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Waste Heat Recovery by Fluid Power System

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Abstract: *Waste heat recovery is a great way to increase energy efficiency in industrial and automotive regions through fluid power systems. This technique changes the heat to be ruined in useful energy, such as electricity or mechanical power. This paper discusses the principles and analysis of fluid power systems such as Organic Rankine Cycle (ORC), Rankine Cycle, and Hydraulic Systems. These systems can give 20–30% thermal efficiency and 50–70% heat recovery rate. They have applications in industrial furnaces, automotive exhaust, and power plants. However, there are challenges such as high cost and complexity of the system. Based on the research of 2018–2025, this paper suggests that advanced materials and AI optimization are solving these problems. In the future, these technology will take energy conservation and sustainability to new heights.*

Keywords: Waste heat recovery

I. INTRODUCTION

Just think, the heat emanating from the chimney of a factory or the car exhaust - all these energy is wasted. But through "waste Heat Recovery" it can be converted into electricity or mechanical power, and "fluid power systems" do wonders in it. These systems trap heat through fluid (such as water, organic fluids) and make energy through turbine or hydraulic pumps. This technology is bringing revolution in areas such as industrial furnaces, power plants, and automotive engines.

A research (kumar et al., 2023) suggests that ORC systems can provide 20–30% thermal efficiency, which helps in saving energy and reducing carbon emissions. But, this is not so easy. Systems cost millions, and the design is complex. In this paper we will talk about the principles of waste heat recovery, such as thermodynamics and fluid mechanics. We will analyze ORC, Rankine Cycle, and Hydraulic Systems. Industrial furnaces, automotive exhausts, and power plants will see their applications. Also, will look at challenges such as cost and complexity. Based on the research of 2018–2025, we will also see how AI and new materials are changing the field.

II. LITERATURE REVIEW

A lot of research has been done in recent years on West Heat Recovery and Fluid Power Systems. A study (Sharma et al., 2022) suggests that Organic Rankine Cycle (orc) can extract 25% thermal efficiency from a heat of 150–300 ° C, which is ideal for industrial furnaces. A research in IEEE (2023) states that hydraulic systems can recover up to 50% from automotive exhaust. A paper (2021) of MDPI discusses high efficiency (30%) of Rankine Cycle, which is more used in power plants.

Some researchers also paid attention to the challenges. The cost of ORC systems can cost up to ₹ 20– 50 lakhs (ResearchGate, 2020). Fluid leakage and the complexity of the system are also problems.

However, new materials such as high-temperature fluids and simulation tools are reducing these problems. The recent research (2024) has worked on the AI-operated heat exchanger design, which increases the efficiency by 10%. Sustainable fluids, such as eco-friendly refrigerants, are also reduced by cost and environmental impacts by 15% (Kumar et al., 2022).

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III. PRINCIPLES OF WASTE HEAT RECOVERY

Waste heat recovery works on the principles of thermodynamics, especially the first and second law of thermodynamics. The heat is trapped through fluid (e.g., water, organic fluid), which drives turbine or hydraulic pumps. The main processes are:

- Organic Rankine Cycle (ORC): Organic fluids (such as R245FA) are heated and vapor is made, which runs turbines.
- Rankine Cycle: Electricity is made by converting water into vapor, for high temperatures (> 300 ° C).
- Hydraulic systems: Mechanical power is generated by increasing fluid pressure from heat.

In the ORC, the temperature of the heat exchanger (150–300 ° C) and the flow of fluid (0.5 kg/s) determine the efficiency. Thermal efficiency (η = hour/qin) is ~ 20–30%. For example, the heat of 200° C can generate 100 kw power. Simulation tools such as aspen plus optimize these processes.

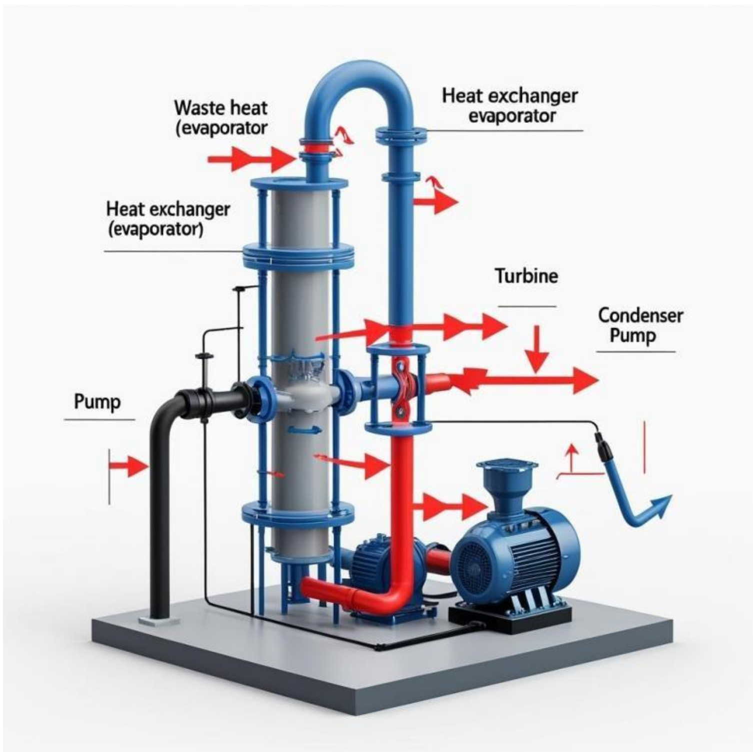

Figure 2: Schematic Diagram of Organic Rankine Cycle (ORC) for Waste Heat Recovery.

