

## HEAT ENERGY RECUPERATION TECHNOLOGIES IN INDUSTRIAL EQUIPMENT

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### Abstract

Industrial enterprises consume a significant portion of global energy resources, and a considerable amount of supplied energy is lost in the form of waste heat. Effective utilization of this waste heat through recuperation technologies represents a key opportunity to improve energy efficiency, reduce operational costs, and minimize environmental impact. This paper examines modern heat energy recuperation technologies used in industrial equipment, analyzes their operating principles, and evaluates their economic and ecological benefits. Special attention is given to heat exchangers, regenerative systems, Organic Rankine Cycle (ORC) systems, and thermal energy storage technologies. The results demonstrate that integrating waste heat recovery systems can reduce overall energy consumption by 15–35% depending on industrial conditions. The quest for more efficient and environmentally friendly transportation has been a driving force behind ongoing innovation in internal combustion engine (ICE) technology. Despite significant advancements, a substantial portion of the energy produced by ICEs is lost as waste heat, representing a missed opportunity for improved efficiency and reduced emissions. Waste heat recovery (WHR) technologies emerge as a promising solution to capture and utilize this untapped energy, offering the potential to enhance the performance of ICEs across various applications

**Keywords:** Waste heat recovery, heat recuperation, industrial energy efficiency, heat exchanger, ORC system, energy optimization, sustainable industry.

### Introduction

Energy efficiency has become one of the primary challenges in modern industry due to rising energy costs and increasing environmental concerns. In many industrial processes, a substantial portion of input energy is dissipated as unused heat through exhaust gases, cooling systems, and equipment surfaces.

Studies indicate that 20–50% of total industrial energy consumption is lost as

waste heat. Recovering this energy through advanced recuperation technologies can significantly improve system efficiency and reduce greenhouse gas emissions.

Heat energy recuperation refers to the process of capturing and reusing thermal energy that would otherwise be discharged into the environment. This approach contributes to sustainable production, resource conservation, and compliance with international energy management standards.

The recovery of waste heat through recuperation technologies provides an effective solution to this problem. Heat energy recuperation involves capturing thermal energy that would otherwise be discharged and redirecting it for useful purposes within the same or another process. This approach reduces fuel consumption, improves system performance, and lowers operational costs. Moreover, it contributes to environmental protection by decreasing harmful emissions and improving resource efficiency.

Waste heat in industrial systems can be classified according to temperature levels. High-temperature waste heat is typically generated in furnaces, kilns, and combustion chambers. Medium-temperature heat is commonly found in drying processes, compressors, and engines. Low-temperature waste heat originates from cooling systems and exhaust air streams. The temperature level determines the appropriate recovery technology and its economic feasibility.

## **Main Part**

### **Analysis of Existing Problems**

#### **1. Sources of Waste Heat in Industrial Equipment**

Waste heat in industrial systems typically originates from:

- Combustion processes (boilers, furnaces, kilns)
- Internal combustion engines and turbines
- Electric motors and generators
- Compressors and refrigeration systems
- Drying and thermal processing equipment

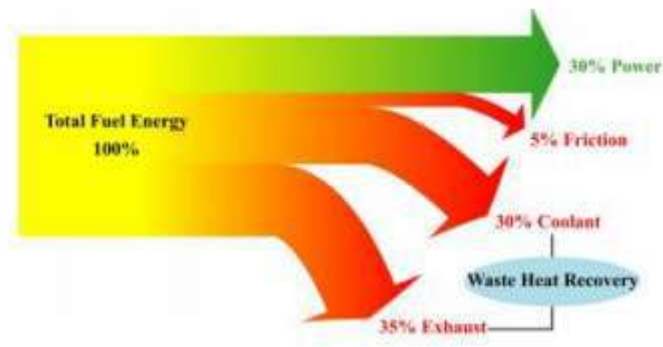
The temperature level of waste heat can be categorized as:

- High-grade heat ( $>400^{\circ}\text{C}$ )
- Medium-grade heat ( $100\text{--}400^{\circ}\text{C}$ )
- Low-grade heat ( $<100^{\circ}\text{C}$ )

Each category requires specific recovery technologies.

Waste heat in industrial equipment originates from multiple thermal and mechanical processes that occur during production. In most industrial systems, energy conversion is not perfectly efficient; therefore, a significant portion of input energy is inevitably transformed into heat and dissipated into the environment. Understanding the sources, characteristics, and thermodynamic properties of this waste heat is essential for selecting appropriate recuperation technologies and achieving maximum energy recovery.

One of the primary sources of waste heat is combustion-based equipment such as industrial furnaces, boilers, kilns, and thermal reactors. In these systems, fuel energy is converted into thermal energy, but a large fraction escapes through exhaust gases at high temperatures. Flue gases discharged through chimneys often contain substantial recoverable heat energy. In many cases, exhaust gas temperatures range from 200°C to over 800°C, representing a significant potential for energy recuperation through economizers, recuperators, or regenerative burners.



Another important source of waste heat is internal combustion engines and gas turbines used in power generation and industrial drive systems. During operation, only a portion of the fuel's chemical energy is converted into mechanical work, while the remaining energy is released as heat through exhaust gases and cooling systems. Engine exhaust temperatures may exceed 400°C, making them suitable for secondary power generation through Organic Rankine Cycle systems or for process heating applications.

Electric motors and electromechanical systems also contribute to thermal losses. Although high-efficiency motors (IE3 or IE4 class) operate with improved performance, they still generate heat due to copper losses ( $I^2R$  losses), iron losses (hysteresis and eddy currents), and mechanical friction. In large industrial installations where numerous motors operate continuously, cumulative heat losses

become significant. This thermal energy, typically considered undesirable, can be captured and redirected for auxiliary heating or drying processes.

