PERFORMANCE COMPARISON OF ORGANIC RANKINE CYCLE (ORC) AND CO_2 CYCLE FOR SIMULTANEOUS UTILIZATION OF LIQUEFIED NATURAL GAS (LNG) COLD ENERGY AND SOLAR ENERGY

Haoshui Yu[1]*, Ning Guo[2], Sylvain Quoilin[3,4], Gürkan Sin[1]

[1]Process and Systems Engineering Center (PROSYS), Department of Chemical and Biochemical Engineering, Technical University of Denmark, Building 229, 2800, Kgs. Lyngby, Denmark

[2]Department of Energy and Process Engineering, NTNU - Norwegian University of Science and Technology, Kolbjørn Hejes v. 1A, NO-7491 Trondheim, Norway

[3]Department of Mechanical Engineering, KU Leuven, Geel. Kleinhoefstraat 4, Geel 2440, Belgium

[4]Integrated and Sustainable Energy Systems (ISES), University of Liège, Allée de la Découverte 17, 4000, Belgium

*Corresponding Author: hayua@kt.dtu.dk

ABSTRACT

LNG is a good way to transport natural gas from suppliers to consumers. However, the LNG cold energy is generally lost during the regasification process at the receiving terminals. LNG cold energy can be a great heat sink for power cycles. Meanwhile, solar energy is abundant on the earth and it is a great heat source for the power cycles. If solar energy and the LNG cold energy can be utilized in an integrated power system, the efficiency of energy utilization and economical profitability would be increased substantially. Organic Rankine Cycle (ORC) and CO_2 cycle can utilize LNG cold energy and solar energy. ORC performs better than the CO_2 cycle for LNG cold energy utilization since organic working fluid can condensate at a much lower temperature, while the transcritical CO_2 cycle may perform better since the supercritical CO_2 can match well with the transfer fluid from the solar collector. One-cycle and dual-cycle power generation systems are proposed and modeled in this study. A single unified model is developed in the Python language and presents the capacity to model different cycle configurations (subcritical, transcritical, supercritical). The rigorous thermodynamic model and system configuration model are established based on the CoolProp platform. The transcritical power generation system has the maximum power output, while the transcritical CO_2 cycle has a much lower volume flowrate at the outlet of the turbine, which may be a better option from the techno-economic point of view.

