as per table 2.

Sr. No.	Feature	Detail
1.	Electrolux Camping Fridge MODEL RM 123E Bottled Gas and 12 / 230 Volt Operation El heater rating [W]	75
2.	Electricity consumption/day, nominal [kJ]	6480
3.	Electricity consumption/day, nominal [kWh]	1.8
4.	Alternatively, LPG consumption [kg/day]	0.13 to 0.2

Table 3 Maximum daily energy for camping fridge

6.4 Sizing heat storage with thermic fluid

Let us consider Shell Heat Transfer Oil S2for illustration. This is recommended as suitable for enclosed circulated heat transfer systems for industrial applications such as textile producers, chemical plants, process industry etc. and in household equipment like oil filled radiators.

Shell Heat Transfer Oil S2 is used in high temperature continuous heat exchange equipment with application limits: Maximum film temperature 340°C and Maximum bulk temperature 320°C [6].

Benefits and Performance Features of this oil are:

- ✓ Extended intervals for maintenance
- ✓ Based on selected highly refined mineral oils
- ✓ Resists oxidation, thickening and oil cracking, thus providing extended oil life
- ✓ Efficient fluid heating[7].

Sr.No.	Feature	Unit	
1.	Density at 15 °C	kg/m^3	866
2.	Flash Point PMCC	°C	210
3.	Flash Point COC	°C	220
4.	Fire Point COC	°C	255
5.	Pour Point	°C	-12
6.	Kinematic Viscosity		
7.	at 0 °C	mm^2/s	151
8.	at 40 °C	mm^2/s	25
9.	at 100 °C	mm^2/s	4.7
10.	at 200 °C	mm^2/s	1.1
11.	Initial Boiling Point	°C	355
12.	Auto ignition Temperature	°C	360
13.	Neutralization Value	MgKOH/g	< 0.05

14.	Ash (Oxide)	%m/m	< 0.01
15.	Carbon Residue (Conradson)	%m/m	0.02
16.	Copper Corrosion (3h/100°C)		class 1

Table 4 Typical Physical Characteristics Shell Heat Transfer Oil S2 [98]

From computation the following results are obtained assuming perfectly insulated container:

Sr.No.	Consider Shell Heat transfer oil S2	Detail
1.	Average specific heat over 150-250 C [kJ/kg °K]	2.538
2.	Density [kg/m^3] at 150 C	778
3.	Density [kg/m^3] at 250 C	713
4.	Density [kg/m^3]Mean density over 150 to 250 C	746
5.	Temp rise [°K]	100
6.	Mass of Shell S2 required to store 24hr heat requirement [kg]	25.54
7.	Volume of Shell S2 required to store 24hr heat requirement [l]	34

Table 5 Data for thermic fluid

It is found that the thermal storage size is reasonably small, even in the rare and extreme case of continuous heat supply for 24 hr. In reality one may expect to use the fridge at the most 16 hr. a day and the storage size can come down further.

6.5 Paraboloidal dish concentrator to drive camping fridge

Calculation have been carried out as shown in table 6 to comprehend the ability of paraboloidal dish concentrator to drive camping fridge.

Sr. No.	Heating rate of solar dish	
1.	Aperture area, nominal [m^2]	2
2.	Daily average sol insolation, assume [W]	500
3.	Daily average sun shine, assume [hr]	6
4.	Daily sol insolation [kWh]	6
5.	Overall solar to heating efficiency, assume %	35
6.	Overall heat energy available/day, [kWh]	2.1

Table 6 Calculation to drive camping fridge

VII. Conclusion

From the computed results it is found that even with conservative estimates of concentrator's performance, it can supply 2.1 kWh (thermal) as against the requirement of 1.8 kW (thermal) of the camping fridge. It can be recognized as novel approach with concentrating solar collectors for application to small size refrigeration. It needs further investigation to solve interfacing issues of these prospective combinations.

VIII. References

[1] http://www.solarchill.org/images/Eurosun2004_paper_254.pdf.
[2] http://www.nationalserroscotty.org/resources/dometic-service-manual.pdf
[3] http://www.giordanobenicchi.it/varie%20camper/Caravan%20Fridges.htm
[4] http://www.nationalserroscotty.org/resources/dometic-service-manual.pdf
[5] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1852674/
[6] Heat-transfer-oil Shell.pdf
[7] Technical data sheet Shell Heat Transfer Oil S2 High Performance Heat transfer fluid