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# How to recover waste heat through energy efficient technique

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## ABSTRACT

*This paper provides basic information about reusing waste heat generated from various chemical and industrial processes, which makes the whole process economically feasible, technically efficient, and environmentally acceptable. Waste heat recovery is utilizing the waste heat released during various methods to provide heat for the existing process and energy for the new process.*

*The fundamental quality of warmth isn't the sum but maybe its "esteem." The technique of recuperating this warmth depends, in part, on the temperature of the squandered warm gases and the financial matters involved.*

***Keywords***- Waste heat, Waste heat recovery system, Feasibility factors, Direct and indirect benefits of waste heat recovery, Techniques for Recovery.

## I. INTRODUCTION

For many decades, heat generated from various industrial and chemical processes has been dissipated in the environment, which not only lowers the efficiency of the process but also creates many environmental problems. In general, waste heat is heat generated in an industrial or chemical process without being put to practical use. Also, waste heat is the waste contained in a substance rejected from a handle at a temperature higher than the surrounding levels of the plant or industry.

Squander-warm recuperation involves capturing and reusing warm waste in mechanical forms for heating or producing mechanical or electrical work. A heat recovery technique reduces operating costs by increasing energy productivity and hence improves the overall efficiency of the process.

Waste heat losses arise from equipment inefficiencies and thermodynamic limitations on the equipment and the process.

Recuperating mechanical waste heat for control could be a generally undiscovered sort of combined heat and power (CHP), which is the utilization of a single fuel source to produce both heat vitality (warming or cooling) and power.

## II. Research Questions and Objectives

### A. *Objectives:*

- To identify the area of heat loss in a process.
- To minimize the heat loss during the process.
- To achieve heat recovery in various industrial process.
- To search various heat recovery systems applicable to industrial processes.

### B. *Research Questions:*

- What areas/process does have heat loss?

- How to recover the heat loss?
- How can we optimize the recovery system through various process?
- What are the advantages and limitations?

## III. Literature Review

Waste heat can be defined as heat stored in materials removed from a process at a temperature above the plant temperature, in sufficient quantity to be recovered from the source and financially reused. The two main factors that cause waste electricity are inefficient equipment and materials, and the thermodynamic limitations of the processes. Between 20% and 50% of waste heat is generated from various sources originating from various industrial processes (furnaces, furnaces, ovens, power plant turbines, internal combustion engines, etc.), as well as from mining sites and compressor stations. Industrial Energy Introduction The potential for industrial utilization of wasted thermal resources and energy loss is significant for the economy and the environment worldwide. Designing efficiently and effectively while facing limited budgets, operating costs, and the environment is a challenge for engineers. In a world where resources are scarce,
and energy needs are high, it is important to understand energy and resource degradation processes and develop methods to improve systems and thereby reduce environmental impact.

## IV. Research Methodology

In considering the potential for heat recovery, it is useful to note all the possibilities, and grade the waste heat in terms of potential value as shown in the following Table-1.

TABLE 1- WASTE SOURCE AND QUALITY

| **Source** | **Quality** |
|---|---|
| Heat in flue gases. | The higher the temperature, the greater the potential value for heat recovery |
| Heat in vapour streams. | As stated above, when condensed, latent heat is also recoverable. |
| Convective and radiant heat lost from the exterior of equipment | Low grade – if collected may be used for space heating or air preheats. |
| Heat losses in cooling water. | Low grade – useful gains if heat is exchanged with incoming fresh water |
| Heat losses in providing chilled water or in the disposal of chilled water | a) High grade if it can be utilized to reduce demand for refrigeration.<br>b) A low-grade refrigeration unit is used as a heat pump. |
| Heat stored in products leaving the process | Quality depends upon temperature. |
| Heat in gaseous and liquid effluents leaving process. | Poor if heavily contaminated and thus requiring alloy heat exchanger. |

*Table 1- waste source and quality*

1. **Feasibility governing factors** parameters which closely affect the feasibility of waste heat recovery are listed below-

- Quantity of the heat
- Temperature of the waste heat
- Composition
- Minimum allowed temperature

**A.** ***Quantity of the heat***- It refers to the amount of energy present in a waste stream, which is the function of both the temperature and mass flow rate of the stream and is related to $E=mh\ (t)$[1]

E is waste heat loss (Btu/hr), m is the waste stream's mass flow rate (lb/hr), and h (t) is its specific enthalpy.