1 INTRODUCTION

LNG contains a significant amount of cold energy due to the energy consumed in the liquefaction process (Lee and You, 2019). However, this cold energy is generally wasted during the regasification process. Power generation with LNG as the heat sink is therefore an energy-saving and environment-friendly solution (Yu et al., 2021). On the other hand, solar energy is abundant and regarded as promising renewable energy for sustainable development (Hu et al., 2020). Organic Rankine cycle (ORC) has been widely investigated and commercially developed to convert heat into power in many applications (Quoilin et al., 2013), such as geothermal power generation (Walraven et al., 2015), compression heat recovery (Yu et al., 2018), refinery waste heat utilization (Yu et al., 2016), engine waste heat recovery (Scaccabarozzi et al., 2018), and solar thermal power generation (Yang et al., 2019). Recently, ORC has been proposed as a power generation alternative to recover LNG cold energy instead of low-temperature waste heat (Yu et al., 2019). Other than ORCs, CO_2 based Brayton cycle is also a promising way to generate electricity. The supercritical CO_2 cycle is extensively investigated for oxy-combustion power generation, waste heat recovery, and renewable energy applications (Ahn et al., 2015). Since the heat sink is above ambient temperature generally, the condensation process takes place above or near the top saturation dome of the CO_2 T-S diagram. However, if lower temperature heat sink is available, the condensation process of the CO_2 can take place in subcritical conditions, which can improve the efficiency of the power cycle significantly. This is suitable for LNG cold energy recovery and the CO_2 power cycle is termed as transcritical CO_2 cycle since both subcritical and supercritical operating conditions occur in this system. Transcritical CO_2 cycle has been applied to heat pumps, air-conditioning and refrigeration applications (Groll and Kim, 2007). Similarly, CO_2 has the potential to be used as a working fluid for the power cycle in the cryogenic temperature range. Lin et al. (2009) proposed to use a transcritical CO_2 cycle for simultaneous LNG cold energy and waste heat recovery. Compared with subcritical ORC, the transcritical CO_2 cycle can achieve a higher energy efficiency since the supercritical CO_2 matches well with the sensible heat source in the evaporator. Pinch limitation in the evaporator is eliminated in transcritical CO_2 cycle. Furthermore, CO_2 is stable, non-flammable, non-toxic, non-corrosive, inexpensive and has low environmental impacts as well as favorable thermodynamic properties. However, the irreversibility of the condensation process with LNG as the heat sink can be larger compared with an ORC system since the condensation temperature is limited to the triple point, which prevents its application at very low temperatures. Chen et al. (2006) compared the transcritical CO_2 cycle and ORC for waste heat recovery, and the condensation temperature is not at cryogenic temperature level. Yu et al. (2019) investigated 22 working fluids for ORC operating across and below ambient temperature to recover LNG cold energy. CO_2 cycle is inferior to other organic working fluids under the fact that the waste heat temperature is assumed to be 150°C and the system configuration is fixed as well. To the best knowledge of the authors, there is no study to investigate the ORC and CO_2 cycle performance for simultaneous utilization of LNG cold energy and solar energy. Therefore, the performance of an ORC system and transcritical CO_2 cycle system is investigated and compared in this study. To that aim, a new model is proposed to optimize both systems. This model accepts both subcritical and transcritical operating conditions for any working fluid. It is written in Python and uses the open-source CoolProp (Bell et al., 2014) thermo-physical properties library. The proposed tool belongs to the category of sizing or design models, in which the nominal thermodynamic conditions are optimized with respect to the boundary conditions, contrary to simulation models (Dickes et al., 2018), in which the system architecture is imposed, and the part-load performance is predicted. The source code of the model is provided under an open license to ensure the reproducibility and transparency of this work (Available at https://github.com/squoilin/LNG-Regasification), which are key features for the quality of science (Pfenninger et al., 2017).

2 SYSTEM DESCRIPTION

LNG is shipped at about -162°C under atmospheric pressure and stored in LNG tanks (Angelino and Invernizzi, 2009). In this study, we propose two different flowsheets of the system utilizing LNG cold energy and solar energy simultaneously. Figure 1(a) illustrates the one-cycle power generation system. The LNG is pumped to high pressures (>70 bar) and then regasified in the condenser of the power cycle. The regasified natural gas is injected into the pipeline to other end users. In the power cycle, there are 5 major components: a pump, a heater, an evaporator, a turbine and a condenser. The working fluid is pumped to high pressure and then heated by the heat transfer fluid from solar collectors. Next, the saturated or superheated vapor expands through a turbine and generates electricity. Finally, the working fluid condensates in the condenser, where LNG evaporates and LNG cold energy is recovered. Due to the large temperature difference between the heat transfer fluid from solar collectors and the cryogenic LNG, one power cycle may not utilize the energy efficiently. To improve the efficiency of the integrated system, a dual-cycle system is proposed in this study as shown in Figure 1(b). The dual-cycle system consists of a low temperature cycle and a high temperature cycle. The high temperature cycle is a transcritical CO_2 cycle, selected for the its good thermal match with the heat source and low volume flowrate of CO_2 at the outlet of a turbine. In the low temperature cycle, low boiling point organic compounds are chosen as the working fluids since such organic compounds can achieve cryogenic condensation temperature and the exergy loss could be reduced.

