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Heat Engine And Efficiency

Basic Mechanical Engineering

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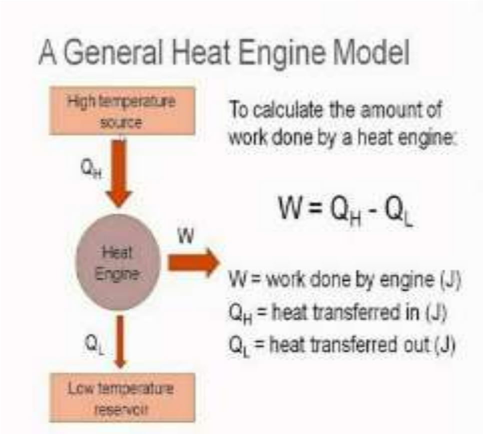
Abstract

In thermodynamics, Heat Engine system is one that converts heat or heat energy into mechanical energy, may be used to perform mechanical work. It does this by bringing the active ingredient from high temperatures to low temperatures. During this process some thermal energy is converted into activity through the properties of an active substance. The active ingredient can be any thermal energy system that is not an egg, but usually a gas or a liquid. During this process, some of the heat is often lost to the environment and is not converted into activation. Reverse Heat Engine is a device that transmits energy from an object with a low temperature to an object at high temperatures by performinga function in the system. This is actually a reversal of the process that takes place inside the heat engine, where energy flows from the top to the lowest temperature and the work is produced as a result. Other common examples of such engines are refrigerators, air conditioners and heat pumps etc. All are measured by the amount known as the Coefficient of Performance (COP).

Review of Literature

Lingen Chen et.al(2000) defined the power density as the ratio of power output to maximum specific volume in the cycle is taken as the objective for performance analysis of an endoreversible closed cycle. Yilmaz (2007) found that the proper optimization criteria to be chosen for the optimum design of heat engines may differ depending on their purposes and working conditions. If the heat engine design was done not to obtain maximum work or power, but to have maximum benefit from energy, then the design objective is to get maximum efficiency



Classification of heat engine

According to place of combustion:

1) **External combustion engine:** Combustion of fuel takes place outside the engine cylinder. Example – steam turbine
2) **Internal combustion engine:** Combustion of fuel takes place inside the engine cylinder. Example-petrol engine

According to type of converting machine

1) **Reciprocating engine:** Piston reciprocates inside the engine cylinder. example - petrol engine
2) **Rotary engine:** Blades rotate when working fluid strikes on rotor. Example – steam turbine

Major components of heat engine

1 Working substance / working fluid
2 Heat source
3 Converting machine / expander/turbine
4 Heat sink
5 Pump/compressor

Working fluid: It is a medium which receive heat from heat source and transmits to the heat engine to do work and rejects some heat-to-heat sink. when a gas, a mixture of gases or vapors is operating in an engine, it is known as working substances

Heat source: It is a high temperature heat reservoir from which heat is supplied to working fluid for example : furnace , combustionchamber etc.

Converting machine: It converts heat energy into mechanical work where working fluid does work. Example steam turbine.

Heat sink: It is a low temperature heat reservoir from where heat isrejected by working fluid example : Condenser **pump :** where the compressor of working fluid is increased.

Heat Engine Efficiency

Let us derive the equation for the efficiency of a heat engine. We candefine heat engine efficiency as: $\eta = W/Q1$ Where,

W= Work done by the engine,
Q1 = Heat taken from the source
After each cycle, the engine returns to its initial state so, $\Delta U=0$.

Also,
$W = Q1 - Q2$

Hence the heat engine efficiency is:

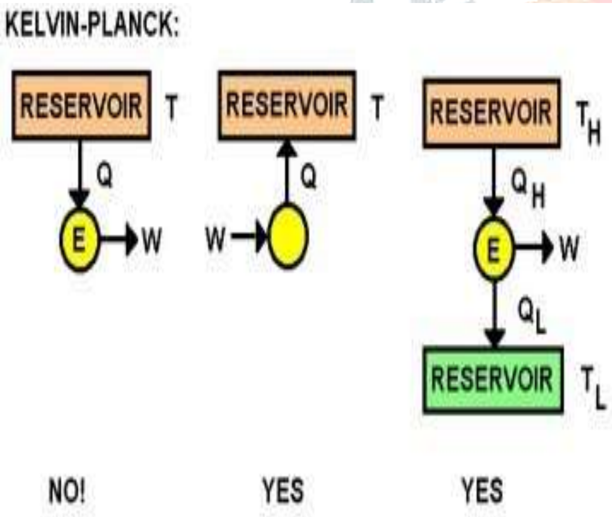
$\eta = (Q1-Q2)/Q1$

$\eta = 1 - Q2/Q1$

So for Q2 = 0, efficiency will be 100% but, in actuality, this isnot possible.