**B.** ***Temperature of the waste warm-*** the warm recuperation framework is proficient when the waste warm source temperature is higher than the temperature of the warm sink. This temperature contrast decides the quality or, one can say, the utility of the waste. Ordinarily, the higher the temperature, the higher the quality, and the more feasible the warm recuperation.

The waste heat source temperature must be higher than the heat sink temperature to enable heat transfer and Recovery. Additionally, the size of the temperature distinction between the warm source and sink is a basic determinant of misuse of heat's utility or "quality". The source and sink temperature differentiate impacts.

- The heat transfer rate per unit surface area of the heat exchanger.
- The most incredible hypothetical productivity of changing from the warm source to another vitality shape.

The temperature of the waste heat source also significantly affects material selection in heat exchangers and recovery systems. Temperature increases dramatically accelerate corrosion and oxidation reactions, like all chemical reactions. The heat recovery surfaces can quickly become damaged if the waste heat source contains corrosive substances.

**C.** ***Composition***—The composition and phase of the waste stream can determine factors such as thermal conductivity and heat capacity that will affect the effectiveness of the heat exchanger.

The fouling material's deposition on the heat exchanger's surface reduces the heat transfer coefficient and inhibits the fluid's flow.

**D.** ***Minimum allowable temperature***- MAT or minimum permissible temperature for the waste stream is related to the corrosion problem. If debilitated gasses are cooled below the dew point temperature, the water vapour within the gas will condense and store destructive substances on the warm exchanger surface. The most common strategy for avoiding chemical erosion is planning warm exchangers with depleted temperatures well over the dew point temperature.

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[1] *Based on 25 quadrillion Btu of energy consumption, which excludes losses associated with electricity generation. US DOE EIA Annual Energy Review 2006.*

TABLE 2 TYPICAL WASTE HEAT TEMPERATURE AT MEDIUM TEMPERATURE RANGE FROM VARIOUS SOURCES

| Type of Device | Temperature, ℃ |
|---|---|
| Steam boiler exhausts | 230–480 |
| Gas turbine exhausts | 370–540 |
| Reciprocating engine exhausts | 315–600 |
| Reciprocating engine exhausts (turbocharged) | 230–370 |
| Heat treating furnaces | 425–650 |
| Drying and baking ovens | 230–600 |

*Table-2-typical waste heat temperature at a medium temperature range from various sources*

### *E. Temperature ranges and recovery methods-*

| Temperature Range | Example source | Advantages | Disadvantages | Recovery Methods |
|---|---|---|---|---|
| High >650℃ | 1. Ni refining furnace (1300-1650)<br>2. Glass melting furnace (1000-1550)<br>3. Zn refining furnace (760-1100)<br>4. Cement kiln- dry (620-730)<br>5. Hydrogen plant (650-1000) | High-quality energy for the devices.<br>High-efficiency power generation.<br>High heat transfer rate per unit area. | High temperature creates thermal stresses on heat exchange material.<br>High risk of chemical activity and corrosion. | Combustion air preheats.<br>Steam generation is used for heat, mechanical, and electricity generation.<br>Furnace load preheating. |
| Mid 230-650℃ | 1. Steam boiler exhausts (230-480).<br>2. Gas turbine exhausts (370-540).<br>3. Drying/baking ovens (230-600).<br>4. Catalytic crackers (425-650). | Higher compatibility with heat-exchanging materials.<br>Practical for the generation of power or electricity. | | Combustion air preheats.<br>Furnace load preheating, feed water preheating.<br>Transfer to low-temperature processes. |
| Low <230℃ | 1. Process steam condensate (55-88).<br>2. Pumps (27-88).<br>3. Internal combustion engines (66-120). | Large quantities of low-temperature heat are contained in numerous product streams. | There are few end uses for low-temperature heat.<br>Low efficient power generation. | Space heating.<br>Domestic water heating.<br>Rankine cycle and heat pumps. |

*Table 3- Temperature ranges and recovery methods*

## V. Result

### A. Benefits of waste heat recovery

There are numerous benefits of waste heat recovery. They are classified as follows-

1. Direct benefits
2. Indirect benefits

*1. **Direct benefits***- Direct efficiency of the process by reflecting on the reduction of the utility and process costs.

