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A study on power generation from low grade heat using organic rankine cycle system in Thailand（タイにおけるオーガニックランキンサイクルを利用した低温熱源発電システムに関する研究）

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論　文　内　容　の　要　旨

An Organic Rankine Cycle (ORC) system has been widely applied for power generation from low-temperature heat sources such as solar energy, geothermal, biomass, wasted heat from industrial processes, etc. However, this technology is less applicable for the heat source having temperature below 70 ° C due to a combination of market and technical barriers. Moreover, there are only a few designed to utilize lower-temperature heat supplies on a small-scale ORC power generation. *Chapter 1* introduces a concept and scope of this thesis. *Chapter 2* describes the theoretical of the main components of the proposed systems are: solar water heating system (SWHS), vapor compression heat pump (VCHP), gas engine-driven heat pump (GEHP), absorption heat transformer (AHT), and Organic Rankine Cycle (ORC) systems. *Chapter 3*, 19 fluids were investigated to find the suitable working fluid for an ORC system and a VCHP system. The operating conditions of the ORC system were power output of 60 kW_{th}, ORC evaporating temperature was in a range of 60 to 100 ° C and ORC condensing temperature of 35 ° C. Moreover, isentropic efficiencies of pump and turbine were 80 and 85%, respectively. It was found that the suitable working fluid for the ORC system is R-365mfc, R-245ca, R-245fa, and R-1234zez, due to they gave low mass flow rate, low evaporating pressure and high thermal efficiency. In addition, it low global warming potential (GWP), toxicity, and non-flammable. For the VCHP system, the operating conditions were cooling capacity of 10 kW, VCHP evaporator temperature was set at 60 ° C, required of hot water temperature is around 70 to 90 ° C. Moreover, isentropic efficiency of compressor, degree of superheating and sub-cooling is 80%, and 5 ° C, respectively. It was found that the suitable working fluid of the VCHP system is R-365mfc due to its low maximum pressure for the heat pump compressor and the highest value of COP for supplying heat at around 70 to 90 ° C.

Chapter 4 analyzes the low-heat upgrading technologies for ORC Power Generation; three upgrading technologies for recovering industrial waste heat (IWH) to work in conjunction with ORC generation are evaluated and compared. These three systems: (i) Vapor compression heat pump (VCHP), (ii) Gas engine-driven heat pump (GEHP), and (iii) Absorption heat transformer (AHT), are

mathematically modeled considering a thermal capacity of 250 kW for all three systems. For VCHP and GEHP, the working fluid is R-365mfc, while the AHT uses H_2O-LiBr. In each combination, a 20 kW_e ORC power generator with R-245fa as working fluid is connected. The results were found that, the VCHP system was considered the most suitable in terms of its compactness, and simplicity in installation, operation and maintenance. According to economic analysis, when the temperature of heat source is around 63 ° C, VCHP-ORC also achieves the lowest levelized cost of electricity (LCOE), followed by AHT-ORC and GEHP-ORC, respectively.

Chapter 5 simulates the performance of the VCHP-ORC power system while the wasted industrial heat is available and upgraded by solar water heating system (SWHS). In this Chapter, simulates the performance of the VCHP system modeled in *Chapter 4* and integrated with the ORC system supplied by the low-grade IWH upgraded by the SWHS for power generation; the supplied heat to the system is at temperature below 70 ° C. A SWHS and a VCHP are used to boost up the heat. A 400 kW thermal capacity VCHP, with R-365mfc as the working fluid, is used to rise the heat from IWH and SWHS before supplying to a 60 kW_e ORC power generator with R-245fa from KOBELCO Company. Three types of solar collectors were used to generate heat: flat-plate, heat pipe evacuated-tube and compound parabolic concentrator (CPC). Between 300 and 700 units of each type of the collectors were connected in parallel. The system is mathematically modeled and simulated to evaluate the net power output, the CO_2 emission, and the LCOE. Six industrial areas consist of, Chiang Mai, Bangkok, Ratchaburi, Songkhla, Nakhon Ratchasima, and Chon Buri, that represent the north, central, west, south, north-east and east part of Thailand, respectively. Their weather data was taken for the simulations. The simulation results showed that the system produced high electricity when the number of the collectors is increased. Moreover, the system located in Chiang Mai produced the highest amount of electricity with the lowest LCOE.

Chapter 6 area where the only heat source is a SWHS were considered, particularly the case which would make the use of heat boosters lose their effectiveness. This was done taking into account that a system that only requires solar collectors, which are more common in Thailand, would be more interesting for the Department of Alternative Energy Development and Efficiency (DEDE) of Ministry of Energy, and reduce the barrier from its implementation. In this Chapter, evaluate a small-scale solar Organic Rankine Cycle (SORC) power system with temperature below 100 ° C; the system performance was analyzed based on two capacities for the ORC system with R-245fa (20 and 60 kW_e) combined in four different configurations with three types of stationary solar collectors (Flat-plate, evacuated-tube and CPC solar collectors). The testing configuration consists of solar collectors between 100 and 1200 units integrated with one, two, and three units of a 20 kW_e ORC system, and one unit of a 60 kW_e ORC system. This system was mathematically modeled and simulated to obtain the optimal flow rate of hot water for the maximum power output, the minimum CO_2 emission, and the LCOE. The weather data from Bangkok chosen as a representative city in the central part of Thailand was used for simulations. The study results were presented according to power output and environment impact based on each model, type, and the number of the employed collectors. The simulation results show that, with the same number of solar collectors, the system can produce the highest power output, when the system combined with the CPC collectors. In terms of the economic analysis, LCOE of a 60 kW_e ORC system has the lowest value in case of taking 950 units of evacuated-tube solar collectors without initial investment of the collectors into consideration. In addition to that, LCOE of the system has the lowest value in case of considering 900 units of the same collectors with initial investment of them.