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Research Article

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Application of solar thermal energy storage systemfor the enhancement of marine heavy fuel oil systems

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ABSTRACT

High viscous heavy fuel oil (HFO) is used as fuel for economic operation of the ship. This HFO cannot be fed to the engine directly without reducing the viscosity. The HFO is stored in the settling tank is heated to a certain temperature in order to maintain the viscosity. The heating of the heavy fuel oil in the settling tank of the ship is achieved by means of application of steam from the boiler and the temperature is controlled by throttling the amount of steam, which results in the fluctuation of the temperature of the oil in the tank. In order to avoid this problem Thermal Energy Storage (TES) using the latent heat of phase changing materials can be used instead of existing steam heating system. Thermal Energy Storage provide a high degree of flexibility since a variety of energy sources such as solar energy, industrial waste heat, heat pumps and off-peak electricity can be utilized, either combined or separately. This paper presents the feasibility of application of solar heating system integrated with thermal energy storage unit for the enhancement of settling tank for marine Heavy Fuel Oil Systems.

Key words: Thermal energy storage, Phase change materials, Heat transfer fluid, Heavy fuel oil, Settling tank.

INTRODUCTION

THERMAL ENERGY STORAGE USING PCM

The heat transfer, which occurs when a substance changes from one phase to another, is called the latent heat. The latent heat change is usually much higher than the sensible heat change for a given medium, which is related to its specific heat. When water turns to steam, the latent heat change is of the order of 2000 kJ/kg. Heat received by the solar collector, waste heat from the engine exhaust etc. can be stored in PCM. The solar thermal energy finds its priority due its renewable and non-polluting nature. Many researchers are working on this field. Investigation on a combined sensible and latent heat storage unit integrated with solar water heating system showed good convergence between numerical analysis and experiment [1]. Finite time thermal analysis revealed the effect of transparent insulation cover on storage solar water heater [2]. Stearic acid is also used as a phase change material in the TES system [3]. Built-in-storage solar water heating systems in is tested in laboratory and field conditions [4]. The performance of TES system improved by using spherical capsules [5]. Heat transfer enhancement is obtained by adding fins in a latent heat storage system [6, 7]. Multiple-phase-change materials are used in charging processes of a cylindrical heat storage capsule [8]. Enhancement of charging and discharging rates in a latent heat storage system by use of PCM with different melting temperatures[9]. The solar TES system applied on paper industry for feed water heating process [10].

FUEL OIL SYSTEM

An economic operation of any ship is not possible without the use of heavy fuel oil. During the operation of ship, Heavy fuel is passed though a series of equipments to make it of the purest form. This heavy fuel oil used in ship engines has an extremely high viscosity. It is for this reason that the oil when on board ship, is passed through a series of settling and purification processes to make it usable for engines. To understand how this is done we will go through the whole process of fuel oil system from the start, when the oil is taken on board the ship. When the fuel is first taken on board a ship, it is stored in separate tanks which are generally located at the ship's double bottom area. In order to reduce the viscosity of the oil so that it flows easily, tanks are continuously heated with steam. The heating also facilitates the pumping operation for transferring the heavy oil from tanks which is usually done by positive displacement transfer pumps. The fuel oil is then transferred to settling tanks where it is further heated. The fuel is retained in the settling tanks for a long time so that dissolved solids and water can settle down through gravity at the bottom and taken away later.

From the settling tank, fuel passes through separators and clarifiers for further purification. The separator removes the water, solid impurities and sludge, whereas the clarifiers remove the remaining solid impurities from the oil. This purification process that involves clarifier and purifier is known as 'two-stage cleaning' process. It is to note the all the machines that are attached in the fuel line have heaters attached to them for making the purification process easy by reducing the oil's viscosity. The heaters generally use steam which is maintained at appropriate temperature by a thermostatic control.

The oil before flowing into the clarifier goes through one more heater. Purified oil from the clarifier is transferred to a clean oil tank wherein the fuel is stored until needed by the engine. The clean oil tank is also continuously heated from a heater. The oil from the tank then passes through a surcharge pump which pushes the oil through a high temperature heater which controls the final viscosity of the fuel oil. The steam heater will heat the fuel oil and provide it with the required injection viscosity. The flow and temperature of the steam is maintained by a viscometer which thus maintains the viscosity of the oil leaving the heater. The oil leaving the viscometer then passes through a fine filter before entering the engine. In this way a high viscosity fuel oil is made of usable quality for the marine engines. It is also to note that some amount of impurities will always remain in the fuel oil even after the purification process.