2. ***Indirect benefits***-

- **a) Decrease in contamination**- A number of poisonous combustible squanders, such as carbon monoxide gas, acrid gas, carbon dark-off gasses, oil slime, Acrylonitrile, and other plastic chemicals, discharging to the air if/when burnt within the incinerators, serve a double purpose: They recuperate heat and diminish the natural contamination levels.
- **b) Reduction in equipment sizes**—Warm recuperation of waste decreases fuel utilization, which leads to diminishment within the pipe gas created. This diminishment occurs in the hardware sizes of all pipe gas equipment, such as fans, stacks, channels, burners, etc.
- **c) Reducing auxiliary energy consumption** in gear sizes has extra benefits, such as decreased assistant vitality utilization, such as power for fans, pumps, etc.

### B. Waste heat recovery technologies

There are four general technologies used to recover waste heat. These include-

- a) Direct usages
- b) Heat exchangers
- c) Heat pumps
- d) Vapour recompression

***1. Direct usage***- This involves using waste heat directly and as it is.
e.g., using boiler off gases for drying, using hot air from the mechanical room to heat the storage area, etc.

*2. **Heat exchangers***- Heat exchangers are most commonly utilized to exchange warmth from combustion and deplete gasses. Ordinary innovations for discussing preheating incorporate recuperators, heater regenerators, burner regenerators, rotating regenerators, and inactive pre-radiators to combustion discussions entering the heater.

***3. Recuperators***—in a recuperator, warm trade is put between the vent gases and the discussion through metallic or ceramic dividers. Channels or tubes carry the discussion for preheating the combustion; the other side contains the squandered warm stream.

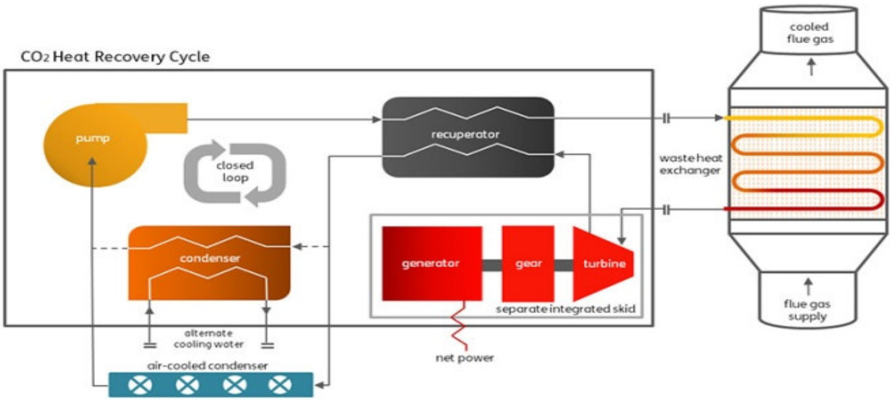

*Figure-1-* recuperator process[2]

4. ***Regenerator***—the Recovery is best for huge capacities and has been broadly utilized in glass and steel softening furnaces.

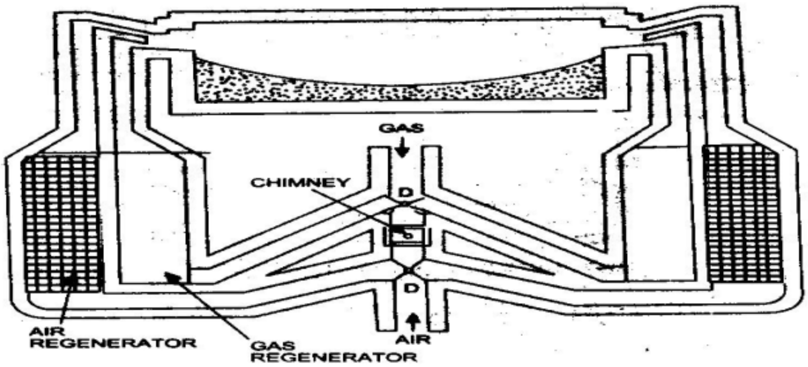

*Figure-2-regenerator process*[3]

The time between the inversions is vital in a regenerator. Long periods would cause a higher warm capacity and, subsequently, higher fetch.