The Kelvin Planck Statement

It states that *"it is impossible to build a device that works in a cycle that does not produce another effect without transferring heat from one body to produce work."* This means that the engine's main purpose is to convert heat from a high source / reservoir into an equal amount of effort that cannot be built. This is an example of the second law of active thermodynamics.



What is a Reverse Heat Engine?

It is a device that transfers energy from an object at a lower temperature to an object at a higher temperature by doing work on the system.

LTER= Low Temperature Energy ReservoirHTER= High Temperature Energy Reservoir

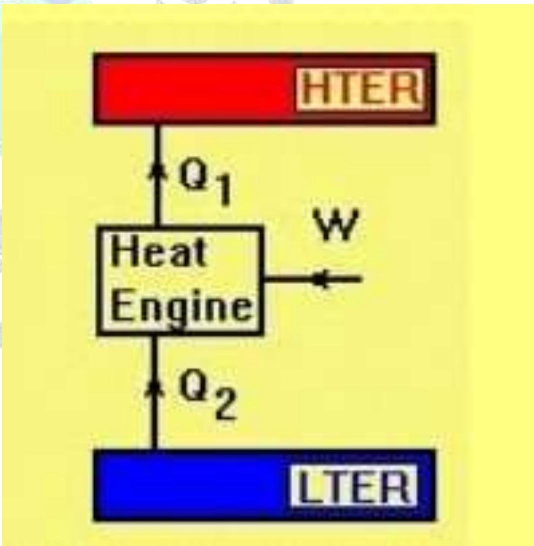
A reverse heat engine has a positive work input such as a heatpump and refrigerator. Applying the first law of thermodynamics:

==> Q1 + Q2 = -W

In case of a reverse heat engine the second law of thermodynamics is as follows: It is not possible to transfer heat from a cooler bodyto a hotter body without any work input i.e

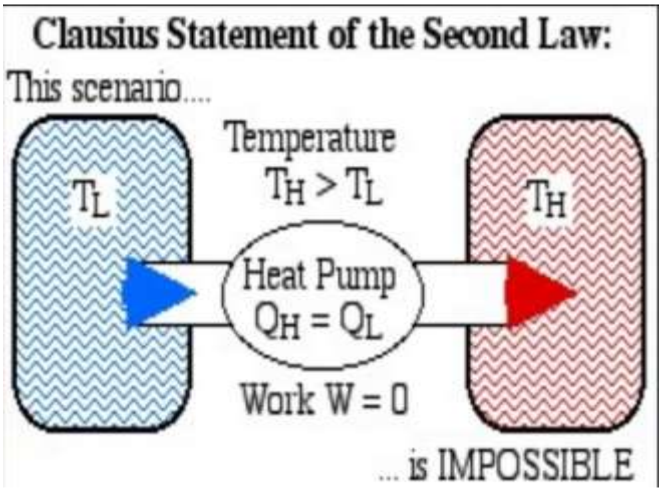
==> W > 0

which means that the cop for a heat pump is greater than unity.



Efficiency of Reverse Heat Engine

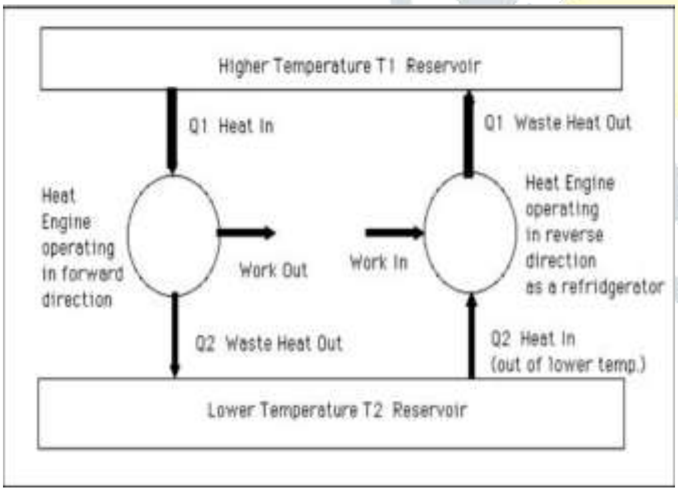
The efficiency of every reversible heat engine working betweenthe same two temperature reservoirs is the same. This indicatesthat regardless of how a



reversible heat engine is built or what the working fluid is, it has the same efficiency as all other heat engines operating at the same two temperatures.

