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A REVIEW OF WASTE HEAT RECOVERY BY USING THEHEAT PIPE AND THERMOELECTRIC GENERATOR

ANIRUDDHA A. KULKARNI
Dept. of Mech., G.H.R.C.E.M, Wagholi, Pune

DIPAK S. PATIL
Dept. of Mech., G.H.R.C.E.M, Wagholi, Pune

R. R. ARAKERIMATH
Dept. of Mech., G.H.R.C.E.M, Wagholi, Pune

ABSTRACT:

This paper continued a detail review of heat pipe and thermoelectric generator application in industrial, automobile and solar waste heat recovery. Each day new greenhouse gasemission further accelerates global warming. The exhaust heat recovery system by usingheat pipe and TEG'sis topotentially reduce the greenhouse gases emission. The use of two specific technologies heat pipe and TEG's make passivesolid state system design. Heat pipe used in system consents more flexible design as TEG location not inadequate to exhaust pipe surface. The conversion efficiency of thermoelectric generator is function of temperature difference (Heat source and heat sink temperature). The thermal performance of thermoelectric generator will be improved or enhanced by using heat pipe as a heat source in thermoelectric generator. Heat pipes do have limitations such as maximum rates of heat transfer and temperature limits. TEGs do have limitations such as low temperature limits and relatively low efficiency. When used in conjunction, these technologies have the potential to create a completely solid state and passive waste heat recovery system.

KEYWORDS: Heat pipe, thermoelectric generator, exhaust heat recovery, passive cooling.

1. INTRODUCTION:

Throughout the previous few years, the world population is increasing fast along with the progress of new technology for assisting our life quality in a more suitable way. In altercation, the rate of energy consumption also rises significantly, from environmental perspective, fuel consumption results in impact on the global natural environment. For example, the emission of carbon monoxide gases from industries waste and transport combustion has destroyed both living thing and ozone layer. A green and ecological approach is required to reduce the greenhouse gas emission [1] In the internal combustion engine (ICE) the chemical energy does not competently convert into mechanical energy. A majority of this energy is dissipated as heat in the exhaust and coolant. Rather than directly improving the efficiency of the engine, efforts are being made to improve the efficiency of the engine indirectly by using a waste heat recovery system. There are two favorable technologies that are originated to be beneficial for this purpose are thermoelectric generators (TEGs) and heat pipes. Both TEGs and heat pipes are solid state, passive, silent, scalable and durable. [2] Waste heat found in the exhaust gas of various process, reuse waste heat and reduce energy consumption and greenhouse gases which harmful to both living thing and ozone layer. Nowadays, the heat pipe and thermoelectric generator are deservedly considered one of the best technical solutions available for the passive silent heat recovery system. Solar energy which comprises radiant heat and light from the sun can be harnessed with some modern technology like photo-voltaic, solar heating and solar thermal electricity. Solar energy produces no pollution, has no environmental effects and is ecologically acceptable [4].

2. HEAT PIPE

The heat pipe is a vapor and liquid phase change device of very high thermal conductance that transfers heat from a heat source (hot reservoir) to a heat sink (cold reservoir) using capillary forces generated by wick material and the working fluid. It is similar to the thermo-siphon in few respects. It combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two interfaces. It is referred as superconductor of heat due to their fast heat transfer capability with low heat loss. Heat pipe consists of the evaporators section, adiabatic section, and condenser section. There are three regions separated as vapor region, wick region and the wall region. The working fluid is assumed to be liquid phase in the wick region and vapor phase in the vapor region. Thermal input at the evaporator region vaporizes the working fluid and this vapor travels to the condenser section through the vapor region. At the condenser region, the vapor of the working fluid condenses by rejecting the latent heat. The condensate returns to the evaporator by means of capillary action in the wick. Originally, the heat pipe was first suggested by Gaugler in 1944. But the operational characteristics of heat pipe were not widely publicized until 1963 when Grover and his colleagues at Los Alamos Scientific Laboratory independently reinvented the concept. Since then many types of heat pipes have been developed and used by a wide variety of industries [5].