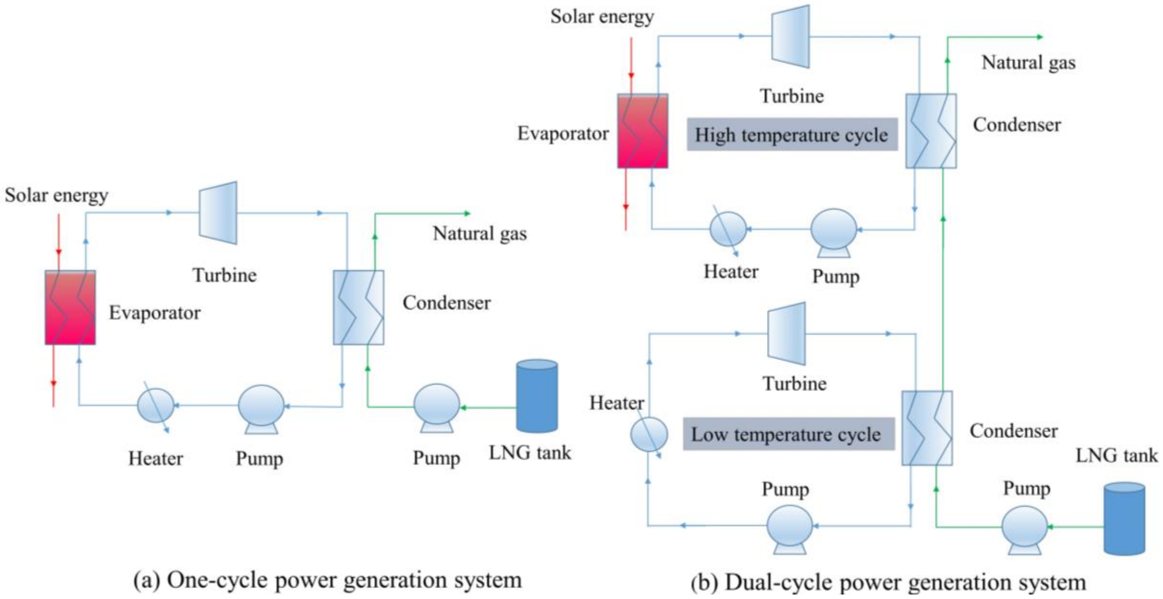

Figure 1: The layout of the power generation system investigated in this study

The one-cycle power system can be operated under transcritical or subcritical conditions, and the corresponding T-S diagrams of the one-cycle power system are illustrated in Figure 2(a) and (b). Figure 2(a) illustrates the T-S diagram of transcritical ORC or CO_2 cycle, where the working fluid matches well with heat transfer fluid from solar collectors. However, for the subcritical ORC, the evaporation process may exhibit large exergy loss due to the isothermal phase change of the working fluid, as shown by the T-S diagram of subcritical ORC in Figure 2(b). The pinch point generally occurs at the evaporation temperature and limits the amount of heat transferred in the evaporator. With proper organic working fluids, an ORC can achieve a much lower condensation temperature. However, the lower the condensation temperature, the lower the critical temperature of the working fluid, which implies that the evaporation temperature cannot be at high temperatures. Therefore, the organic working fluid selection plays an important role in the system. For the dual-cycle power system, the T-S diagram is illustrated in Figure 2(c), the low temperature cycle mainly focuses on recovering the LNG cold energy at cryogenic temperature level. The cooling water from other industries or seawater can be used as the heat source in the low temperature power cycle. At cryogenic temperature, the CO_2 cycle is impossible to operate due to the triple point of CO_2 limitation and an ORC is adopted for the low temperature cycle.