SETTLING TANKS

Settling tanks have several important functions in the proper treatment of heavy fuel oil. They provide a settling function for gross water and solids, a heating function, a deaeration function, and a thermal stabilizing function. Ships' settling tanks are designed to accept fuel oils with a 60°C minimum flash point. The two settling tank concept is the most common arrangement, with each tank holding up to one day's required fuel oil supply at full power. Designs that are more conservative have increased settling tank residence time up to four days per tank. Normally, one tank is being filled from the transfer system and holding fuel while the other tank is supplying fuel to service tanks via heaters and separators. As soon as a settling tank is filled, it is heated to 6 ° C below the flash point. From a safety standpoint, fuel oils must never be heated in tank of the ship at or above the fuel's flash point. In a diesel propulsion system, once tank contents have been heated to the selected temperature, settling tank heat should be secured and the fuel allowed to settle undisturbed for as long as possible. The tanks are insulated in order to reduce heat loss. It is important to secure the settling tank heat source once it attains the required temperature, because continuous heating will produce thermal currents within the tank which interfere with the settling process. Because of constant heat loss from a settling tank, it may be necessary to reactivate the tank heating system periodically in order to maintain its contents at 60 ° C. The properties of HFO are given in Table 1.

Table 1 Fuel oil properties

Property	Unit	Test method	Typical range
Kinematic viscosity at 100°C	mm^2/s	ISO 3104	6.0 to 55.0
Density at 15°C	Kg/m^3	ISO 3675	950 to 1010
Flash point	°C	ISO 2719	> 60
Pour point	°C	ISO 3016	< 30

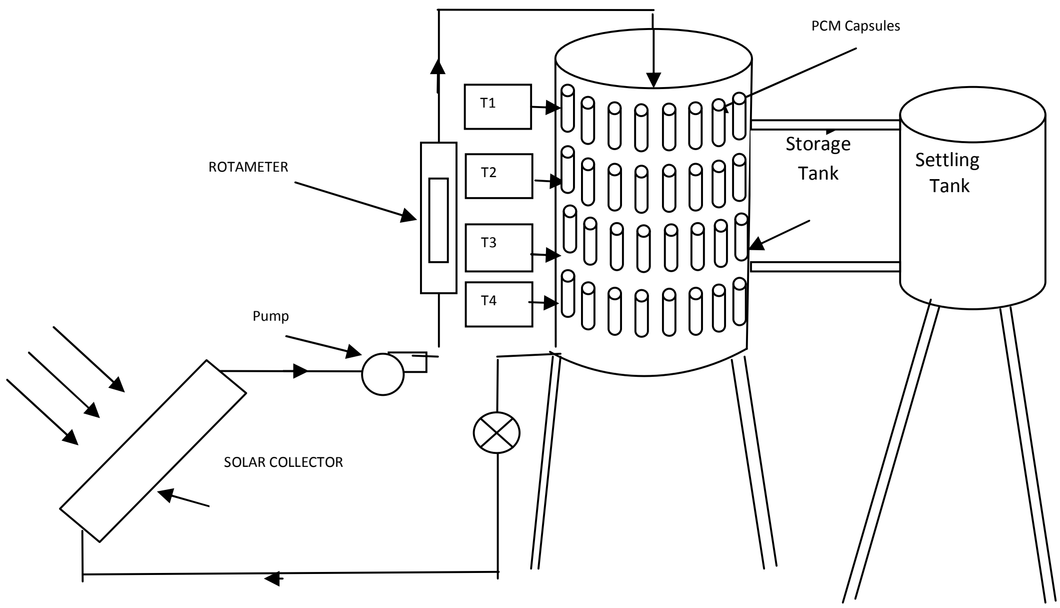

Fig.1 Schematic of Application of solar heating system integrated with thermal energy storage unit for the enhancement of settling tank for Marine Heavy Fuel Oil Systems

The objective of the present work is to study the feasibility of application of solar heating system integrated with thermal energy storage unit for the enhancement of settling tank for marine Heavy Fuel Oil Systems.