Compressors and refrigeration systems generate considerable amounts of low- and medium-temperature waste heat. During gas compression, temperature rises due to thermodynamic compression processes. The heat released in aftercoolers and condenser units is often discharged into ambient air or cooling water systems without utilization. However, this heat can be effectively reused for space heating, water heating, or preheating process fluids.

Drying equipment used in textile, agricultural, and food industries represents another major source of recoverable heat. In these systems, hot air is circulated to remove moisture from materials, and the exhaust air leaving the drying chamber still contains substantial thermal energy. Installing air-to-air heat exchangers allows preheating of incoming fresh air, reducing overall fuel or electricity demand.

Mechanical processes also generate waste heat through friction between moving parts such as bearings, gears, belts, and rotating shafts. Although individual frictional losses may appear small, their cumulative effect in large-scale industrial systems can be considerable. High rotational speeds and inadequate lubrication further increase temperature levels and energy dissipation.

### **Types of Heat Recuperation Technologies**

Several technologies are used to capture and reuse heat in industrial processes. The choice of technology depends on the type of equipment, operating temperatures, and intended use of the recovered energy.

#### **a. Heat Exchangers**

Heat exchangers are the most common devices used in industrial heat recuperation. They transfer heat from a hot fluid (gas or liquid) to a cooler one without mixing them. Types include:

- Shell-and-tube heat exchangers – suitable for high-pressure applications.
- Plate heat exchangers – compact design, ideal for liquids.
- Air-to-air heat exchangers – used for exhaust gases in furnaces and dryers.

#### **b. Recuperators**

Recuperators are specialized heat exchangers used to recover heat from hot exhaust gases in high-temperature processes, such as metalworking furnaces or gas

turbines. They improve thermal efficiency by preheating incoming air or fuel using exhaust energy.

c. Regenerators

Regenerators store heat in a thermal storage medium (like ceramic or metallic matrices) and transfer it to incoming gases periodically. This technology is widely applied in glass and steel manufacturing, where high-temperature exhaust gases are available.

d. Combined Heat and Power (CHP) Systems

CHP systems, also known as cogeneration, simultaneously produce electricity and heat from a single fuel source. Industrial plants using turbines or engines can recover exhaust heat to produce steam, hot water, or air for processes, achieving energy efficiencies of 60–80%.

e. Thermoelectric Generators (TEGs)

Thermoelectric generators convert temperature differences directly into electricity using the Seebeck effect. Although currently less common due to cost, TEGs are gaining attention for recovering low-grade heat from industrial machinery.

## Conclusion

Heat energy recuperation represents one of the most practical and impactful strategies for enhancing energy efficiency in industrial operations. By capturing waste heat that would otherwise be lost to the environment, industries can not only reduce fuel consumption and operational costs but also significantly lower greenhouse gas emissions, contributing to global sustainability efforts.

The adoption of technologies such as **heat exchangers, recuperators, regenerators, combined heat and power (CHP) systems, and thermoelectric generators** demonstrates the versatility of heat recovery across various sectors—from metallurgical and chemical industries to food processing and power generation. These systems allow industries to reclaim energy from high-temperature exhaust, preheat process fluids, generate electricity, and even optimize thermal processes for improved productivity.

Despite challenges such as high initial investment, maintenance needs, and material limitations, the long-term economic and environmental benefits of heat recuperation far outweigh the drawbacks. Furthermore, ongoing advancements in materials science, thermoelectric technology, and IoT-enabled monitoring promise to make heat recovery systems more efficient, compact, and cost-effective in the

near future.

Ultimately, heat energy recuperation is not merely an optional upgrade but a **strategic necessity** for industries aiming to remain competitive, reduce their carbon footprint, and meet increasingly stringent energy regulations. As global energy demand continues to rise, the efficient reuse of waste heat will play a critical role in achieving a more sustainable and energy-resilient industrial landscape.

## References

1. Saidur, R., Rezaei, M., Muzammil, W. K., Hassan, M. H., Paria, S., & Hasanuzzaman, M. (2012). *Technologies to recover exhaust heat from internal combustion engines*. *Renewable and Sustainable Energy Reviews*, 16(8), 5649–5659. DOI: 10.1016/j.rser.2012.05.018 — An extensive review of waste heat recovery methods, including thermoelectric generators and bottoming cycles.
2. Rahbari, H. R., Elmegaard, B., Bellos, E., Tzivanidis, C., & Arabkoohsar, A. (2025). *Thermochemical technologies for industrial waste heat recovery: A comprehensive review*. *Renewable and Sustainable Energy Reviews*, Vol.215, 115598 — Covers thermochemical heat transformers and low-temperature heat recovery technologies.
3. Jouhara, H., Khordehgah, N., Almahmoud, S., Delpech, B., Chauhan, A., & Tassou, S. (2018). *Waste Heat Recovery Technologies and Applications*. *Thermal Science and Engineering Progress* — Reviews industrial waste heat recovery methods such as recuperators, regenerators, ORC, heat pumps, and emerging technologies.
4. Liu, Z., Ma, K., Cai, Q., & Yue, J. (2024). *The Development and Research of Waste Heat Recovery Technology*. *Academic Journal of Science and Technology*, 9(2), 252–255 — Discusses global development and research trends in waste heat recovery technology.
5. Heat recovery potentials and technologies in industrial zones. *Journal of the Energy Institute*, 90(6), 951–961 (2017) — Provides insight into industrial heat recovery potential and methods across industrial sectors.