5. ***Heat wheels/ Rotary regenerators***- Rotary regenerators operate similarly to fixed regenerators. Heat exchange is encouraged by putting away warm air in a permeable medium and substituting the stream of hot and cold gasses through the regenerator. Rotating regenerators, now and then alluded to as discussed preheaters and warm wheels, utilize a turning permeable plate set over two parallel conduits, one containing the hot squander gas, the other containing cold gas.

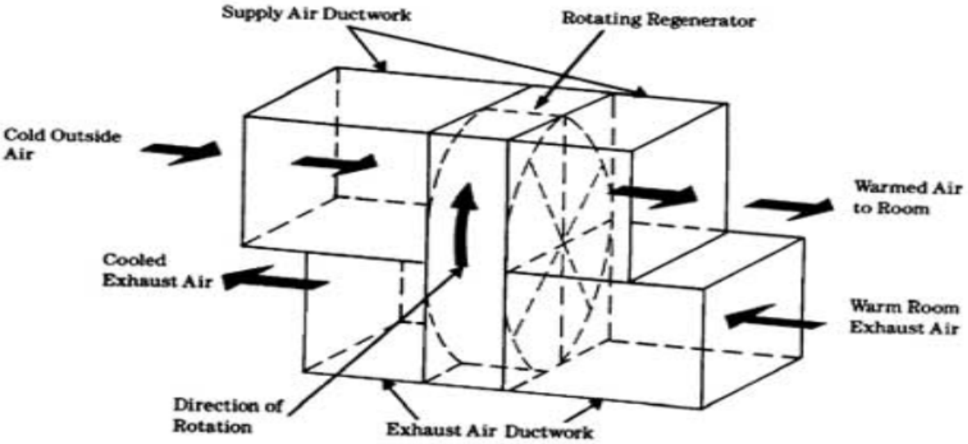

*Figure-3-rotary regenerator process*[4]

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[2] *Bahman Zohuri, in Molten Salt Reactors and Integrated Molten Salt Reactors, 2021*

[3] *Pinar Mert Cuce, Saffa Riffat, in Renewable and Sustainable Energy Reviews, 2015*

[4] *Sustainable Energy Technology, Business Models, and Policies, 2024*

6. ***Heat pumps***—Heat pumps use external energy or driving force inputs to drive a cycle that absorbs energy from a low-temperature source and rejects it at a higher temperature. Depending on the design, heat pumps can serve two functions: upgrading waste heat to a higher temperature or utilizing waste heat as a vitality input for driving a retention cooling framework. Heat pumps are most applicable to low-temperature product streams found in process industries, including chemicals, petroleum refining, mash and paper, and nourishment preparation.

The following relation can estimate the performance efficiency of the heat pump-

$$COP = Q/W$$

COP is the coefficient of performance, Q is the valuable heat output from the pump, and W is the work input.

It is estimated that the boiler requires 1.25 million Btu of fuel to provide 1 million Btu of heat. In contrast, the heat pump requires only 0.72 Million Btu for electricity generation in conjunction with the 0.78 Million Btu already available from the waste heat stream.

