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Performance of Sunflower Oil as a sensible heat storage medium for domestic applications

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ABSTRACT

Experimental results evaluating the thermal performance of edible Sunflower Oil as a heat storage medium for domestic cooking applications are presented. The thermal performance of Sunflower Oil is evaluated during charging, 24 h heat retention and discharging cycles. Results of charging reveal that high temperature charging is the most viable option. This is because it results in higher energy, higher exergy, higher exergy factor and higher stratification number values. The charging efficiency is found to only represent the rate of heat transfer and it indicates nothing about the quality of the stored energy. The optimal charging time proposes that charging be continued until a point when the stratification number drops to 80% of its peak value. Heat retention results during 24 h show that high temperatures result in more heat losses during the cool-down heat retention processes. An optimal heat retention temperature is also suggested by the results. An optimal discharging flow-rate is also suggested by the discharging results. This is a compromise between obtaining a high rate of heat transfer and using the stored energy more effectively. The stratification number profiles show initial rises during the discharging cycles since the top temperatures drop at slower rates as compared to the bottom temperatures which results in larger thermal gradients as compared to the initial thermal gradients.

1. Introduction

In developing countries, deforestation is high due to the cutting of trees to provide fire wood for cooking food. Solar cookers offer an alternative means of cooking food to reduce the demand of electrical energy. Their use is however limited to sunshine hours [10]. To make solar cookers more useful during periods of low or no solar radiation, small thermal energy storage (TES) units can be employed [26,17,25,14]). TES units for solar cookers fall into two main categories; which are sensible heat thermal energy storage (SHTES) and latent heat thermal energy storage (LHTES) systems. LHTES systems are more expensive due to their construction complexity, the thermal degradation of phase change material (PCM) and the cost of the PCM itself. Small SHTES systems for solar cookers are thus more appropriate to the developing world since they are easy to fabricate and maintain.

Water can be used both as a heat transfer fluid and as a heat storage medium; however, its usefulness for TES at high temperatures for cooking food is limited by its boiling point. This is because it cannot be stored beyond its boiling point without pressurizing it, but pressurizing it adds additional costs to the storage vessel. Water also does not stratify properly in simple storage tank without suitable stratification devices which adds an additional cost to the storage tank. [2,28,35]. Thermal oils can be used to store thermal energy at temperatures greater than the boiling point of water where thermal properties do vary significantly affecting thermal stratification in the storage tank [8,21,23,24,29].

Thermal oils for TES applications are usually expensive application specific heat transfer oils. An example is Therminol used in solar thermal power plants [13], which requires well regulated operating conditions. It might not be economically viable to use these specialized heat transfer oils for domestic scale TES applications such as the cooking of food. Sunflower Oil is widely used in the cooking industries in South Africa for preparing fast foods like chips and fried foods. It is also locally manufactured in South Africa and reasonably priced at R 300(~USD 29) per 25 l, hence its widespread usage in South Africa. Most of the used

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Nomenclature

c_{av}	Average specific heat capacity of oil (J kg^{-1} K^{-1})
E_{out}	Output energy (J)
E_{st}	Stored energy (J)
E_T	Total exergy (J)
E_{XF}	Exergy factor (-)
E_{XT}	Total exergy (J)
Str	Stratification number (-)
T	Temperature (K)
T_{amb}	Ambient temperature (K)
T_{iav}	Average temperature of a segment (K)
T_{iniav}	Average initial temperature of a segment (K)
T_{inlet}	Inlet storage tank temperature (K)
T_{oulet}	Outlet storage tank temperature (K)
V	Volume (m^3)
V^{chav}	Average charging flow-rate (mls^{-1})
V_{dis}	Average discharging flow-rate (mls^{-1})
y	Axial distance (m)
ρ_{av}	Average density of oil (kg m^{-3})
η_{ch}	Charging efficiency (-)
η_{dis}	Discharging efficiency (-)

Sunflower Oil for cooking foods in South African homes or restaurants is disposed of in environmentally non-friendly ways. This used oil after some simple filtering process to remove solid impurities could be stored in small TES units for re-use or for preheating water for cooking, thus reducing the demand for electrical energy for cooking. Charging of these small domestic Sunflower Oil storage tanks could be done solely by renewable energy resources like solar energy or biogas. Charging could also be done in conjunction with conventional energy sources like electrical energy and liquid petroleum gas (LPG) in hybrid systems.