Advantages of heat pipe are as follows:

- They possess an extra-ordinary heat transfer capacity and heat transfer rate with almost no heat loss.
- Heat Pipe is a device that can transfer large quantities of heat without any power inputs.
- There are no moving parts, there is no maintenance and nothing to break.
- The life time of Heat Pipes is much more without any maintenance (generally 18 to 20 years).
- Very high thermal conductivity. Less temperaturedifference needed to transport heat than traditional materials (thermal conductivity up to 90 times greater than copper for the same size) resulting in low thermal resistance.
- While the evaporator experiences variable heat fluxes a constant condenser heat flux can be maintained. Efficient transport of concentrated heat Temperature Control. The evaporator and condenser temperature can remain nearly constant while heat flux into the evaporator may vary.
- Geometry control. The condenser and evaporator can have different areas to fit variable area.

2.1. PRINCIPLE OF OPERATION:

The main regions of the standard heat pipe are shown in Fig.2.1

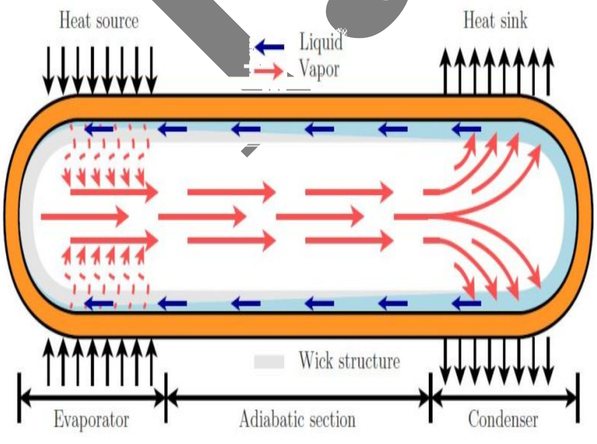


Figure 1: Heat pipe [5]

Heat pipe consists of three components such as, the container, the working fluid .and the wick. Heat applied by a heat source at the evaporator section vaporizes working fluid in that section. This also creates a pressure difference that make the vapor flow from evaporator to condenser section where it condenses latent heat of vaporization. This liquid returns to the evaporator by means of a wick (via capillary forces) so that the heat pipe can continuously transport the heat of vaporization from evaporator to condenser. This process is capable to transporting the heat from hot region to a cold region. Therefore, a heat pipe transport large amount of heat with a small temperature difference.

2.2. HEAT PIPE COMPONENTS AND MATERIALS:

The three basic components of a heat pipe are as follows:

(i) The working fluid
(ii) The wick structure
(iii) The container.

In the selection of a suitable combination of the above, there is a number of factors may arise, and the principle bases for selection are discussed below.

2.2.1. THE WORKING FLUID:

- Purpose

a. To transfer the heat from source to sink
b. To generate vapor pressure.

The first consideration in the selection of the working fluid is the operating vapor temperature range. Within the approximate temperature range, there is a number of working fluids may exist and a variety of characteristics must be examined in order to determine the most acceptable fluids for the required application. In heat pipe design, a high value of surface tension is desirable in order to operate heat pipe against gravity and to generate a high capillary driving force. The vapor pressure must be sufficiently great over the operating temperature range to avoid high vapor velocities, which cause flow instabilities due to large temperature gradients setup.

The prime requirements are as Follows:

(i) Working fluid Compatibility with wick, wall material.
(ii) Thermal stability
(iii) Wettability of wick and wall materials
(iv) High latent heat
(v) High thermal conductivity
(vi) Low liquid and vapor viscosities
(vii) High surface tension

2.2.2. THE WICK OR CAPILLARY STRUCTURE:

In this part of section, we can easily separate the two different frequencies by multiplying the rows of W with the

- Purpose
  a) To generate capillary pressure to transfer the working fluid from the condenser to the evaporator.
  b) It must also be able to distribute the liquid around the evaporator section.

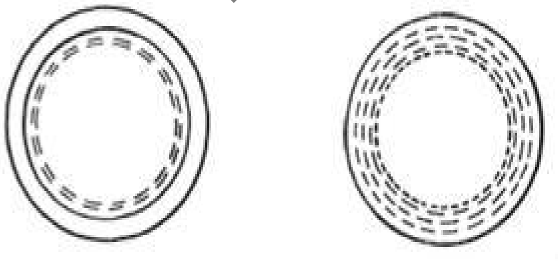
The wick structure within the heat pipe is present to return condensate to the evaporator region. Large pores are preferred within the wick due to that the movement of the liquid is not restricted too greatly but small pores are needed at the liquid vapor interface to develop high capillary pressures. For this reason, many different types of wick structures have been developed in order to optimize the performance of the capillary heat pipe.
There are two categories of wick structures:

a) HOMOGENEOUS WICK:

