American Journal of Applied Science and Technology

VOLUME Vol.05 Issue02 2025
PAGE NO. 56-60
DOI 10.37547/ajast/Volume05Issue02-14

Application of modern technologies in the development of energy-efficient technologies

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Received: 24 December 2024; **Accepted:** 26 January 2025; **Published:** 28 February 2025

Abstract: The article analyzes the heat supply systems of industrial production processes and the amount of various emissions released into the atmosphere from them. The use of heat pump systems in industry is of great importance, taking into account environmental protection regulations and fluctuating fuel prices. Studies on the energy integration of industrial heat pumps have revealed that, due to the widespread use of high-temperature heat pump systems (>90 °C), there are several opportunities for heating capacities from 20 kW to 20 MW, especially in the food, paper, metal, and chemical industries. The problems of transitioning to a heating system based on renewable energy sources have been studied.

Keywords: Production processes, secondary energy sources, energy efficiency, heat pump devices, CO2, environmental protection.

Introduction: Heat supply is widely used in industrial production, including chemical plants, for disinfection, distillation, drying, regeneration and other purposes. Heat flows with temperatures from 60 °C to 140 °C are required to meet the heat supply needs of the fertilizer, pulp, paper, and food industries. Burning organic fuels usually provides the heating process, which hinders efforts to decarbonize this sector. On the other hand, waste heat is a by-product of these facilities, as it is generated in exothermic chemical reactions occurring in industrial and chemical plants. Despite the amount of residual energy, low-grade waste heat is usually discharged into the environment, which increases the energy consumption of the system for cooling. In this regard, heat pumps can use the available waste heat at low temperatures to improve and meet heating requirements, while partially or completely replacing fuel-fired boilers and minimizing environmental impacts [1,2]. Unlike electric resistances, which convert power into heat energy; a large part of the energy input to a heat pump is waste heat, which simultaneously reduces the cooling load and electricity imports.

METHODS

As part of the project, the authors conducted a literature review, using analytical methods, observation, and other traditional methods.

The potential for heat pump systems in industry is significant, especially given the environmental regulations and volatile fuel prices. According to the International Energy Agency’s Net Zero by 2050: A Roadmap for the Global Energy Sector report, heat pumps could meet 15% of the process heating demand of light industry by 2030, and this share could increase to 30% by 2050 [3]. The use of high-temperature heat pumps has been proposed to increase efficiency and reduce emissions in various energy conversion systems [3]. Indeed, the effective use of heat pump technology could reduce CO_2 emissions in district heating systems by 35%. The improvement and dissemination of knowledge on the state-of-the-art, performance, and future developments of high-temperature heat pumps (HTHPs) has been the subject of various studies [3]. Collaboration has been carried out within the framework of the IEA Heat Pump Technology (HT) Cooperation Programme to promote the development and implementation of the technology. Problems related to the need for high-temperature heat transfer, as well as the need for refrigerants with low global warming potential (GWP), have been identified. Attention has been paid to the improved reliability and safety of existing compressor technologies for large heating capacities (>1 MW) [1,2,3].

In studies on the energy integration of industrial heat pumps, several possibilities have been identified for large-scale use of high-temperature heat pump systems (>90 ℃), especially in the food, paper, metal and chemical industries, with heating capacities ranging from 20 kW to 20 MW. Most cycles are single-stage, differing in the type of compressor and the refrigerant used (e.g. R245fa, R717, R744, R134a or R1234ze(E)). Raising the temperature from 95 K to 40 K requires performance factors of 2.4 to 5.8. However, overly conservative assumptions and generalizations, such as the temperature conditions of the heat sources, lead to incorrect conclusions about future electricity requirements and fixed costs. According to the researchers, it is recommended to study suitable waste heat sources at high temperatures to reduce the temperature rise and consequently the electricity costs.

RESULTS AND DISCUSSION

In addition, sustainable global warming will lead to greater utilization of waste and environmental heat, which will reduce costs. According to estimates, the current annual waste heat in China will save 1.3 billion tons of equivalent fuel (calculated based on the ratio of recycled waste heat to total national energy consumption), and the recovery of waste heat equivalent to 1 ton of equivalent fuel can prevent the release of 2.77 tons of carbon dioxide into the environment, which would be of great significance in the use of renewable energy and the reduction of CO2 emissions.

When CO2 emissions are reduced to zero, an energy transition based on expanding sources of energy demand and reducing costs is expected. At the same time, four challenges need to be addressed to transform the heat sector in the coming decade, including measures to generate, supply, store and use heat, as well as to achieve zero CO2 emissions. These challenges include (1) shifting heat to electrification, (2) utilizing decommissioned thermal power plants, (3) meeting the demand for large-scale heat storage, and (4) identifying the final "10%" savings (Figure 1). Taking into account the above challenges, four approaches are proposed to overcome the energy transition problem and develop an incentive strategy.