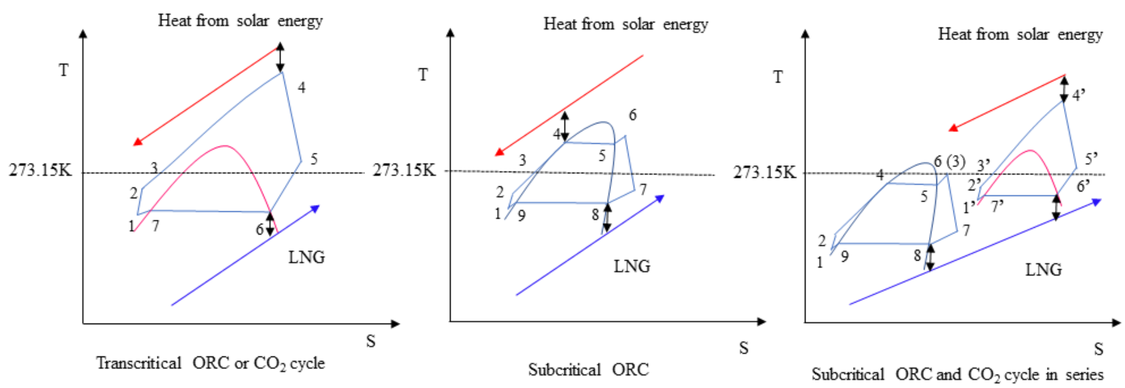

Figure 2: T-S diagram of different power generation systems

3 PROCESS MODELING AND OPTIMIZATION

Before developing the model of the power system, some key parameters should be defined and some assumptions have to be made as follows. The LNG inlet temperature is -160°C and regasified at different pressure levels depending on the applications of the natural gas. For local distribution, the regasification pressure is around 30 bar, while the regasification pressure can be as high as 70 bar for long distance distribution (Bisio and Tagliafico). In this study, the natural gas is targeted for long distance distribution. The LNG is simplified as a material stream with constant specific heat capacity since the evaporation pressure is higher than 70 bar and the phase change of LNG during the regasification can be ignored (Yu et al., 2021). Figure 3 illustrates the temperature profile of LNG regasification process under different pressures. With the increase of the regasification pressure, the phase change of LNG disappears generally. When the evaporation pressure is 70 bar, the T-Q diagram can be regarded as a straight line, which is the basis of the assumption of constant specific heat capacity. That is because the T-Q diagram is convex and nearly a straight line, and thus it is totally fine to treat the curve as a straight line. The supply temperature of the heat transfer fluid from the solar collectors is assumed to be 200°C. The heat capacity flowrate of the LNG and the heat transfer fluid are both assumed to be 100 kW/°C for the sake of simplicity. At 70 bar, if the heat capacity flowrate of LNG is 100 kW/°C, the mass flowrate of LNG is about 4950 kg/h based on the energy balance calculation from Aspen HYSYS. Therefore, the LNG curve and the heat transfer fluid from solar collector curve in the T-Q diagram are parallel. These parameters can be optimized as well, but they are assumed to be constants in this study. The pinch temperature difference is assumed to be 10°C. The degree of superheating and subcooling is assumed to be 5°C. The isentropic efficiency of the pump and turbine is assumed to be 60%. The minimum condensation pressure is assumed to be 1 bar to avoid vacuum operation.

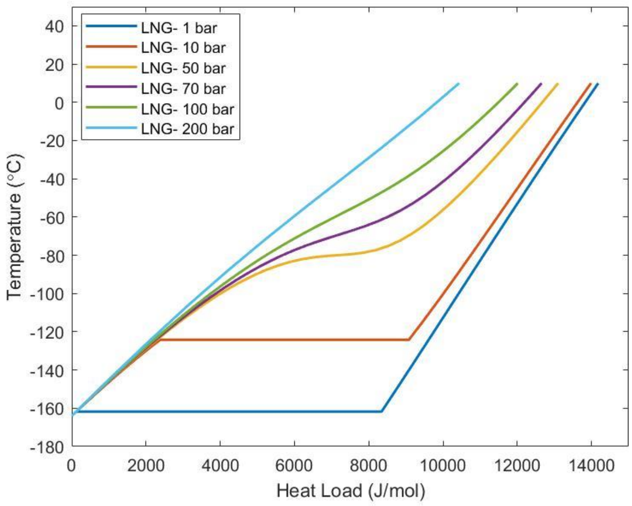

Figure 3: LNG regasification process under different pressures

In this study, CoolProp is chosen as the thermo-physical properties library, which is written in C++ with wrappers available for the majority of programming languages (Bell et al., 2014). CoolProp includes more than 100 working fluids. The desired properties of the working fluid can be retrieved easily with the help of ProsSI function.

