Renewable and Sustainable Energy Reviews 39 (2014) 986–994

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Statistical analysis of patent data relating to the organic Rankine cycle

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ARTICLE INFO

Article history:
Received 2 September 2013
Received in revised form
30 May 2014
Accepted 7 July 2014
Available online 9 August 2014

Keywords:
Organic Rankine cycle
Patent analysis
Patent map
Technology life cycle

ABSTRACT

This study analyzed patent data to explore the technological developments based on the organic Rankine cycle (ORC), which is one of the most economical and efficient methods for converting low-grade thermal energy into electricity. The patent data were obtained from the Thomson Innovation commercial database, which contains patent information from various countries and offices. After querying, filtering, and organizing the results into patent families in accordance with International Patent Documentation Center guidelines, this study analyzed data on 304 ORC-related patents. The results show that the number of patent applications increased gradually before 2006, and then rapidly from 2009 to 2011, primarily because of contributions from patent applications in China (CN) and the Republic of Korea (KR). The present findings indicate that 2009 is an important year regarding developments in ORC systems and the number of patent applications. Furthermore, the assignees from the United States (US) were the most prominent contributors. However, the most patent applications were filed in CN, indicating that the market for ORC systems in CN might offer the most potential for future development. This study also examined the top ten patent assignees, as well as the trends of the number of patent applications, size of patent families, and frequency of patent citations. The results show that all of the top ten assignees were from the US, CN, and KR. Moreover, most of them filed their patent applications in recent years, particularly after 2008. The results further indicate that the most active assignee is currently General Electric Company (US). In addition, the top five patent families and the five most frequently cited patents are briefly reviewed and discussed. The patent data analysis results indicate that the technology life cycle status of the ORC is currently in the growth stage.

Contents

1. Introduction

In principle, an organic Rankine cycle (ORC) is identical to the steam Rankine cycle, except it involves using organic fluids with

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http://dx.doi.org/10.1016/j.rser.2014.07.070
1364-0321/

a low boiling point as a working fluid to generate power from low-temperature heat sources [1]. The ORC is considered one of the most economical and efficient methods for converting low-grade thermal energy, such as geothermal energy, solar thermal energy, waste heat recovery, biomass energy, and ocean thermal energy, into electricity [2,3]. Recent studies on the ORC have applied various perspectives and research tools, including conducting technical–economic–market surveys [1,4], developing methods for selecting working fluids [5], evaluating waste heat recovery from a power plant [6], onboard ships [7], and at data centers [8], as well as proposing proof-of-concepts [9], optimal control strategy models [10], quasi-dynamic models [11], assessing the effect of optimal pinch point temperature range of evaporators on system performance [12], prototype testing [13], and off-design performance analysis [14].

Quoilin et al. [1] conducted a techno-economic survey of ORC systems. They performed a market review based on various factors, including cost figures of several commercial ORC modules and manufacturers. Regarding technical challenges, they indicated that working fluids and expansion machines are two key aspects of ORC technology. In addition, they showed that state-of-the-art ORC units are typically designed for nominal operating points. Consequently, they perform poorly under off-design conditions. Vélez et al. [4] provided an overview of the technical and economic aspects, as well as the evolution of the ORC market for converting low-grade heat to generate power. They reported that the ORC capacity from the available providers was typically limited to 0.2–2.0 MWe, costing approximately €1000–€4000/kWe. Bao and Zhao [5] reviewed methods for selecting both pure and mixed working fluids used in ORC systems. They concluded that heat transfer characteristics, flammability, and material compatibility are key parameters involved in selecting pure working fluids, whereas thermal physical properties and heat transfer characteristics were considered the most crucial parameters for selecting mixed working fluids.

Gewald et al. [6] evaluated the waste heat recovery of the Ano Liosia gas-fired power plant in Greece to improve its productivity and efficiency in generating electricity. They proposed two waste heat recovery cycles (the water/steam cycle and ORC) for the power plant based on a detailed thermodynamic cycle simulation and economic evaluation. Aghahosseini and Dincer [9] analyzed the performance of a low-grade heat source ORC system that used both pure and zeotropic-mixture working fluids. They reported that the system efficiency increased in conjunction with both the expander inlet pressure and boiling point temperature of the working fluid. In addition, they showed that when the working fluid was superheated, the energy efficiency of the system remained almost constant but the exergy efficiency decreases.

