CHAPTER 7

CONCLUSIONS AND FUTURE SCOPE

7.1. Conclusions

This research work has integrated four organic PCMs (capric acid, lauric acid, paraffin wax, and stearic acid) with a TES system with IC engine exhaust for waste heat recovery. At the beginning of the work, the energy and exergy analysis of the concentric cylindrical TES system with various mass fractions of organic PCMs was examined. However, the thermophysical properties of nano additives-based NEPCMs were investigated. The optimum level of nano additives vol. fraction-based organic PCMs had shown a drastic improvement in the thermal performance of the TES system.

Furthermore, the thermal performance analysis has been discussed with nano additives-based NEPCMs of the TES system. Also, a theoretical comparative study has been done with inline and staggered tube bundles arrangement thermal energy storage (TES) methods. The number of tubes, longitudinal and parallel spacing on two consecutive tubes for inline and staggered tube arrangements has been considered by 5, $1.25D_o$, and $1.25D_o$, respectively. Effect of outlet air temperature, pressure drop, dimensionless number (Nusselt and Reynolds number), convective heat transfer coefficient, heat transfer rate on tube diameter, and airflow velocity tube length has been discussed well.

Based on the results of the theoretical studies, the design and fabrication of inline and staggered heat exchanger based, an effective TES-based waste heat recovery system for automobiles has been developed for conducting the experiments. These experiments were performed for air heating and cabin heating purposes with the waste heat from the exhaust of the IC engine. The following conclusions are drawn from the theoretical and experimental analysis:

- The maximum variation in charging time is 129.16% for the PW-PCM from 0.1kg to 0.4kg. Also, 0.4kg mass fraction, PW-PCM results in a higher charging time than CA, LA, and SA PCMs.
- The charging energy efficiency increased by 122.85%, 5.63%, and 99.17% for CA, LA, and SA PCMs. However, The energy efficiency of charging for the PW-PCM-based TES system decreased by 68.87% when the mass was increased from 0.1kg to 0.4kg.
- However, 0.4kg of LA PCM based TES system saves 44.16% more energy than paraffin wax and 68.15% more energy than stearic acid PCMs.
- In addition, the TES system with 0.4 kg of LA PCM saves 37.24% more exergy than paraffin wax and 57.56% more exergy than stearic acid PCMs.
- At an engine load of 7kg and engine speed of 1500 rpm, the TES system loaded with 0.1% vol. fraction Al_2O_3 nano additives based LA NEPCM needed 16.13%, 8.06%, 38.71%, 25.81%, and 32.26% less charging time than pure LA PCM, CuO-LA NEPCM, PW PCM, Al_2O_3-PW NEPCM, and CuO-PW NEPCM, respectively.

- When compared to pure LA, CuO-LA NEPCM, pure PW, Al_2O_3, and CuO nano additives based PW NEPCMs TES system, Al_2O_3-LA NEPCM filled in the TES system has 7.69%, 4.61%, 38.45%, 22.57%, and 35.38% higher heat extraction rate from shell and tube heat exchanger.
- Comparing the maximum heat storage case, CuO nanoparticles-based stearic acid NEPCM is 7.14% and 36.36% higher than Al_2O_3 nanoparticles-based stearic acid NEPCM and stearic acid PCM, respectively, at 50 minutes.
- The best result in energy analysis for an integrated TES system has been observed for 0.1% vol. fraction Al_2O_3 of lauric acid and 0.1% vol. fraction CuO of stearic acid PCMs based TES systems.
- The energy saved by TES system filled with lauric acid-based 0.1% Al_2O_3 nano-enhanced PCM was 90.17%, 2%, and 87.77% higher energy than Al_2O_3 nanoparticles based CA, PW, and SA NEPCM, respectively.
- The addition of 0.02% vol. MWCNT to organic PCMs increased the thermal performance and latent heat of the material and melting point, and energy transfer rate.
- For 0.02% MWCNT of CA, LA, PW, and SA composite phase change materials, the heat capacity (solid-state) was enhanced by 35.9%, 34.26%, 36.54%, and 25.86 %, respectively, against CA, LA, PW, and SA phase change materials.
- In CA, LA, PW, and SA composite PCMs, the thermal conductivity (solid) for 0.02 % vol. fraction MWCNT increased by 14.4%, 37.8%, 24.44%, and 13.54%, respectively, as compared to CA, LA, PW, and SA PCMs.

- With in the TES systems, the maximum heat transfer for 0.02% MWCNT in paraffin wax was 37.2% and 215% higher than the 0.02% volume fraction of MWCNT in lauric acid and stearic acid, respectively.

- The energy study for TES system integrated with engine exhaust revealed an optimum value for 0.02% vol. fraction of MWCNT-based PW-PCM.

- The heat transfer rate increased by 305 and 265%, respectively, for inline and staggered tubes with a changes in air velocity from 1 to 10 m/s over the tube bundle.

- The heat transfer rate for a 0.1% vol. Al_2O_3-based lauric acid-based staggered tube arrangement TES system was 52.72% and 40% higher than for lauric acid-based inline and staggered tube arrangement type TES systems, respectively.

- Experimental investigation on staggered tubes type TES system with 0.1% vol. fraction Al_2O_3-LA NEPCM, revealed a 8.6^{o}C highest temperature difference between the exit and intake of air.

- However, staggered tube arrangement TES system with 0.02% vol. fraction of MWCNT-PW NEPCM revealed a the maximum temperature difference of 8.4^{o}C between exit and inlet air. Also, 0.1% vol. fraction of CuO-SA NEPCM revealed a maximum temperature difference of 7.7^{o}C.

- For a space of 1m^3 volume capacity, the 0.1% vol. fraction of Al_2O_3-LA NEPCM based staggered tube arrangement type TES system has a 6.2^{o}C increase in temperature at 2m/s air velocity.

- The staggered tube type TES system has a less payback duration than the inline tube type TES system, as determined by economic study. The payback duration for a 0.1% vol. fraction of Al_2O_3 based LA NEPCM, staggered tubes type TES system is 10.24% and 5.84% less than 0.02% vol. fraction of MWCNT – PW and 0.1% vol. fraction of CuO-SA NEPCMs, respectively.

7.2. SCOPE FOR FUTURE WORK

It is evident that there is a lot of scope for new and creative ideas for creating energy-efficient and cost-effective cool and heat thermal storage systems on the research-oriented approach to the development of organic PCMs/NEPCMs. Future research topics include:

- The numerical study may be expanded to include other geometrics, and additional research with different geometrical parameters can be conducted.
- Shell and multiple tubes with fins-type TES systems can be investigated experimentally.
- An experimental study of how metal nanoparticles, graphene, and graphene oxide can improve the thermal conductivity of organic PCMs.
- A study of the thermal and rheological characteristics of nano-particle embedded PCMs with surface modification.
- An analytical investigation of the transient interface position of nanomaterials embedded PCMs filled with cylindrical encapsulation.
- An environmental investigation of the TES system with the I.C engine will be carried out.

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