Once the properties of the working fluid at each state point in the T-S diagram in Figure 2, the model of the system can be developed based on energy and mass balance equations. Condensation pressure and evaporation pressure are chosen as the independent variables in the system design. The mass flowrate of the working fluid is also a critical parameter of the system. However, the mass flowrate of the working fluid is limited by the pinch point in the condenser or evaporator. The black arrows in Figure 2 denote the possible location of pinch points. For example, for the subcritical ORC as shown in Figure 2, the pinch point may locate at state point 8 or 4.

If the pinch point occurs at state point 8, the LNG is heated up and the heat load below the pinch point can be calculated by Equation (1).

$$Q_{LNG} = (T_8 - \Delta T - T_{LNG}^{in}) \cdot Cp_{LNG} \tag{1}$$

Then the mass flowrate of the working fluid based on the energy balance from the condenser can be calculated by Equation (2).

$$m_{con} = Q_{LNG} / (h_8 - h_1) \tag{2}$$

Similarly, if the pinch point occurs at state point 4, the heat released from the heat transfer fluid above the pinch point can be calculated by Equation (3).

$$Q_{HTF} = (T_{HTF}^{in} - T_4 - \Delta T) \bullet Cp_{HTF} \tag{3}$$

Then the mass flowrate of the working fluid based on the energy balance from the evaporator can be calculated by Equation (4).

$$m_{eva} = Q_{HTF} / (h_6 - h_4) \tag{4}$$

Then the final mass flowrate of the working fluid should be the minimum one as shown in Equation (5).

$$m = \min\{m_{con}, m_{eva}\} \tag{5}$$

For the transcritical cycle, the pinch point can occurs in the process of heat exchanger other than the hot end of the heat exchanger. Therefore, the heat exchange process is discretized into N cells in total. For example, the heat transfer fluid heat load in each cell can be calculated by Equation (6).

$$Q_{cell} = Q_{HTF} / N \tag{6}$$

Then the enthalpy at n+1 cell can be calculated by Equation (7)

$$H_{n+1}^{HTF} = H_n^{HTF} - Q_{cell} \tag{7}$$

The corresponding temperature at each cell boundary can be determined by the CoolProp inbuilt function. Based on these temperatures, the pinch temperature difference can be identified. If the pinch temperature difference is less than the specified minimum pinch temperature difference, the target temperature of the superheated working fluid has to be decreased until the pinch temperature difference is greater or equal to the specified minimum pinch temperature difference.

Once the mass flowrate of the working fluid is determined, the net power output of the system under the specified evaporation and condensation pressure can be determined. The mass flowrate of the working fluid can be calculated in a similar way for the transcritical power generation system and the dual-cycle power generation system. However, for the dual-cycle power system, it is more complex since there are two cycles and the mass flowrate of working fluids has to be determined twice.

Once the model of the system is established, the next step is to identify the optimal operating conditions. To determine the optimal operating conditions (optimal evaporation and condensation pressure of the power system). The Particle Swarm Optimization (PSO) algorithm from the Pyswarm Python library (https://pythonhosted.org/pyswarm/) is employed to solve the optimization problem in this study. PSO is a gradient-free evolutionary algorithm (Bai, 2010), and is quite suitable for solving the non-linear optimization problems on black-box models in which the partial derivatives are not known. For the one-cycle power system, there are two independent variables, namely the evaporation and condensation pressures. For the dual-cycle power system, there are four independent variables, namely the evaporation and condensation pressures for both low and high temperature cycles. For the PSO algorithm, the population size is set as 50 and the maximum iteration is set as 100. The lower and upper bounds of the variables are set appropriately depending on the working fluid.

4 RESULTS AND DISCUSSION

The optimal results for the one-cycle and dual-cycle power generation system are presented in Table 1. Several promising working fluids for ORC at cryogenic temperature levels are tested. For the one-cycle power generation system, propane and R1270 are chosen as the working fluid for the subcritical cycle, while propane and CO_2 are chosen as the working fluid for the transcritical cycle. Since the turbine outlet stream volume flowrate is a critical parameter in the turbine design and directly determines the capital cost of the system, the turbine outlet stream volume flowrate is also investigated.

