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Use of Heat Pipes and Thermoelectric Generator System for Waste Heat Recovery and Power Generation

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ABSTRACT

Waste heat is produced in almost every energy conversion process. This waste heat is lost to the environment and has an adverse effect on it. Studies show that almost 33% of the total consumed energy is lost as waste heat. Nowadays it is of utmost importance to recover and conserve this energy as the fossil fuels are depleting quickly. The waste heat can be reused in a number of ways thereby increasing the efficiency of the processes. This research paper focuses on one of these methods i.e. generating electricity. Heat pipes and thermoelectric generators are used for this purpose. Heat pipes serve as heat transferring devices and thermoelectric generators are used to generate electricity from the temperature difference across its junctions. Thermoelectric generators work on the principle of Seebeck's effect. Thermoelectric generators have a number of advantages over other electricity generators such as pollution free, solid state, maintenance free, light weight, noise free and it is also a passive device. Heat pipes are very efficient in transferring heat as they have a high thermal conductivity. They transfer heat with minimum temperature drop and maintain a temperature difference across the junctions of the thermoelectric generators. This system is used as a power source in various fields such as space exploration, remote unmanned sites, cathodic protection, automobiles, etc.

Keywords: ***Waste heat recovery, Thermoelectric generator, Heat pipes.***

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1. INTRODUCTION

All machines which do work or other energy conversions produce heat along with the output. This heat is known as waste heat as it is released in the environment and wasted. The waste heat after being released in the environment causes the mean temperature of the environment to rise. This has an adverse effect on the environment. Generation of heat shows that a part of the input energy is wasted and not converted into useful work. Ideally there should be no waste heat but it is not practically possible to convert all the input energy into work. It can be difficult or complex to increase the efficiency of any machine directly but if the waste heat produced by it is further used for other purposes it can be said that the efficiency of that machine is indirectly increased. Converting the waste heat into electricity is an effective method. Thermoelectric generator is a device which can be used to convert heat into electricity.

1.1 THERMOELECTRIC GENERATORS

Thermoelectric generator (TEG): TEG is a device which works on the principle of Seebeck effect i.e. it converts temperature differences into electricity. A temperature difference is necessary at both ends of a TEG to produce a voltage. More the temperature difference more is the magnitude of the voltage produced. TEGs are normally made up of Bismuth Telluride (Bi2Te3) alloys and Lead Telluride (PbTe) alloys.

1.2HEAT PIPES

Heat pipes: Heat pipes are also used along with thermoelectric generators to increase the heat transfer rates. Heat pipe is a device which has very high thermal conductivity. It is made of a hollow tube inside which a fluid is filled at vacuum pressure. Heat pipes reduce the thermal resistance in the system making it more efficient. Heat pipes work in a specific temperature range i.e. below 300°C.

2. APPLICATIONS

1. Thermoelectric generators are commonly used on gas pipelines. For example, for cathodic protection, radio communication and other purposes. For power consumption of up to 5 kW thermal generators are preferable to other power sources.

2. TEGs are used as remote power generators for unmanned sites. They are the most reliable power generator in such situations as they do not have moving parts (thus maintenance free), work day and night, perform under all weather conditions, and can work without battery backup.
3. Many space vehicles, including the Mars Curiosity rover use thermoelectric generators as power source. Radioactive materials are also used in the TEGs.
4. Cars and other automobiles produce waste heat in the exhaust. Using a thermoelectric generator, the fuel efficiency of the car can be increased.

3. THERMOELECTRIC GENERATORS (TEGs)

Working principle: The basic working principle of the thermoelectric generators is based on the Seebeck effect. The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances.

Construction: Thermoelectric generators contain three main components: thermoelectric materials, thermoelectric modules and thermoelectric systems.
Thermoelectric materials: Thermoelectric materials generate electricity from heat by converting temperature gradients into electric voltage. These materials should have both high electrical conductivity (σ) and low thermal conductivity (κ) to be good thermoelectric materials. Having low thermal conductivity makes sure that when one side is made hot, the other side stays cold, which helps to generate a large temperature gradient. The measure of the magnitude of electrons flow in response to a temperature difference across that material is given by the Seebeck coefficient (S). The efficiency of a given material to produce a thermoelectric power depends on the term zT which is known as the figure of merit.

$$zT = S2\sigma T/k$$

Bismuth telluride (Bi_2Te_3), Lead telluride (PbTe), and Silicon germanium (SiGe) are mainly used as thermoelectric materials as they both have low thermal conductivity and high electrical conductivity. These materials contain rare elements which make them very expensive.

Thermoelectric module: A thermoelectric module is made up of units of thermoelectric materials which are connected electrically in series and thermally in parallel. An n-type (negatively charged) and a p-type (positively charged) semiconductor are coupled to form a pair. There are many couples in a module. A current will flow in the circuit when there is a temperature difference between the two materials.

Thermoelectric system:A thermoelectric system generates power by taking heat from a source like a hot exhaust gas using thermoelectric modules. The system needs a large temperature gradient to do that which is not easy in actual applications. The cold side should be cooled by air or water. Heat exchangers are used on both sides of the modules to supply this heating and cooling.
It is very challenging to design a reliable TEG system that operates at high temperatures.To achieve high efficiency in the system it requires extensive engineering design in order to balance between the heat flow through the modules and maximizing the temperature gradient across them. To do this, designing heat exchanger technologies in the system is one of the most important aspects of TEG engineering. Also, the thermal losses due to the interfaces between materials at several places should be minimized. Another challenging task is avoiding large pressure drops between the heating and cooling sources.