Although a lot of recent work has been done on Sunflower Oil in terms of characterization of its chemical and physical properties [30,12,3,1,31], very little work has been reported on its use as a heat storage medium. The use of Sunflower Oil as a TES medium for cooking applications is justified by the following reasons; (i) Sunflower Oil is readily available, (ii) Sunflower Oil is edible and food-grade, (iii) its characteristics are comparable to other thermal oils used for domestic heat storage applications reported in literature [16,18], (iv) Sunflower Oil is generally non-toxic and its fumes are generally tolerated (v) and its flash point is around 250 °C, a temperature that is above the cooking temperature of most foods. It is important mention that other edible thermal oils with reasonably low viscosities at room temperature like coconut oil could be used but Sunflower Oil was opted for because of its price, availability and wide usage in South Africa.

In an attempt to understand the stratification process and energy storage performance of Sunflower Oil under different operating conditions where the thermal properties vary significantly, laboratory experiments are presented. The experimental setup uses a copper spiral coil in the thermal contact with an electrical heater to heat up the oil since the objective of the study is to understand the storage performance under different controlled conditions. The storage system may be used with a solar concentrating system for a solar cooking application after fully understanding its performance in the laboratory. Results of charging, heat retention and discharging experimental tests under different conditions are presented in this paper. Thermal charging tests are carried out at low temperature (low power and high flow-rate), medium temperature (low power and low-flow-rate) and high temperature (high power and low flow-rate) cycles. Heat retention tests are carried out by leaving the storage tank to cool down for 24 h after high temperature, medium temperature and

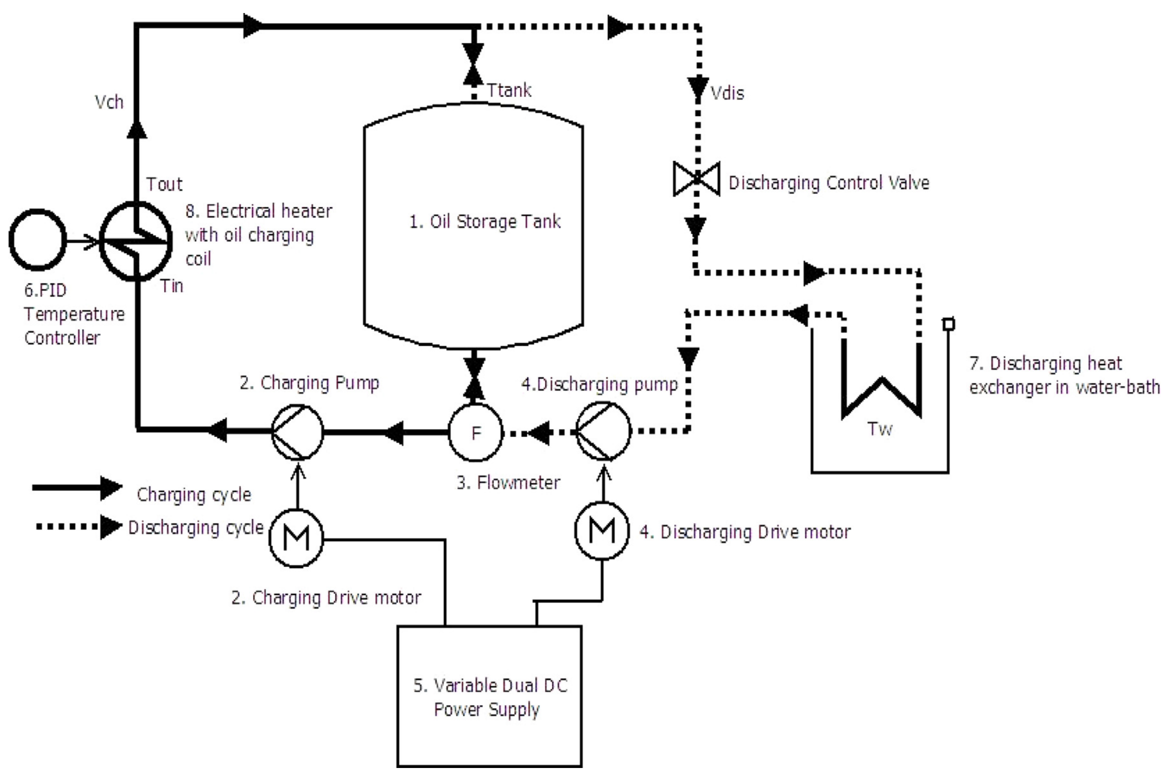

Fig. 1. A schematic diagram of the experimental setup and operation.