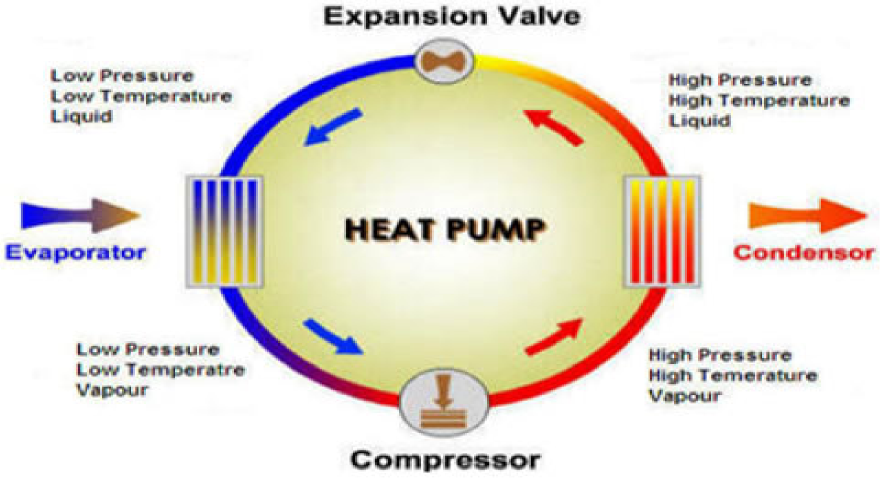

*Figure-4-heat pump process*[5]

7. ***Vapour recompression***—Vapour recompression, a waste heat recovery technique, accounts for the rise in the temperature and pressure of the low-temperature waste stream so that it can be utilized as a source of vitality. In this process, the compressed vapour is returned to supply heat for evaporation.

Vapour recompression can be achieved by two means-
1. Mechanical recompression
2. Thermal recompression

The name signifies mechanical, including the usage of centrifugal and positive displacement compressors, and thermal, including the combination of low and high-pressure vapour to achieve medium-pressure vapour.

### C. Power generation techniques via waste heat recovery

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[5] *Jiaxin Yang, Yufei Wang, in Computer Aided Chemical Engineering, 2020*

1. ***Steam Rankine Cycle (SRC)*** – The foremost commonly utilized framework for control era from squander warm includes utilizing the warm to produce steam in a waste warm evaporator, which at that point drives a steam turbine.

Steam turbines are among the most seasoned and flexible prime mover innovations. Warm recuperation boiler/steam turbine frameworks work thermodynamically as a *Rankine Cycle.*

In the steam Rankine cycle, the working fluid—water—is first pumped to elevated pressure before entering a heat recovery boiler. The pressurized water is vaporized by the hot debilitate and extended to a lower temperature and weight in a turbine, creating mechanical control that can drive an electric generator. The low-pressure steam is depleted to a condenser at vacuum conditions, where warm is cleared by condensing the vapour back into a liquid. The condensate from the condenser is, at that point, returned to the pump, and the cycle continues.

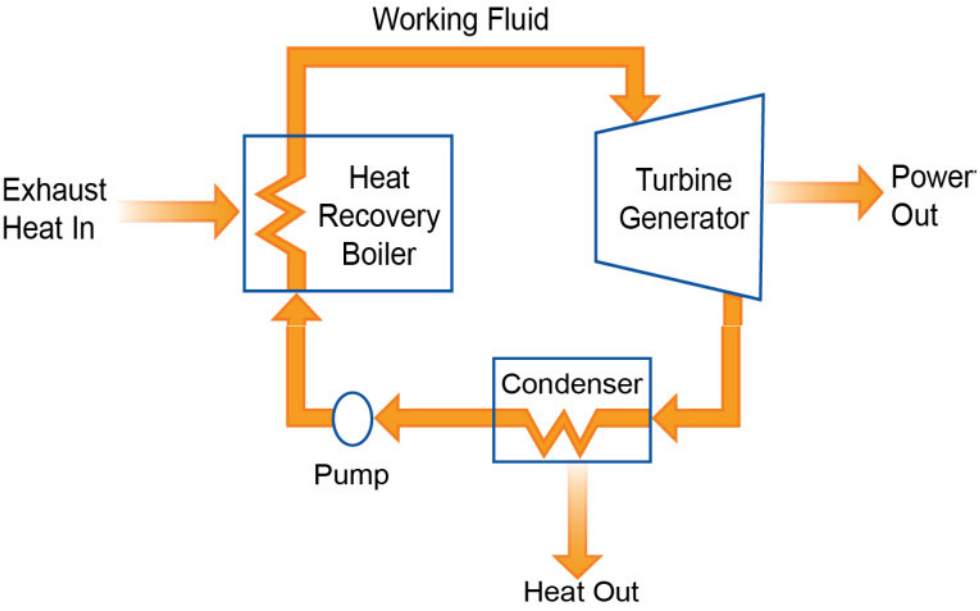

*Figure-5-* Rankine cycle[6]

2. ***Organic Rankine Cycles (ORC)***—In ORC warm motors, Other working liquids with much better efficiencies at lower warm source temperatures are utilized.

