Graduate School of Fundamental Science and Engineering
Waseda University

博 士 論 文 概 要
Doctoral Thesis Synopsis

論 文 題 目
Thesis Theme

Optimal Operation of Solar Energy Driven Single-Double-Effect Absorption Chiller

太陽熱で駆動する一重二重効用吸収冷凍機の最適運用に関する研究

申請者
(Applicant Name)

ARNAS
アルナス

Department of Applied Mechanics, Research on Dynamics and Control of Mechanical Systems

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The high daily temperatures in Asian tropical climates necessitate air-conditioning systems, which create a thermal comfort zone for the daily indoor activities. During the hot season, the air-conditioning system is required even more. Consequently, the energy consumption of the building sector could increase and this would burden the energy load of a country. Due to the high electricity consumption of the building sector's cooling systems, solar energy is one of the most promising future alternative energy sources, because non-renewable energy, such as fossil fuels that are still in use, is limited and associated to environment issues. Moreover, solar energy can be obtained from nature without direct cost. Some tropical Asian countries are geographically aligned with the equator, and their locations are thus characterised by the abundant availability of solar energy throughout the year. Therefore, tropical Asian countries have big potential for an average daily solar radiation.

As a thermally driven technology, absorption chillers can be efficiently driven by solar energy in a wide range of heat input temperatures. Utilising solar energy for an absorption chiller system in Asian tropical areas comes along with the significant advantage of large availability of radiant heat, which constitutes a power source able to make up for the high ambient temperature throughout the year.

Absorption chillers that use solar energy as heat input have been described as one of the promising cooling systems that could meet all the requirements needed to solve the energy and environmental issues. The excellence of this system is its high performance, low-temperature heat input, low operational costs, and environmentally friendly working fluids. Therefore, in several countries, many types of solar cooling systems, with single or double-effect absorption chiller systems, have been investigated in order to understand their characteristics and performance. A single-double-effect absorption chiller combines the single and double-effect systems to take advantage of the merits of both these individual configurations in one unit. Combining system in one unit has several advantages, such as compact dimension, back-up/second system has a quick response, easy to synchronise both systems. However, this configuration could be associated with other operability issues, particularly, the control of this system becomes more complex. Even though the performance of the single-double-effect absorption chiller is high, when considering the complexity of the configuration and the annual performance factor (APF) of this system, the possibility of further enhancement of the performance of this system to minimise its primary energy consumption is explored.

Therefore, in this study, the author presents the best-combined system based on the criteria of low primary energy consumption as one of the latest progresses in the solar cooling field. The new system configuration is designed to maximise the utilisation of waste heat or solar energy. The characteristics and performance of this system are firstly modelled and clarified with reference to the influence of internal parameters. Accordingly, a newly developed performance maximisation method is suggested, showing that the operation performance of this system can be improved by manipulating the absorber outlet solution flow rate and the solution distribution ratio, thus, achieving a significant reduction of the primary energy consumption, without any additional cost. Finally, an optimal operation strategy is suggested to minimise the primary energy consumption for this advanced system configuration in various operation conditions, verifying its feasibility with unsteady numerical simulations.

In chapter 3 the simulation model of the single-double-effect absorption chiller is constructed for simulating the steady-state and the transient or dynamic conditions in order to confidently obtain the best performance operation with high reliability. Both steady-state and dynamic simulation models are based on mass and energy balances, but the latter also considers the mass and thermal storage in the evaporator, condensers, absorber, and three generators (special, low, and high-temperature generator). The Newton-Raphson method with finite-difference Jacobian is applied in MATLAB to solve the approximated differential equations. To support the validity of the results, these are compared to the experimental data.

Firstly, the understanding of the characteristics and performance of the single-double-effect absorption chiller according to the environment and disturbances through steady-state simulations is necessary for clarifying its seasonal performance and potentiality in a tropical climate. Steady-state simulations are also used for identifying the optimum condition of this system with reference to the influence of internal parameters. However, as this system is driven by dual-heat sources (solar energy and gas) at the same time during most of its operation, and the availability of solar energy is influenced by the instantaneous weather conditions, the dynamic analysis plays an important role to predict the real characteristics and performance of the system. With reference to the optimum conditions selected by manipulating internal parameters (absorber outlet solution flow rate and solution distribution ratio), the model is used to find an appropriate control strategy that can minimise the primary energy consumption and increase the performance without affecting the stability of the cooling capacity.

Chapter 5 discusses the steady-state simulation results, where the system is characterised by simulating its performance in various conditions in terms of the cooling water (28–34 °C) and the hot water (75–90 °C) inlet temperatures. The reference operating condition of this system is 239 kW of cooling capacity, as the experimental equipment installed at the University of Indonesia. The mathematical model is validated and shows a good agreement with experimental data. In the operative range considered, simulation results yield a coefficient of performance between 1.4 and 3.3, and a gas reduction ratio from 7 to 58% when compared to a double-effect absorption chiller driven by gas.

As the single-double-effect absorption chiller combines the single and double-effect configurations to compensate for the unpredictable instantaneous availability of solar radiation and cooling load fluctuations, the operative performance of this system is strongly affected by internal parameters such as the solution mass flow rate of the absorber outlet (the total solution mass flow rate) and the solution distribution ratio (the solution flow rate that enters the high-temperature generator), which connect the operability of the single and double-effect configurations. Therefore, chapter 6 presents the maximisation of the operation performance of the single-double-effect absorption chiller by adjusting these internal parameters according to the cooling capacity and the hot water inlet temperature. By using an appropriate combination from those internal parameters, the maximum performance and also safe operability from the single-double-effect absorption chiller operation can be achieved. For the real application, the performance from the appropriate internal parameter combinations selected in this analysis is used as the reference for defining an operation strategy able to reach advanced system performance.

In chapter 7, when selecting among the several possibilities of an operation strategy that can be applied to this system, besides efficiency, also applicability and simplicity are taken into consideration in this study.

Accordingly, the operation strategy which keeps constant the total volumetric flow rate of the solution, maintaining the solution level of the high-temperature generator and adjusting the chilled water outlet temperature by the gas flow rate is chosen because the steady-state simulation result of this operation strategy can reach the reference COP from chapter 6. From the simulation results, for the hot water inlet temperature of 90 °C, this suggested operation strategy can enhance the COP up to 32% compared to the conventional operation strategy. Therefore, this operation strategy is then suggested to be used for the single-double-effect absorption chiller.

早稲田大学　博士（工学）　学位申請　研究業績書

(List of research achievements for application of doctorate (Dr. of Engineering), Waseda University)

氏 名(ARNAS)　　　　　　　　　　印

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