Manente et al. [10] proposed an off-design model of an ORC system for identifying optimal control strategies. They argued that the optimal maximum pressure of the ORC system can approach the critical pressure level during both subcritical and supercritical cycles, but the optimal operation strategies for subcritical and supercritical cycles differ. Bamgbopa and Uzgoren [11] proposed a transient modeling approach for an ORC system operating under various heat input conditions. They investigated the transient mode of ORC system operation, and they reported that heat exchangers (i.e., the evaporator and condenser) are key system components because ORC systems are based on heat-to-power conversion processes. Li et al. [12] showed that the optimal pinch point temperature difference of the evaporator was approximately 13 °C, whereas that of the condenser was approximately 17 °C. Moreover, various organic working fluids facilitated the maximal net power output per unit area of heat transfer under pinch point temperatures similar to that of the evaporator. In addition, they showed that the optimal pinch point temperature difference of the evaporator decreased in conjunction with the pinch point temperature of the condenser.

Lee et al. [13] studied the influence of various evaporators on the response of an ORC system. They reported that the effect of heat source flowrate of the evaporator on the transient response of the ORC system was negligible, indicating that the flow rate of the heat source should be minimized to maximize system efficiency. In addition, they showed that the effect of the evaporate exit superheat on the ORC system depends on the type of evaporator. For a plate evaporator, superheat less than 10 °C may result in an unstable ORC system. However, for a shell-and-tube type evaporator, no unstable oscillation of the ORC system was observed when the exit superheat was between 0 °C and 17 °C. Fu et al. [14] analyzed the effect of off-design heat source temperature on the heat transfer characteristics and system performance of an ORC system. They showed that a higher heat source temperature yielded better heat transfer performance of the shell-and-tube type preheater and required a smaller evaporator heat capacity, and the net power output and system thermal efficiency increased linearly in conjunction with the heat source temperature.

Patent documents contain critical research results that are valuable to the industrial, business, law, and policy-making communities [15]. Four major applications of patent information are listed as follows [16]: (1) analyzing competitors; (2) pretesting and tracking technology; (3) mastering crucial technology; and (4) identifying the trends and conditions of patent development in various national markets. Careful analysis of patent documents can assist in elucidating technological details and relationships, identifying business trends, inspiring novel industrial solutions, or developing investment policies [17]. In addition, Cantwell and Janne [18] indicated that using patent information would reduce research and development (R&D) time and costs by 60% and 40%, respectively. Patent analysis, which involves statistical, analytical, and comparative methods for examining information in patent documents, has been widely applied in studies examining R&D capacity, technological fields, industrial departments, and company levels [19].

Numerous research articles and documents have been published on the ORC. However, based on our research, no study has conducted a patent analysis of the ORC. Therefore, this study performed a statistical analysis of patent data to explore the technological developments of ORC systems. The evolution of numerous patents and assignees, technology life cycle, and major International Patent Classification (IPC) of the patent data were studied, and the patent data were analyzed based on country/office and assignee nationality. In addition, this study explored the top ten patent assignees and the trend of patent applications, patent families, and patent citations, and reviewed the top five patent families and five most frequently cited patents.

2. Methodology

Because the term "organic Rankine cycle" is an established term, this study used it as a keyword to search for patent data. When searching for patents from the United States Patent and Trademark Office, this study performed a keyword search for this term appearing in titles, abstracts, claims, or description/specification. When searching for patents from the World Intellectual Property Organization (WIPO) and European Patent Office (EPO), a "full text" keyword search was performed. Finally, when searching for patents from the Thomson Innovation (TI) commercial database, a keyword search was performed for the term appearing in titles, abstracts, or claims. These strategies covered a wide range of patent data that was beneficial to the statistical analysis. Table 1 shows a summary of the patent search results. Finally, this study