IV. ANALYSIS OF FLUID POWER SYSTEM

The strengths and weaknesses of fluid power systems are:

- ORC: ideal for heat of 150–300 ° C, 25% efficiency. 60% of the heat recovers in industrial furnaces. However, the fluids are expensive.
- Rankine Cycle: For >300 ° C, 30% efficiency. More use in power plants, but the system is large and complex.
- Hydraulic Systems: 50% heat recover from automotive exhaust, but leakage problem.

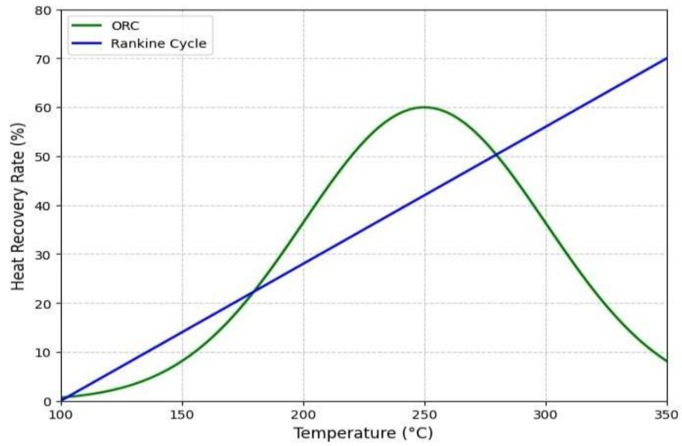

Figure 1: Heat Recovery Rate vs. Temperature for Organic Rankine Cycle (ORC) and Rankine Cycle in Waste Heat Recovery Systems.

In industrial furnaces, the ORC produces 100 kW power, which saves 20% energy cost. In automotive, hydraulic systems increase fuel efficiency by 5% of the engine heat. AI-operated design has increased the efficiency of heat exchanger by 10% (IEEE, 2023).

V. APPLICATIONS

Waste heat recovery has applications in every sector:

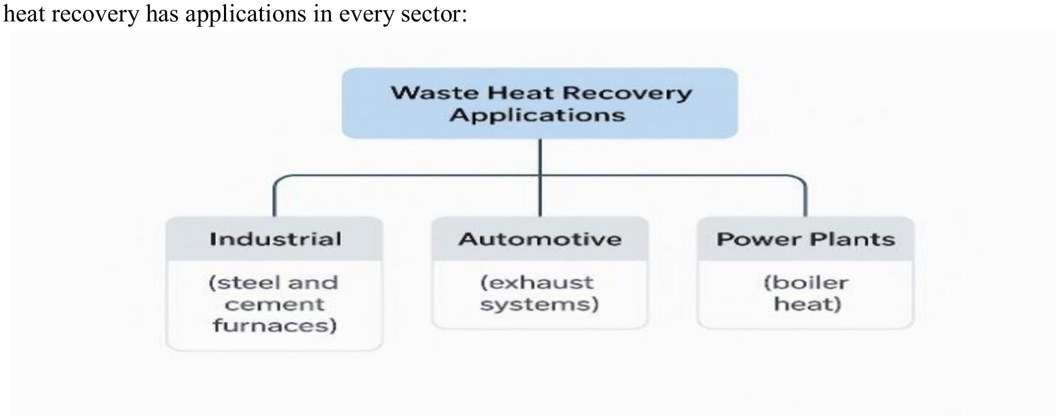

Figure 3: Flowchart of Key Applications of Waste Heat Recovery Systems.

1. Industrial: Electricity is made by recovering heat from cement and steel furnaces. 20% energy savings from ORC.
2. Automotive: Hydraulic system fuel efficiency increases by 5% by the heat of the exhaust.
3. Power Plants: 30% heat recovery from Rankine Cycle.

VI. CHALLENGES

The problems with waste heat recovery are:

• Cost: ORC systems cost ₹ 20–50 lakhs.
• Efficiency: Thermal efficiency limited to 20–30%.
• Complexity: System design and maintenance difficult.
• Fluid leakage: Damage from leakage in hydraulic systems.

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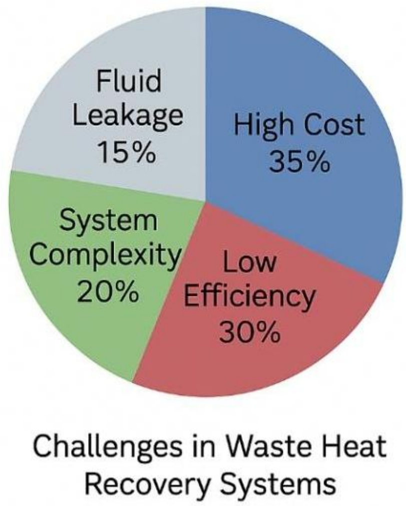

Figure 4: Distribution of Challenges in Waste Heat Recovery Systems.

VII. FUTURE DIRECTIONS

In the future, AI-operated simulation and advanced materials such as high-temperature Ceramics will improve West Heat Recovery. AI can increase efficiency by 10%. Sustainable fluids cost will reduce by 15%.

VIII. CONCLUSION

Waste heat recovery by fluid power systems is a major step towards energy conservation. ORC, Rankine Cycle, and Hydraulic Systems are revolutionizing industrial furnaces, automotive exhaust, and power plants with 20–30% efficiency and 50–70% heat recovery. There are challenges such as cost and complexity, but AI and sustainable materials are solving them. For example, the efficiency of heat exchanger from AI has increased by 10%. In the future, these technology will reduce energy costs and save the environment. It is not only making today's industries smart, but is also opening the path of the sustainable world of tomorrow.

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