EXPERIMENTAL SECTION

The system designed consists of the cylindrical TES tank, which holds the PCM in a 4 layered packed bed of cylindrical aluminium capsules, Constant temperature bath, flow meter, temperature indicator and a circulating pump.

The stainless steel TES tank has a capacity of about 47 litres. With an internal diameter of 360mm and a height of 460mm, it houses the PCM capsules and allows for heat transfer between the PCMs and the Heat Transfer Fluid (HTF). The tank is insulated with 50mm of glass wool and is provided with an aluminium cladding.

The PCM is encapsulated in Aluminium cylinders of internal diameter 34mm and height 110mm, with wall thickness 2mm. Each cylinder contains 75gm of PCM by weight. The cylinders are packed in layers one over the other, with every two layers separated by a wire mesh to enhance the rigidity of the setup. The setup consisted of 4 layers of cylinders. RTDs are provided at four different locations of the storage tank and inside four PCM capsules to measure temperature changes of HTF between layers of PCM and in every layer of the PCM capsules, with an accuracy of ±0.3°C. The flow rate of the HTF through the system is measured using a Rotameter. The PCM used is industrial grade granulated paraffin wax with a melting point range of 58-61°C and water is used as both the HTF and the sensible heat storage(SHS) material. The TES tank is connected to a Solar flat plate collector of 2 m^2 colleting area and the PCM capsules in the TES tank are surrounded by water. Scaled down model of the settling tank has the 68 litres capacity filled with HFO of 57 litres and it contains copper coils connected to TES tank. The key experimental parameters are HTF inlet temperature and its flow rate.

EXPERIMENTAL METHOD

During the charging process, the HTF from Solar collector is circulated through the TES tank continuously. The HTF absorbs heat from solar collector sensibly, and exchanges this heat with the PCM in the TES tank, which is initially at atmospheric temperature. The PCM slowly gets heated, sensibly at first, until it reaches its melting point temperature. As the charging proceeds, energy storage as Latent heat is achieved as the Paraffin wax melts at constant temperature (60±2°C). After complete melting is achieved, further heat addition from the HTF causes the PCM to superheat, thereby again storing heat sensibly. The charging process continues till the PCM and the HTF attain thermal equilibrium. Temperatures of the PCM and HTF at the different locations are recorded at intervals of 10 minutes. Heating of HFO in the settling tank is achieved by circulating the HTF from TES tank, which recovers the stored heat energy in PCMs, to the settling tank. The HFO in the settling tank is heated continuously to attain the required temperature of 60°C.

RESULTS AND DISCUSSION

The temperature histories of HTF and PCM at four segments of the TES tank i.e. at x/L = 0.25, 0.50, 0.75 and 1.0 are shown in Figures 2 and 3. Figure 2 represents the temperature variation of the HTF inside the storage tank for a mass flow rate of 2 litres per minute. It is observed from the figure that the temperature of the HTF at all the segments increases gradually until it reaches the temperature of 62 or 63°C and then it remains nearly constant around 65°C for a period of 45 minutes during which the PCM undergoes phase change at 60±1°C. After that the HTF temperature increases up to 71 or 72°C.

Figure 3 represents the temperature variation of PCM during the charging process for the mass flow rate of 2 litres per minute. It is seen from the figure that the PCM temperature increases gradually at the beginning of the charging period and remains nearly constant around 60°C during melting process and increases sharply during heating of liquid PCM. Also it is noted from the figure that the PCM in the first segment is completely charged nearly 85% of the total charging time. The charging process is terminated when the PCM temperature in all the segments reaches 70°C.It is also observed from both the figures that there is no significant temperature difference between each segment from top to bottom of the storage tank during the sensible heating of the solid PCM and also during phase change period. The reason is that the water temperature in the storage tank increases gradually in accordance with inlet temperature of HTF supplied from the solar collector and the PCM temperature also increases gradually along with HTF temperature.

