Shell-and-tube based thermal energy system coupled with flat plate solar collector

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To secure optimum utilisation of solar energy sources, a novel shell-and-tube heat exchanger with multi-tube passes and extended surfaces based latent heat storage (LHS) system was designed, developed and commissioned with an integration to flat plate solar collector in Organic Rankine Cycle (ORC). Paraffin, HFE-7000 and water were employed as thermal storage material and heat transfer fluids to sustain simultaneous generation of electricity and heat. It was noticed that the melting/solidification rates and charging/discharging powers were significantly augmented with an increase in Stefan number. However, an increase in Reynolds number had offered a moderate enhancement. The proposed design solution proficiently captured and released 14.35 MJ and 13.63 MJ while charging and discharging at constant inlet temperature for 3 h and 1.5 h, respectively. It was deduced that heat and electricity demands for domestic and industrial applications could be achieved and supplied by regulating inlet operating conditions of LHS system and/or by assembling LHS systems in series or parallel combinations.

INTRODUCTION

In order to reduce dependency on fossil fuels to generate heat and electricity for domestic and industrial applications, an Organic Rankine Cycle (ORC) based system has been designed and developed at NCEM, Bournemouth University [1]. A solar energy capture, energy conversion and energy storage system patent [GB2540670] has been secured. HFE-7000 was utilised as the working fluid and flat plate solar collector was employed as heat source. However, the widespread benefits were limited by intermittent and unpredictable nature of solar energy. Therefore, a novel LHS design solution with paraffin (RT44HC) as thermal storage material and shell-and-tube heat exchanger with multi-tube passes and longitudinal fins configuration was designed, developed and commissioned to sustain uninterrupted generation of heat and electricity [2-4]. The proposed novel design solution was not reported in previous literature and was capable of comparatively higher thermal energy storage/retrieval, charging/discharging power, average effectiveness and augmented natural convection. Besides, the proposed design supports easier mass production and integration to practical applications.

NUMERICAL / EXPERIMENTAL STUDY

Transient numerical simulations were conducted to optimise geometrical configuration of novel vertical shell-and-tube heat exchanger with extended surfaces [2]. During experimental investigations, paraffin (RT44HC) was filled in shell container, whereas water was employed to transfer thermal energy between solar collector and LHS system, as shown in **Fig. 1**. Series of sixteen close loop charging cycles and twelve open loop discharging cycles were performed to evaluate thermal performance at varied operating conditions; ranging from 52 – 67 ^{o}C for charging cycles and 5 – 15 ^{o}C for discharging cycles with volume flow rate from 1.5 – 3 l/min, respectively [3,4].

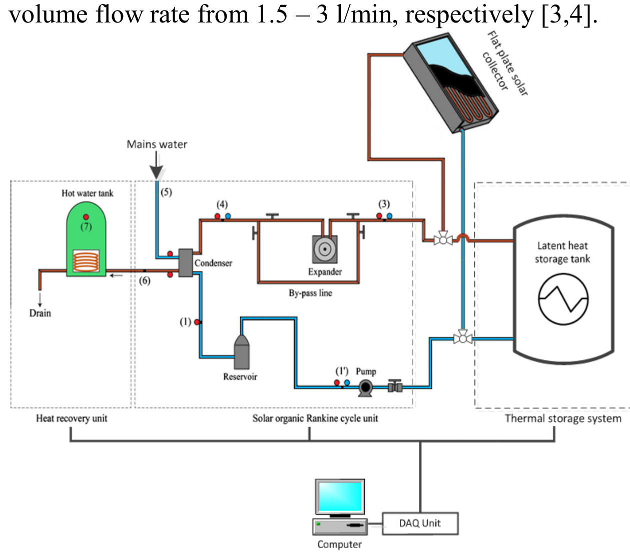

Fig. 1 LHS system coupled with solar collector and ORC [1-4]

RESULTS AND DISCUSSION

Experimental analyses showed that natural convection was dominant mode of heat transfer during charging cycles, whereas discharging cycles were influenced by conduction. Inclusion of longitudinal fins significantly enhanced melting/solidification rate of paraffin in shell container. Phase transition rates, average power and accumulative thermal energy storage/retrieval were significantly improved by 50.08%, 69.71% and 72.17% during charging cycles and 48.11%, 36.05% and 18.58% for discharging cycles with an increase in temperature gradient between paraffin and water. Furthermore, the empirical correlations for average effectiveness of LHS system during charging/discharging cycles were developed to facilitate predictive analytics for various thermal storage materials and operating conditions.

CONCLUSION

Thermal evaluations of proposed LHS system encouraged employability into wide-ranging domestic and industrial applications for continual generation of heat or electricity.

REFERENCES

1. H.U.Helvaci, Z.A.Khan. Energy Conv. Mgmt. 138(2017)493–510
2. Z. Khan et al. Energy Conv. Mgmt.127 (2016) 355–65
3. Z. Khan, Z.A. Khan. Appl. Energy. 206 (2017) 1158–68
4. Z. Khan, Z.A. Khan. Energy Conv. Mgmt. 154 (2017) 157-67

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