The total volume flowrate and the specific volume flowrate at the turbine outlet are listed in Table 1. The transcritical cycle with propane as the working fluid has the maximum power output. However, the volume flowrate of propane under transcritical conditions is much larger than that in other scenarios. On the contrary, CO_2 has the lowest volume flowrate among all the investigated working fluids. The specific volume flowrate at the turbine outlet in the transcritical CO_2 cycle is just 0.75 m^3/MW. A smaller volume flowrate means a smaller turbine, and thus the capital cost can be significantly reduced. If the rigorous function between the volume flowrate and the capital cost of a turbine is available, the techno-economic assessment can be performed.

Table 1: The optimal results for all of the power systems investigated in this study

System configuration		Working fluid	Net power output (kW)	Volume flowrate (m^3/s)	Specific volume flowrate (m^3/MW)	Heat source final temperature (°C)
One-cycle	Subcritical	Propane	2016.8	11.35	5.63	90
		R1270	1861.5	10.04	5.39	103
	Transcritical	Propane	3290.6	15.76	4.79	38
		CO_2	2437.2	1.83	0.75	52
Dual-cycle		R116 & CO_2	2183.7	7.6 & 0.56	6.9 & 0.52	27
		Ethane & CO_2	2384.1	6.0 & 0.67	5.7& 0.50	27

For the dual-cycle power generation system, CO_2 is the working fluid for the high temperature cycle due to its low specific volume flowrate. For the low temperature cycle, the working fluid should have a condensation temperature close to the LNG temperature to utilize the LNG cold energy efficiently. R116 and ethane are selected as candidate working fluids based on these considerations. However, the results indicate that the subcritical ORC performs the worst. This is due to the large temperature difference between the heat transfer fluid from the solar collectors and the LNG stream.

Subcritical ORC is limited by both condensation and evaporation pressures. The transcritical power cycle performs best among the others. The T-S diagrams of the transcritical power cycle with CO_2 and propane as the working fluids are illustrated in Figure 4. For the transcritical CO_2 power cycle, the pinch point occurs at the outlet of the evaporator, which means the turbine inlet temperature has reached its maximum value. For the transcritical propane cycle, the pinch point occurs in the evaporator. The supercritical propane match well with the heat transfer fluid from the solar collectors. Even though the net power output of the transcritical propane cycle is higher than the transcritical CO_2 cycle, the volume flowrate of CO_2 is much lower than that of propane. This advantage may justify the transcritical CO_2 system from the techno-economic point of view, which deserves further investigation. The temperature difference in the LNG evaporator is large for both the transcritical CO_2 cycle and the propane ORC. For the transcritical CO_2 cycle, the condensation temperature is limited by the triple point of CO_2. For the ORC with propane as the working fluid, the condensation temperature is limited by the saturate temperature under ambient pressure. On the contrary, the temperature difference in the heat exchanger between the working fluid in the power cycle and the heat transfer fluid from solar energy is much lower, which results in much less heat transfer irreversibility.

The final temperatures of the heat source from the solar energy are presented in the last column of Table 1. It is clear that the subcritical one cycle system exhibits much higher final temperatures of heat source, which indicates the solar energy is not utilized effectively. The dual cycle can utilize the solar energy effectively, however, the total net power output of the dual cycle does not show improvement compared with transcritical one-cycle system. The reason is that even though the solar energy is effectively utilized in the dual cycle system, the dual cycle requires two times heat transfer, which cause exergy losses. Therefore, the net power output is not increased compared with the transcritical one-cycle power system.

The dual-cycle power generation system does not improve the performance of the system in terms of net power output. If the working fluid in the low-temperature cycle can be heated further by the heat transfer fluid from solar collectors, the performance could be improved. However, the modeling and optimization of such system are more complicated since the interaction between low and high temperature cycle is much stronger. The low and high temperature cycles have to be considered and optimized simultaneously in such a case, which will be investigated in our future work.