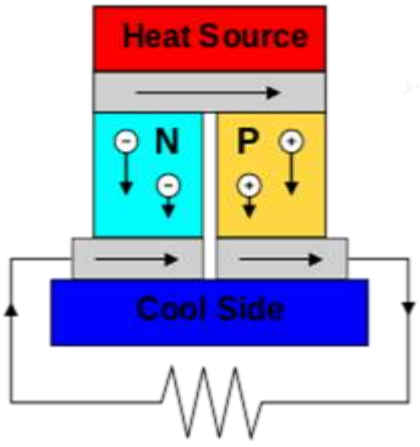


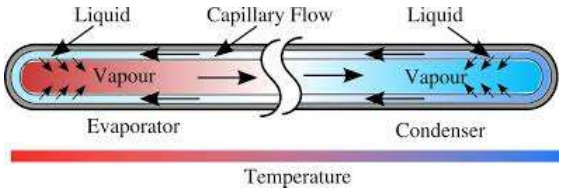
Fig-1: Thermoelectric generator

4. HEAT PIPES

A heat pipe is a device which transfers heat from one end to another with minimal temperature drop.

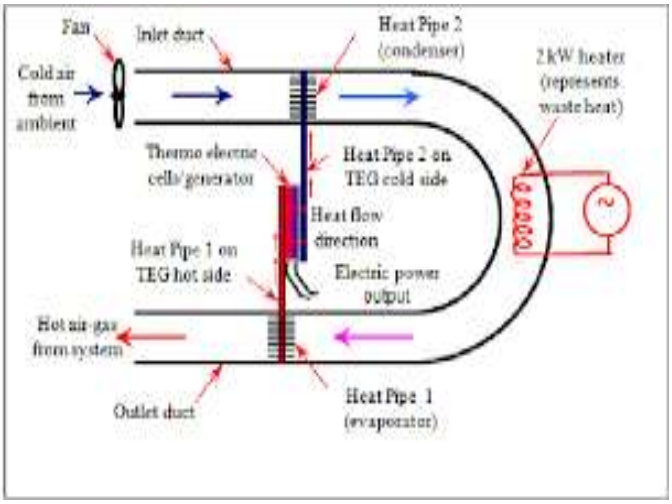
Working principle:
A heat pipe is a closed system consisting of a sealed, hollow tube whose inside walls are lined with a wick. The pores of the wick are saturated by a suitable working fluid. When heat is applied to the heat pipe, the liquid in the wick heats and evaporates. As the evaporating fluid fills the heat pipe, it diffuses throughout its length. Whenever the temperature is even slightly below that of the evaporation area, condensation of the vapor occurs. The vapor gives up the heat it acquired during evaporation, as it condenses. Near constant temperatures along the entire length of the pipe are maintained due to the high thermal conductivity. The condensate returns to the evaporator section through the wick structure and completes the cycle.

Structure:
A typical heat pipe consists of a vessel in which its inner walls are lined with a wick structure. The heat pipe vessel is first vacuumed, then filled with a working fluid, andsealed. When the heat pipe is heated at one end, the working fluid evaporates from liquid to vapor. The vapor then travels through the center of the heat pipe to the other end of the heat pipe at near sonic speed, where heat energy is being removed by a heat sink or other means. Here, the vapor condenses back to liquid and releases heat at the same time. The liquid then travels back to the original end of the heat pipe via the wick by capillary action.



5. HEAT PIPE ASSISTED THERMOELECTRIC GENERATOR SYSTEM

Heat pipes and thermoelectric generators can be used in combination to develop an efficient system to generate electricity with the help of waste heat. Thermoelectric generators require a temperature difference between its two junctions. Greater the temperature difference greater will be the voltage produced. Heat pipes are used to maintain this temperature difference. One set of heat pipes is used on the hot side while another set of heat pipes is used on the cold side. Heat pipes provide quick and efficient heat transfer which increases the efficiency of the thermoelectric generators.



6. ADVANTAGES

Thermoelectric generators have a number of advantages which makes them a good power generating source. They are solid state devices which means they have no moving parts. This makes them virtually maintenance free. There are no chemical reactions in them which make them pollution free. Thermoelectric generators are very light in weight and noise free and can be used in space exploration probes effectively. They are passive devices which mean they do not need any external power source to function.

7. LIMITATIONS

TEGs have limitations such as low efficiency and maximum surface temperatures. Other than low efficiency and relatively high cost, many problems are present in using thermoelectric devices such as a relatively high electrical output resistance, which increases heating, and a relatively low thermal conductivity, which makes them unsuitable for many applications. For a material to be suitable for thermoelectric generators it needs to have low thermal conductivity and high electrical conductivity. It is very rare for a material to possess both these properties. Hence semiconductors are used as thermoelectric materials which are very difficult and expensive to manufacture.
Heat pipes have limitations such as maximum rates of heat transfers and working temperature ranges.

CONCLUSION

- Using HP-TEG system for waste heat recovery and power generation is an effective method to indirectly increase the efficiency of any system.
- The conversion efficiency of the thermoelectric generators depends on the temperature difference across it.
- As the thermoelectric generators are small in size they can be easily installed. This system is silent, flexible, in design and has no moving parts.
- It is a reliable source of energy and almost maintenance free. They do not produce any kind of pollution, hence are eco-friendly.
- One of the major drawbacks of these systems is the cost and availability of thermoelectric materials.
- Research needs to be done on the manufacturing of suitable semiconductor which possesses all the required properties.
- Heat pipe assisted thermoelectric generators can be effectively used as a major power source in the future.

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