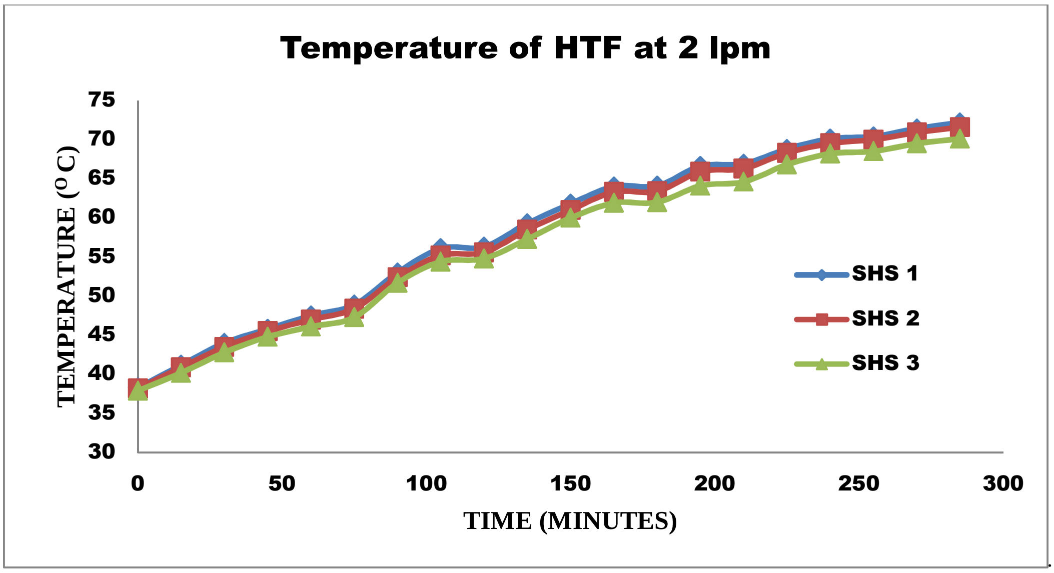

Fig. 2. Temperatures of HTF during charging process

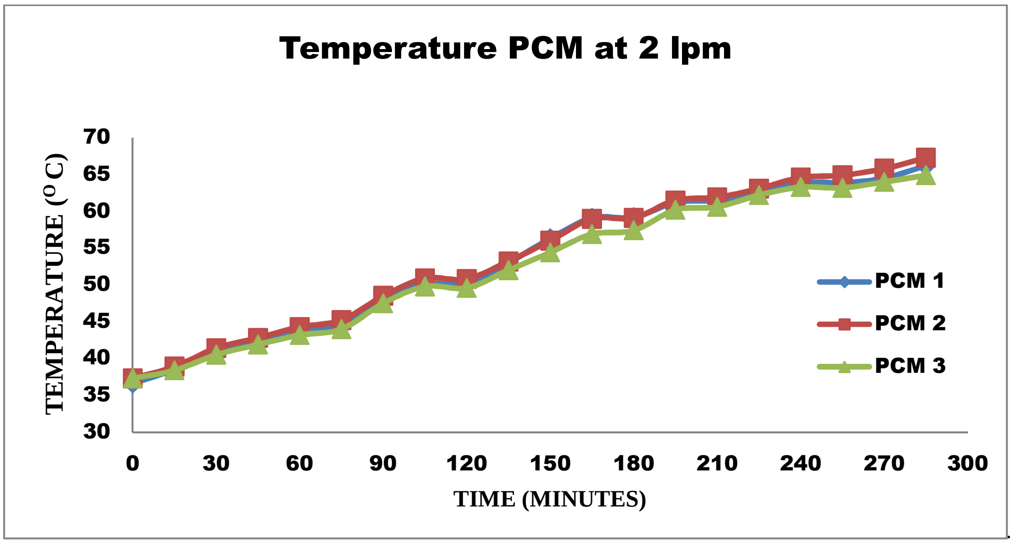

Fig. 3. Temperatures of PCM during charging process

CONCLUSION

Settling tank with the capacity of heating 57 litres of HFO coupled to cylindrical TES tank containing PCM in cylindrical capsules of 47 litres capacity is designed. The feasibility study of enhancement of settling tank for marine Heavy Fuel Oil Systems using thermal energy storage system is investigated. From the results, it is obvious that the heating of PCM occurs at constant temperature. Since the intended work is aimed at determining the feasibility of enhancement of settling tank for marine Heavy Fuel Oil Systems using thermal energy storage system, it is obvious from studies, the TES system integrated with solar heating system is suitable for heating of HFO in settling tank which enhances the settling operation. TES system can be applied to heat the HFO at nearly constant temperature due to the constant temperature behaviour of TES, which is desirable for efficient operation of settling tanks.

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