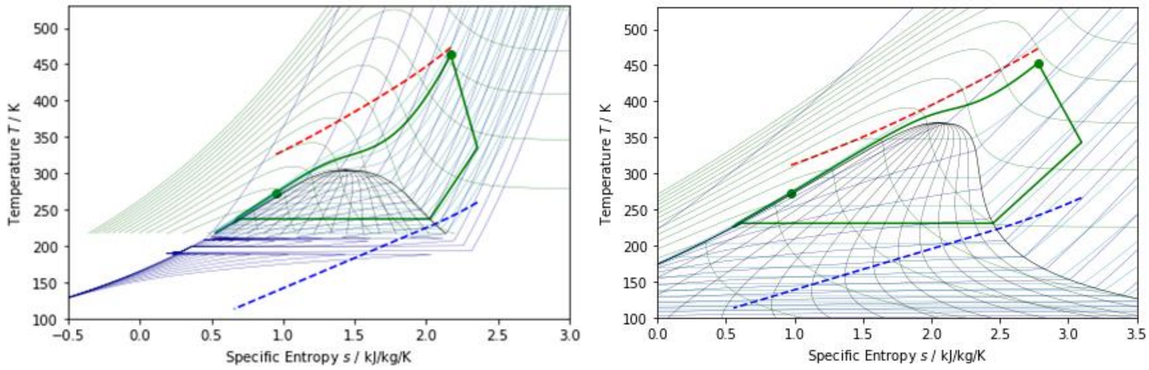

Figure 4: T-S diagram of the transcritical one-cycle power system with CO_2 (left) and propane (right) as the working fluid under optimal operating conditions

5 CONCLUSIONS

In this study, power generation systems for simultaneous utilization of LNG cold energy and solar energy is investigated. Organic Rankine cycle and transcritical CO_2 cycle are investigated and compared. One-cycle and dual-cycle power generation systems are proposed. A unified model of different power generation systems is developed in Python based on the CoolProp library. This model is designed to ensure convergence in all conditions (subcritical and supercritical) and with all working fluids (CO_2, Ethane, etc.), which is a necessary condition to run an optimization. The power generation systems are optimized under subcritical and transcritical conditions with the particle swarm optimization (PSO) algorithm. The results reveal that a one-cycle transcritical power generation system with propane as the working fluid performs best in terms of net power output. However, the CO_2 power cycle has the merits of being compact in turbomachinery and environment-friendly, which is favorable in both the economy and environment. The specific volume flowrate of the transcritical CO_2 cycle is just 0.75m^3/MW, which is much lower than ORC. The transcritical CO_2 cycle may be more competitive from the techno-economic point of view. The techno-economic evaluation of the transcritical CO_2 cycle power generation system should be performed. Besides, a dual-cycle power generation system can not improve the net power output compared with the transcritical one-cycle power system. The solar energy can be utilized effectively in the dual-cycle power system, however, the net power output is not increased since dual cycle power system requires twice heat transfer and the exergy losses is more significant. The performance of the dual-cycle power generation system can be improved if the low temperature cycle can be heated up by the heat transfer fluid from the solar collectors further. The techno-economic analysis of the turbine and the dual-cycle power generation system improvements will be investigated in future work.

REFERENCES

Ahn, Y., Bae, S.J., Kim, M., Cho, S.K., Baik, S., Lee, J.I., Cha, J.E., 2015. Review of supercritical CO2 power cycle technology and current status of research and development. Nuclear Engineering and Technology 47, 647-661.

Angelino, G., Invernizzi, C.M., 2009. Carbon dioxide power cycles using liquid natural gas as heat sink. Applied Thermal Engineering 29, 2935-2941.

Bai, Q., 2010. Analysis of particle swarm optimization algorithm. Computer and information science 3, 180.

Bell, I.H., Wronski, J., Quoilin, S., Lemort, V., 2014. Pure and Pseudo-pure Fluid Thermophysical Property Evaluation and the Open-Source Thermophysical Property Library CoolProp. Industrial & Engineering Chemistry Research 53, 2498-2508.