Homogeneous wicks are manufactured with one kind of material or machining technique. The most common type of wick structure is a screen wick is seemingly the simplest. The screen mesh consists of a metal or cloth fabric which is inserted into the heat pipe with wrapping around a mandrel. Then the mandrel is removed and the wick held by the tension of the wrapped screen, in the case of a metal fabric. For a cloth fabric, a spring may be inserted into the heat pipe to hold the wick against the inside of the pipe wall.

b) COMPOSITE WICK:

To generate high capillary pumping pressures composite wick structures employ small pores and having large pores for increasing the permeability of the liquid return path. The simplest type of composite wick is again the screen wick, except that two screens with different pore sizes are used. A number of wraps of a screen with a large pore size is used against the inner pipe wall for the liquid return path, and a much smaller pore size single wrap screen is placed adjacent to the vapor space to develop high capillary pressures. [6]



Homogeneous wick Composite wick

Figure 3: Wick structure

2.2.3. THE CONTAINER:

- Purpose
  a) To isolate the working fluid from the outside environment.

It has leak-proof to maintain the pressure differential leak-proof to maintain the pressure differential across. its walls and enable to transfer the heat into and from the working fluid. The heat pipe container, including the end caps and filling tube, is selected on the basis of several properties of the material used and these are listed in However, the practical implications of the selection are numerous. There are many materials available for the container, but most commonly used materials are copper, aluminum and stainless steel. Copper is eminently satisfactory for heat pipes operating between 0^{0}C and 200^{0}C in applications such as electronics cooling. Like aluminums and stainless steel, the material is readily available and can be obtained in a wide variety of diameters and wall thicknesses in its tubular form. Aluminum is less common as a material in commercially available heat pipes but used in aerospace applications due to its less weight.

Again this is readily available and can be drawn to suit by the heat pipe manufacturer, or extruded to incorporate, for example, a grooved wick. Stainless steel is not generally used as a container material with working fluid as water where a long life is required, owing to gas generation problems, but it is perfectly acceptable with many other working fluids.
Selection of the container material depends on several factors. These are as follows:

(i) Material should be compatible with working fluid
(ii) Strength-to-weight ratio
(iii) Thermal conductivity
(iv) Easy to fabricate, good machinability and ductility
(v) Porosity
(vi) Wettability

3. THERMOELECTRIC MODULE:

A thermoelectric module is a circuit containing thermoelectric materials that generate electricity from heat directly. The thermoelectric module consists of two dissimilar thermoelectric materials N-type and P-type semiconductors joining in their ends. It is also called as seebeck generator, is a solid state device that converts heat directly into electricitythrough a phenomenon called as seebeck effect. The working principle of TEG's shown in fig.

TEG works on the principle of Seebeck effect. A TEG is made up of many elements of N type and P type semiconductor material which are connected electrically in series but thermally in parallel. When one side of the

TEG is heated and the other side cooled, a voltage is generated. The voltage generation means there are applications for these TEGs to generate electricity where temperature differences are present.

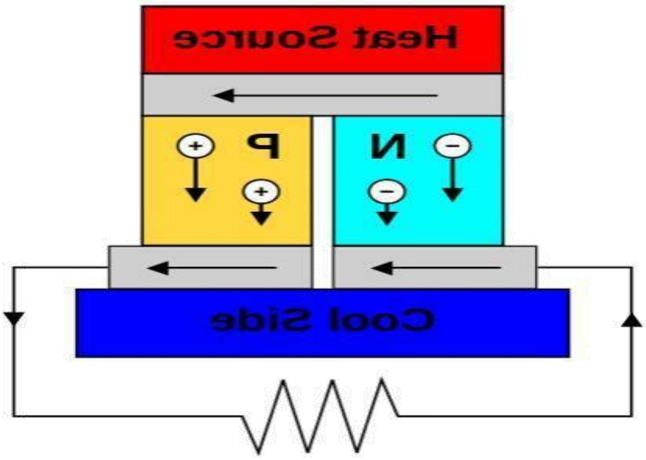


Figure 4: Principle of seebeck effect

Recovery systems would be materials rated for a high temperature. This means a larger temperature difference can be present and potentially more power and higher efficiency can be achieved. The use of high temperature TEGs also allows for the simplification of a design because efforts do not need to be made to prevent the TEGs from overheating. [2]