- ORCs utilize a natural working liquid that features a lower bubbling point, higher vapour weight, higher atomic mass, and higher mass stream than water. Together, these highlights engage higher turbine efficiencies than in an SRC. ORC frameworks can be utilized to waste warm sources as much as 300°F, whereas steam systems are limited to heat sources greater than 500°F. ORCs have commonly been used to generate power in

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[6] *Alibakhsh Kasaeian, Bardia Jamjoo, in Applied Thermal Engineering, 2022*

geothermal power plants and, more recently, in pipeline compressor heat recovery applications.

- The Kalina Cycle is another Rankine cycle. It employs a blend of water and smelling salts as the working liquid, which permits a more effective vitality extraction from the warm source. The Kalina cycle has a working temperature run that can acknowledge squandering warm at 200ºF to 1,000ºF and is 15 to 25 per cent more efficient than ORCs at the same temperature level. Kalina cycle systems are becoming increasingly popular overseas in geothermal power plants, where the hot fluid is often below 300ºF.

### D. Direct Electrical Conversion Devices:

- Conventional control cycles include utilizing heat to form mechanical and, eventually, electrical energy. Modern innovations are being created that can produce power straightforwardly from heat.

1. ***Thermoelectric Era:*** Thermoelectric (TE) materials are semiconductor solids that permit a coordinate era of power when subject to a temperature differential. These frameworks are based on a marvel known as the Seebeck impact: when two diverse semiconductor materials are subjected to a warm source and a warm sink, a voltage is created between them. Then again, TE materials can also be utilized for cooling or warming by applying power to different semiconductors.

