A study on the development of direct thermal to hydraulic energy conversion systems

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論 文 内 容 の 要 旨

Thesis Summary

The majority of the global primary energy demand is lost after conversion, which contributes to the abundance of low-grade heat. While the generation of electricity is one of the common approaches to the low-grade heat utilizations, the investigation of direct energy conversion systems is also worthy of an investigation. For applications where the required final output form of energy is hydraulic work, a class of devices called thermally driven pumps (TDP) would be attractive to consider. The transportation of salt water in salt farms, the desalination of brackish water, the transport of water for agricultural applications over low elevations, are among some of the applications where direct use of low-grade heat can be converted to hydraulic work. The current study primarily focuses on the possible utilization of waste heat generated from renewable energy based microgrid system that are being investigated for the electrification of rural communities in developing countries, where the population density is lower, the national grid extension cost is high and hence microgrid systems are possible alternatives. Waste heat generated by the components of the microgrid systems, such as the biogas driven generators (BDG), presents the potential of utilizing the low-grade heat in a way that can contribute to the sustainability of such energy systems. From the points of view of affordability, local manufacturability, and applicability for agriculture, thermally driven pumps may be attractive for coupling with such microgrid systems. Therefore, the current study has focused on the development of a new type of thermally driven pumping system as a potential waste heat utilization component for microgrid applications in rural areas.

The scope of the study is mainly centered on the investigation of the technical challenges of TDPs which limits their applicability. Therefore, emphasis is given on the performance limits from thermodynamic perspective. Thus, as the initial step of the study, a thermodynamic assessment on the thermodynamic cycles related to TDP systems have been considered. Through the assessment, major limitation on the performance of unconventional cycle based TDPs was observed, and the Thermal Power Pump (TPP) cycle was observed to have yielded relatively higher performances. Therefore, the study continued with the investigation of the TPP cycle. An investigation on the TPP cycle using nine potential working fluids for cycle performance and the system size requirements, which is affected by heat transfer capabilities. The heat source temperature of the range 50 – 150 ℃, was considered. It was found that working fluids with stronger molecular forces seem to approach the properties of an ideal working fluid for better performance of a TDP system. Among the working fluids,

cyclopentane exhibits as an attractive choice of working fluid, due to its superior cycle performance over the wide range of heat source temperatures with moderate system size requirements.

Then, an attempt was made to develop a new thermally driven pumping system that is potentially simple, reliable, and low-cost for coupled operation with microgrid systems for rural communities in developing countries. A proof-of-concept prototype was developed, and parametric experimental investigations were carried out. It was found that the system performance strongly depends on the heat addition rate and delivery capacity of the system. For the heat source temperature of 60 ℃, delivery pressures in the range of 119 – 174 kPa were attained and the thermal efficiencies were in the range of 0.51 - 0.68%. The performance values are higher than the literature, however, to put the results into the perspective of the intended application, the capability of the proposed TDP when it is driven by the waste heat from the engine coolant of a BDG unit was estimated. The experimental data were used to estimate whether the proposed system can pump enough water that needs to be supplied for the biogas production to supply a 10 kW BDG unit of a microgrid. It was found that 87 – 93% of the total pumped water (13 – 27 m^3) would be available for agricultural and other purposes while only 6 – 13% would need to be fed to the biogas digester. Generally, the results seem to be promising, and yet there are potentials for the optimization and improvement of the proposed system, hence they have been pointed out.

Porous mesh that is made up of thin copper filaments was introduced as an economical method of passive heat transfer enhancement for the developed TDP system. The enhancement method resulted in 47 – 144 % increment of the heat transfer rate and 38 - 186% increment in the delivery flow rate of the system in comparison to the case where no porous mesh was used. Thus, the results suggest that the enhancement method could be promising for the intended application.

Finally, to extend the performance limitation of TDPs for general applications, a hybrid approach was introduced by developing the concept of a variable force transmission mechanism VFTM. Results of the simulation that was conducted on the proposed hybrid system show that the hybrid approach has the potential to enhance the performance of low-grade heat to hydraulic work conversion.

Further studies on the proposed conversion system are necessary, specially, the area specific techno-economic investigation of the proposed thermally driven pumping system for the coupled operation with waste heat sources would be necessary.