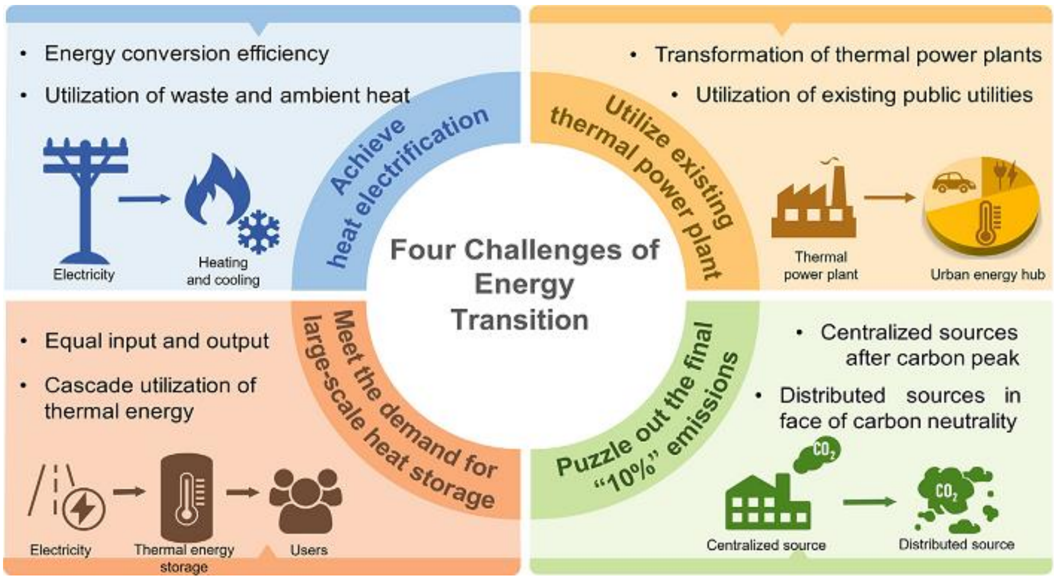

Figure 1. Four challenges of switching to a heating system based on renewable energy sources.

To achieve CO2 neutrality, electricity generated in thermal power plants (TPPs) using fossil fuels should be replaced by renewable electricity from solar photovoltaics, wind power, etc. [4]. Heat supply based on fossil fuels is provided by electricity generated in this case from renewable or low-CO2 emission heat supply systems, and in the future from renewable sources [5]. The efficiency of converting large amounts of electricity into heat falls below 1 according to thermodynamic laws, so the price of heat supply can never be lower than the price of electricity. In addition, a large amount of waste heat generated in industrial processes and ambient heat from nature has not yet been fully utilized [6].

In this case, high-potential heat pumps for the use of electricity and low-potential heat energy have an effective effect on the electrification of heat supply systems. The heat energy extracted from the low-temperature heat source through mechanical or thermal work is transferred to the high-temperature heat receiver, thereby establishing a connection between electricity and heat. In the cycle of the electrically powered vapor compression heat pump in Figure 2 the low-grade heat energy extracted from the ambient heat or waste heat is increased, thereby further expanding the scope of low-grade heat energy utilization.

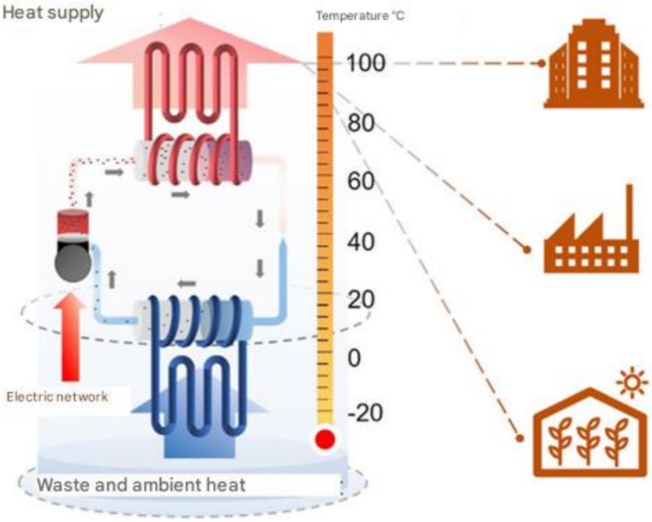

Figure 2. Schematic diagram of a vapor compression heat pump.