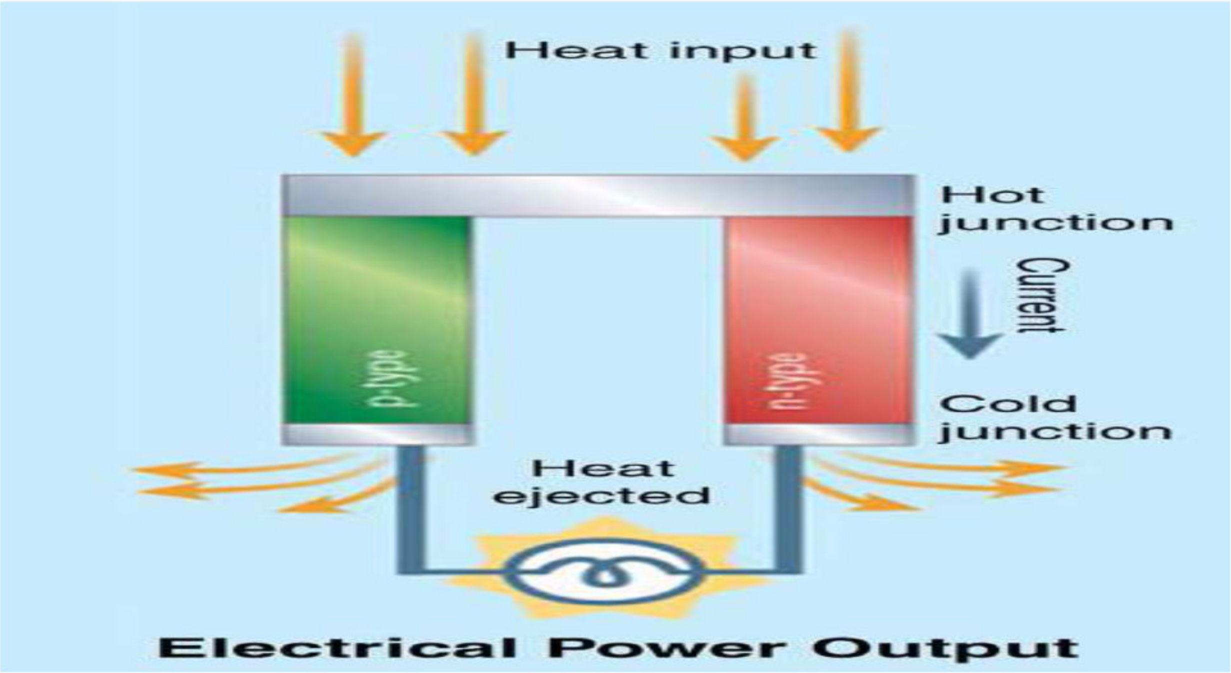

*Figure-6-Thermoelectric process*[7]

2. ***Piezoelectric Control Era**:* Piezoelectric Control Era (PEPG) is a choice for changing over moo temperature squander warm (200300Âº F or [100150Â°C]) to electrical energy. Piezoelectric gadgets change mechanical vitality within the frame of surrounding vibrations to electrical vitality. A piezoelectric lean film layer can use an oscillatory gas extension to make a voltage output.
3. ***Thermionic Era**:* Thermionic gadgets work similarly to thermoelectric gadgets; however, whereas thermoelectric contraptions concur with the Seebeck effect, thermionic contraptions work by implying thermionic radiation. In these systems, a temperature difference drives the stream of electrons through a vacuum from a metal to a metal oxide surface.

**E. Waste heat recovery opportunity areas**

Based on gauges of waste warm misfortunes in different applications, a few patterns were distinguished concerning opportunity regions and Investigate Improvement needs for waste warm recuperation. They are as follows:

- **Low-temperature waste heat sources:** Most unrecovered waste heat is at low temperatures. About 60% of waste heat losses are below 450°F [230°C].
- As of now, frameworks are counting waste warm recuperation that can be encouraged and optimized to decrease warm misfortunes. The degree of warm recuperation from existing frameworks is frequently obliged by costs and temperature limits for the warm recuperation framework. In numerous cases, cement preheaters, ovens and recuperative glass heaters debilitate gasses, leaving the recuperation gadget within the medium to tall temperature run. This speaks to an opportunity for extra waste warm recuperation. Openings are too accessible to maximize warm recouped quality since offices frequently use weakening to lower the temperature of waste warm streams.
- Tall temperature frameworks where warm recuperation is less common- there are advertise portions where squandering warm recuperation is less common, typically due to obstructions such as chemical constituents in depleted gasses that meddled with warm trade, as well as confinements on economies of scale for littler squander warm streams.
- Alternate waste heat sources are typically not considered for waste heat recovery. This study focused on combustion and process exhaust gases. However, alternate heat sources from waste were also found to be significant. These alternates include heat radiated, convicted, and conducted from heated products (e.g., cast steel, hot cokes), the heat lost in aluminum cell sidewalls and after pyro processes where slag or materials are solidified to protect the vessel walls.

## VI. Discussion

**A. Research development for low-temperature waste heat recovery-**

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[7] V. Subramanian, D. Varade, in Biopolymer Composites in Electronics, 2017

1. **Developing Heat Exchangers for Low Temperatures:** A significant challenge for low-temperature heat recovery from exhaust gases is the condensation and corrosion caused by cooling exhaust gases below their dew point temperature. Condensation heat recovery requires significantly higher capital and operating costs, which usually are not worth the energy-saving benefits. While condensing economizers are commercially available, capital costs can be as much as three times that of conventional boilers.

Recovery at low temperatures becomes increasingly challenging with chemically laden gas streams. These waste heat sources will have more significant limitations that prevent cooling flue gases to low temperatures. To enable the expansion of low-temperature heat recovery, RD&D might involve improving methods for cleaning exhaust streams, developing low-cost advanced heat exchangers that can withstand corrosive environments, developing heat exchangers that can be easily cleaned, or perhaps modifying process technologies to prevent the introduction of chemicals that would prevent heat exchange. Another challenge for heat exchangers when working with low-temperature fluids is the large heat transfer area required, especially if heat is to be recovered from gaseous exhausts. Developments that increase heat transfer coefficients in heat recovery systems could partially address this issue.