Bisio, G., Tagliafico, L., 2002, On the recovery of LNG physical exergy by means of a simple cycle or a complex system. Exergy, an International Journal 2, 34-50.

Chen, Y., Lundqvist, P., Johansson, A., Platell, P., 2006. A comparative study of the carbon dioxide transcritical power cycle compared with an organic Rankine cycle with R123 as working fluid in waste heat recovery. Applied Thermal Engineering 26, 2142-2147.

Dickes, R., Dumont, O., Guillaume, L., Quoilin, S., Lemort, V., 2018. Charge-sensitive modelling of organic Rankine cycle power systems for off-design performance simulation. Applied energy 212, 1262-1281.

Groll, E.A., Kim, J.-H., 2007. Review of recent advances toward transcritical CO2 cycle technology. Hvac&R Research 13, 499-520.

Hu, M., Zhao, B., Ao, X., Ren, X., Cao, J., Wang, Q., Su, Y., Pei, G., 2020. Performance assessment of a trifunctional system integrating solar PV, solar thermal, and radiative sky cooling. Applied Energy 260, 114167.

Lee, I., You, F., 2019. Systems design and analysis of liquid air energy storage from liquefied natural gas cold energy. Applied Energy 242, 168-180.

Lin, W., Huang, M., He, H., Gu, A., 2009. A transcritical CO_2 Rankine cycle with LNG cold energy utilization and liquefaction of CO2 in gas turbine exhaust. Journal of Energy Resources Technology 131, 042201.

Pfenninger, S., DeCarolis, J., Hirth, L., Quoilin, S., Staffell, I., 2017. The importance of open data and software: Is energy research lagging behind? Energy Policy 101, 211-215.

Quoilin, S., Broek, M.V.D., Declaye, S., Dewallef, P., Lemort, V., 2013. Techno-economic survey of Organic Rankine Cycle (ORC) systems. Renewable and Sustainable Energy Reviews 22, 168-186.

Scaccabarozzi, R., Tavano, M., Invernizzi, C.M., Martelli, E., 2018. Comparison of working fluids and cycle optimization for heat recovery ORCs from large internal combustion engines. Energy 158, 396-416.

Walraven, D., Laenen, B., D'Haeseleer, W., 2015. Economic system optimization of air-cooled organic Rankine cycles powered by low-temperature geothermal heat sources. Energy 80, 104-113.

Yang, J., Li, J., Yang, Z., Duan, Y., 2019. Thermodynamic analysis and optimization of a solar organic Rankine cycle operating with stable output. Energy Conversion & Management 187, 459-471.

Yu, H., Eason, J., Biegler, L.T., Feng, X., Gundersen, T., 2018. Process optimization and working fluid mixture design for organic Rankine cycles (ORCs) recovering compression heat in oxy-combustion power plants. Energy Conversion and Management 175, 132-141.

Yu, H., Feng, X., Wang, Y., Biegler, L.T., Eason, J., 2016. A systematic method to customize an efficient organic Rankine cycle (ORC) to recover waste heat in refineries. Applied Energy 179, 302-315.

Yu, H., Gundersen, T., Gençer, E., 2021. Optimal liquified natural gas (LNG) cold energy utilization in an Allam cycle power plant with carbon capture and storage. Energy Conversion and Management 228, 113725.

Yu, H., Kim, D., Gundersen, T., 2019. A study of working fluids for Organic Rankine Cycles (ORCs) operating across and below ambient temperature to utilize Liquefied Natural Gas (LNG) cold energy. Energy 167, 730-739.

ACKNOWLEDGEMENT

This work was funded by the 2019 Scholarship of Knowledge Center on Organic Rankine Cycle (www.kcorc.org), awarded to Dr. Haoshui Yu for the collaboration with Prof. Sylvain Quoilin at KU Leuven. Thermodynamic Lab at University of Liege is acknowledged for the technical support and office space provided during the scholarship. The authors also greatly acknowledge the financial support from Horizon 2020 Marie Skłodowska-Curie Actions-Individual Fellowships (891561).