According to the results of the conducted research, it was found that the user's energy consumption mainly consists of 20% electricity, 50% heating and cooling, and 30% fuel. Ideas that can store heat, cold, electricity and fuel by the ratio of energy consumption provide energy savings and significantly improve safety. Thermal power plants can be converted into energy centers that can store renewable energy in the form of heating, cooling, electricity, and fuel. The energy centers in Figure 2 allow the integration of electricity, heating, cooling, and pipeline networks and the delivery of energy types to the city, acting as a bridge between the demand and supply sides.

In particular, when transmitted over long distances, some of the renewable electricity is stored directly in batteries or in high-temperature thermal storage based on a Carnot accumulator and then transmitted to users via the local grid. The Carnot accumulator uses heat engines and turbines in thermal power plants and offers large-scale storage of renewable energy, although the output of electricity is only 50% of its input.

Another part of the delivered renewable electricity is used by heat pumps to provide heating and cooling in a reverse cycle.

After being improved and scaled up, the thermal energy is stored and then delivered via the heating and cooling networks. In this process, the efficiency and flexibility of the heating and cooling supply can be further increased by thermal energy regulation methods, which are expanded in the next section. The remaining renewable electricity can be used to produce compressed and stored hydrogen and methane, which is delivered to users through a pipeline network or hydrogen stations.

The control of the operation of energy hubs is based on optimizing costs and efficiency and adjusting power and capacity over time. As energy consumers and suppliers, energy hubs participate in the coordinated management of the energy market and the operation of all three utility networks.

The widely discussed 1.5°C scenario in early 2020 requires a reduction of 500 Gt of CO_2 emissions [7]. By mid-2022, 100 Gt of this amount had been absorbed, leaving 400 Gt remaining. Existing and planned power plants, mainly solid fuel-fired, will produce approximately 500 Gt of CO_2 over their lifetime [7]. The power generation capacity of existing and soon-to-be-commissioned coal-fired power plants will thus fully cover the remaining 1.5°C CO_2 budget. The main reason for this disproportionate impact is that most of the existing power plants are still new. Of the 2000 GW of global generation, 720 GW is from solid-fuel thermal power plants that have been in operation for less than 10 years, and 630 GW is from thermal power plants that have been in operation for up to 20 years [8].

This is one of the reasons why the International Energy Agency’s recent special report on CO_2 capture and storage (CCS) in the Energy Technology Outlook states that net zero cannot be achieved without CCS [1]. In addition to the potential for decarbonization by upgrading existing emission sources (e.g. relatively new coal-fired thermal power plants), CCS ensures the decarbonization of complex sources (heavy industry), the production of low-carbon fuels, and the capture of CO2 that has already been emitted from the atmosphere.

The research focuses on the potential of CCS to decarbonize existing infrastructure, which relies heavily on the development and deployment of practical and cost-effective post-combustion CO2 capture technologies. Currently, expensive technologies are a major barrier to the development of decarbonization processes, but costs can be reduced. For example, SaskPower, the operator of one of the two large-scale CCS processes for coal-fired power plants built and operated to date, estimates that second-generation CO2 capture devices could reduce costs by 67% [5].

The rapid development of such second-generation CO2 capture technologies is critical to preventing the lock-in of more expensive first-generation technologies.

There are various ways to achieve this integration. For example, the two large coal-fired CHP projects implemented to date use different approaches with different advantages and disadvantages [9]. Boundary Dam uses steam from a direct coal-fired CHP plant, while Petra Nova uses a separate gas-fired CHP unit to provide recovered heat and additional power.

The Boundary Dam approach is a preferred option for deep decarbonization, particularly in Asia, where 77% of the world's coal is consumed and where much of the natural gas must be imported at high cost. Designing CHP plants is an important step in preparing for this CCS upgrade, but it faces uncertainty about the steam conditions required for future CO2 capture processes. However, although significant modifications to the power cycle are required, there are various schemes for retrofitting non-CAB plants with only modest efficiency gains [10].

CONCLUSIONS

This work explores another retrofit approach using a CO2 capture concept that uses only electrical energy as an input, which limits or eliminates any integration with steam cycles that would increase the complexity of the retrofit design. The concept is derived from the Rotary Adsorption Reactor Cluster (RARC), which uses heat and vacuum pumps to regenerate the sorbent using a combination of temperature and vacuum oscillations. Competitive efficiencies can be achieved in coal-fired power generation, but the concept is more effective for processes that do not have low heat to regenerate the sorbent, such as cement production. However, given the urgency of the RARC to rapidly upgrade the "megaproject" of the world's largest coal-fired power plants, in this work, the operation of heat and vacuum pumps was compared with the use of low-pressure steam under these conditions.

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