2. **End Use Technologies for Low-temperature Heat:**

A further challenge for low-temperature waste heat recovery is the limitations on available end uses. Potential end uses for low-temperature heat include low-temperature process heating, domestic water heating, and space heating.

Heat pumps and low-temperature power generation are options for Recovery from low-temperature heat sources. Warm pumps can "update" squander warm if a warm stack is accessible at a temperature somewhat higher than the squander warm temperature. Heat pump technology is well developed, but improvements could be made to lower capital costs or improve heat pump performance.

Low-temperature power generation technologies are an emerging opportunity. Power cycles such as organic Rankin cycles and the recently developed Kalina cycle have been successfully installed in low-temperature industrial applications. Longer-term technologies under investigation, such as piezoelectric generation, still need to be economical. Efforts can be made to demonstrate emerging power cycles further, improve these power cycles, and develop alternative generation systems.

3. **RD&D Needs for Optimizing Existing Recovery Systems**

Optimizing Recovery Systems- Development opportunities could involve low-cost solutions that address chemical attacks on heat exchanger materials, increase heat transfer efficiency, and enable heat recovery at low-temperature ranges.

Beyond optimizing heat recovery systems to increase the quantity of recovered energy, there are also opportunities to improve the quality of energy recovered. In many high-temperature applications, dilution air is introduced into the waste heat stream to protect ducts and heat exchanger materials from damage.

Most options for Recovery include the Recovery of high-quality heat, which will require the availability of low-cost manufacturing technologies for advanced materials for use in high-temperature applications. It is often more economical for facilities to introduce dilution air that reduces the heat temperature of waste. In these cases, there is no loss in the quantity of heat in the exhaust stream; however, since the temperature is reduced, it is of lower quality. An alternative to air bleeding is using more advanced alloys and composite materials for heat exchangers and ducts. RD&D that reduces these materials' costs will maximize recovery systems' efficiency.

## VII. CONCLUSION

The study of waste heat recovery finally leads us to the conclusion that rather than releasing the heat generated from various industrial processes, one can utilize it to make the process economically feasible and environmentally acceptable, as the waste heat or unused heat reduces the efficiency of the whole process as well as creates many types of environmental problems.

The determination of the warm recuperation strategy will depend on key variables such as the temperature, stage, and chemical composition of the depleted stream and the nature of the specified endues for recouped warm.

In this report, we conclude that although several technologies are already available for heat recovery, the constraints listed above may prevent their applicability to a given waste heat source or prevent them from being installed economically. RD&D focused on enhancing existing technologies will extend their applicability to diverse waste heat sources.

This includes extending the range of temperatures over which heat recovery can be performed (i.e., including low-temperature heat recovery as well as high-temperature heat recovery), extending the use of heat recovery equipment to processes with high levels of chemical activity, and extending technologies into new applications.

### A. Summary of Research, Development, and Demonstration Opportunities for Waste Heat Recovery:

In order to advance warm recuperation, a few endeavors may be made to decrease framework costs, optimize warm trade materials, warm exchange rates, moo temperature recuperation, and accessible endues for wasting heat. Openings for RD&D that address innovation and fetched obstructions are recorded below.

- Low-cost, novel materials Create low-cost materials for resistance to destructive contaminants and high temperatures.
- Reduce and high costs financially, scale down warm recuperation gear, and decrease relative costs for small-scale operations.
- More straightforward support: Create financial recuperation frameworks that can be effortlessly cleaned after exposure to gases with high chemical activity.
- Process changes: Create elective fabricating forms that produce less waste heat. Or create forms that maintain a strategic distance from presenting contaminants into handling off gases, empowering less demanding warm exchange from depleted gases. Of course, both must have satisfactory item quality and monetary returns.

- Gas cleaning – Develop low-cost methods for cleaning exhaust gases.

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