4. HEAT RECOVERY

4.1. CASE STUDY 1 - HEAT PIPE ANDTEG'S FOR INDUSTRIAL EXHAUST HEAT RECOVERY SYSTEM [1]:

As mentioned before, global warming hot topic concern inall countries. To reduce co_2 production and other particulates transfer in atmosphere, use the exhaust heat recovery technology in industries. This is a passive heat transfer system called combined heat pipe thermo-electric generator (CHP-TEG) has been introduced in this study of recovering the free energy from the industrial waste heat. A thermoelectricgenerator (TEG) is incorporated into this system for generating electricity that works using the "Seebeck effect".

TEG works on the principle of Seebeck effect. A TEG is made up of many elements of N type and P type semiconductor material which are connected electrically in series but thermally in parallel. When one side of the TEG is heated and the other side cooled, a voltage is generated. The voltage generation means there are applications for these TEGs to generate electricity where temperature differences are present. The conversion efficiency of the TEGs is typically 5-8%. At the heart of the thermoelectric effect is the fact that a temperature gradient in a conducting material results in eat flow; this results in a diffusion of charge carriers between the hot and cold regions in turn creates a voltage difference.

The most popular form of thermoelectric material is Bismuth Telluride. The use of this material in generators is limited because their maximum hot side operating temperature is relatively low. As they are widely used and mass produced, their cost is low compared to other thermoelectric materials. Other materials and techniques have been used to improve the power generation and efficiency of TEGs. The most promising and practical materials to be used for TEGs in exhaust heat

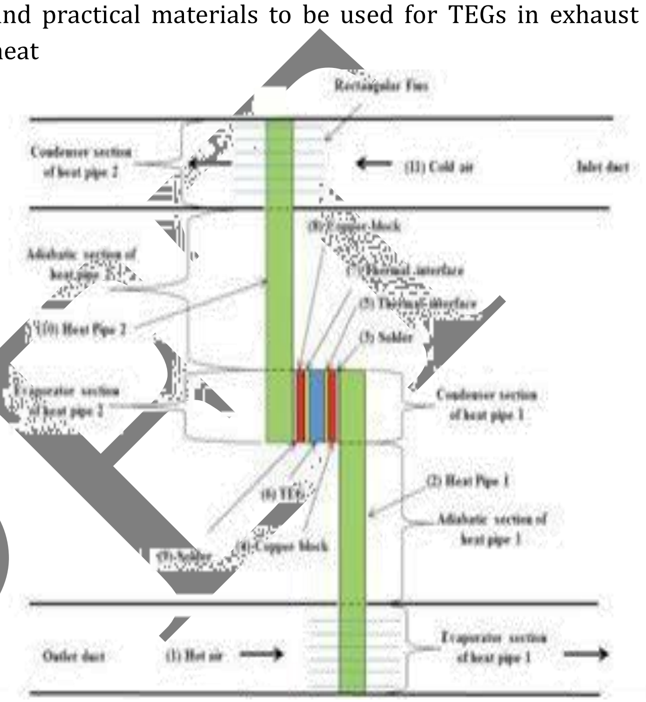


Figure 4: A schematic of the combined heat pipe-thermoelectric generator (CHP-TEG) heat exchanger in a counter flow arrangement and the thermal resistances of the CHP-TEG module [1]

A theoretical model was developed to predict the rate of heat transfer and the effectiveness of the heat exchanger system. An experimental investigation using a laboratory scale of such system was conducted, and the results from this experiment were used to validate the theoretical model. It was found that the theoretical prediction and experiment results match in the sense that both results shared the same trend.

4.2. CASE STUDY 2 - AUTOMOTIVE CAR EXHAUST HEAT RECOVERY SYSTEM USING HEAT PIPE AND TEG'S [2]:

The internal combustion engine (ICE) does not efficiently convert chemical energy into mechanical energy. A majority of this energy is dissipated as heat in the exhaust and coolant. Rather than directly improving the efficiency of the engine, efforts are being made to improve the efficiency of the engine indirectly by using a waste heat recovery system shown in figure, in this system the thermoelectric generator is sandwiched between two heat pipes. The heat pipe 1& heat pipe 2 works heat sink and heat source respectively. The obtained heat at exhaust is exerted by fin attached to heat pipe and transfer to hot side of TEG through heat pipe. TEG converts the few amount of heat into electricity and remaining heat at cold side of TEG is transferred to cold air section through heat pipe 2.in that section fan is used to introduce cool atmospheric air in the pipe. The heat pipe and TEG make this system is passive and pollution free.

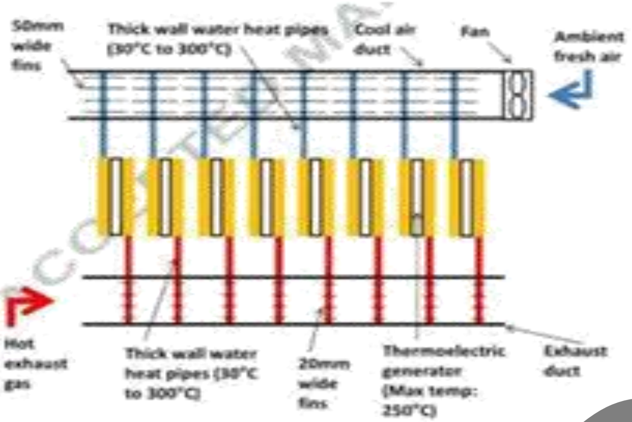


Figure 5: Schematic of the car exhausts heat recovery [2]

4.3. CASE STUDY 3 – HEAT PIPE FOR WATER HEATING USING CONCENTRATED SOLAR THERMAL ENERGY:

This technology for the purpose of offering solar water heating, solar PV for electricity and heat recovery system to commercial business sector as well as to the private home owners Solar energy which comprises radiant heat and light from the sun can be harnessed with some modern technology like photo-voltaic, solar heating and solar thermal electricity. Solar energy produces no pollution, has no environmental effects and is ecologically acceptable.

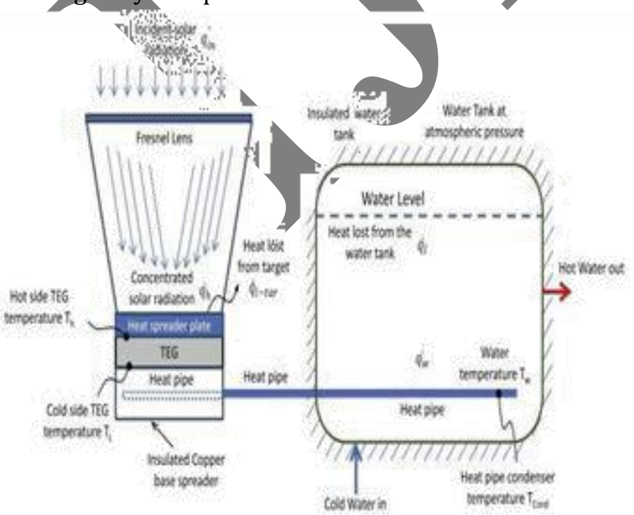


Figure 6: water heating using concentrated solar thermal energy [3]

The heat pipe for water heating use concentrated solar thermal energy shown in fig. A novel system is proposed that can generate electricity and hot water utilizing the flow of heat from a solar collector via a thermoelectric generator to hot water storage tank. The system also uses the solar concentrator improve the performance of thermoelectric generators and heat pipes to cool one side of TEG and passively transfer the heat to the water storage tank.Mathematical modeling is presented to predict the transient and steady state behavior of the various temperatures in the proposed system. Lab experiments have been performed to validate the mathematical model predictions. An important part of this modeling is the knowledge of value for the rate of heat loss from the hot water storage tank. A case study with a system design of basic components is presented for a typicalhouse with 4 occupants and daily hot water demand of 400 l. It is determined that having less TEG's, a higher concentrationratio and hence higher temperature difference will produce more electric power than having more TEG's and lesstemperature difference.

5. CONCLUSION:

The conversion efficiency of thermoelectric generator is function of temperature difference (Heat source and heat sink temperature). The thermal performance of thermoelectric generator will be improved or enhanced by using heat pipe as a heat source in thermoelectric generator. Heat pipes do have limitations such as maximum rates of heat transfer and temperature limits. TEGs do have limitations such as low temperature limits and relatively low efficiency. When used in conjunction, these technologies have the potential to create a completely solid state and passive waste heat recovery system.

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