Clausius Statement

It is not possible to build a device that works in a cycle but does not produce any other effect than transferring heat from a cooler body to the body.



Heat Engine cycles

Following are the various types:

1. Carnot cycle
2. Rankine cycle
3. Otto cycle
4. Diesel cycle

Carnot cycle

A Carnot cycle is defined as an ideal irreversible closed thermodynamic cycle in which there are four successive operations involved, which are isothermal expansion, adiabatic expansion, isothermal compression and adiabatic compression. During these operations, expansion and compression can be done to the desired location and returned to the original position.

According to Carnot theorem - **"No cycle can be more efficient than a reversible cycle operating between the same temperature limits**. "

Efficiency

The Carnot cycle is useful to compare the efficiency of any cycle under consideration with the efficiency of a reversible cycle operating between the same temperatures.

Carnot cycle efficiency represents the maximum potential efficiency of any engine engine system within specified temperature limits. The efficiency of the energy conversion systems used in the real world remains less than the efficiency of the Carnot cycle. However, increasing the temperature in the middle of the cycle or lowering the temperature in the cycle usually increases the efficiency of the whole cycle or provides an opportunity to doso.

Limitation of Carnot cycle

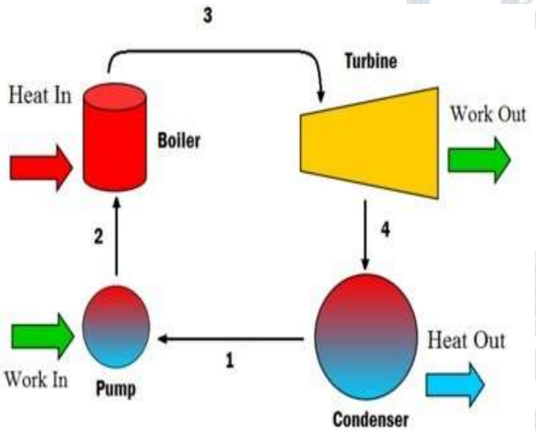
- The Carnot Cycle is Hypothetical (something that doesn't really exist)
- Practically it is not possible to neglect friction between piston &cylinder.
- The output obtained per cycle is very small.

Applications

All types of vehicles- caps, motorcycles, trucks, ships, aero planes, and many other types of engines, work on the basis of the second law of thermodynamics and Carnot Cycle. They may be using petrol engines or diesel engines, but the law remains the same. All the refrigerators, deep freezers, industrial refrigeration systems, all types of air- conditioning systems, heat pumps, etc. work on the basis of the Carnot cycle.

RANKINE CYCLE

Rankine Cycle or Rankine Vapor Cycle is a process widely used in energyindustries such as coal-fired power plants or nuclear attackers. In this machine, gasoline is used to generate heat inside the boiler, converting water into steam and then expanding it with a wind turbine that produces useful work. This method was developed in 1859 by Scottish engineer William J.M. Rankine. This is a thermodynamic cycle that converts heat into mechanical energy — often converted into electricity by generating electricity.



Rankine Cycle

Efficiency of Rankine cycle

The efficiency of the Rankine cycle is limited by the high temperature ofliquid evaporation. The liquid must be circulated and used regularly, therefore; water is not the most active liquid in this cycle. This is not thereason why many electrical industries are located near water sources that is, waste disposal.

As the water condenses in the condenser, the waste heat is released in the form of water vapor — which can be seen blowing into the cooling towers of the plant. This waste heat is required for any thermodynamic cycle. As a result of this squeezing action, the pressure from the turbine decreases. Thismeans that the pump requires less work to compress the water — resulting in a more complete efficient operation.

Carnot cycle vs Rankine cycle

Carnot cycle and Rankine cycle normal air cycles. The Carnot cycle is a good heat engine cycle that offers the highest efficiency among a given temperature variation but the theory cycle and in fact no engine operates onit. Rankine cycle is a good cycle of evaporation or production of steam energy. All power industries operate in this cycle. It uses water as an active ingredient. Both of these cycles have different characteristics which I will describe below.

The Carnot cycle consists of 2 isothermal processes and 2 isentropic processes. Heat is added and rejected isothermally and pressure and expansion occur with constant entropy. Theoretical cycle because it is actually difficult to achieve the addition of isothermal heat and rejection. Provides maximum efficiency between a given temperature difference. As Isaid, the Rankine cycle is an ideal power generation cycle used in steam engines. It contains two isobaric processes and two isentropic processes.

Heat is added and rejected by constant pressure and the expansion and congestion of steam occurs entropically. First, water is pumped into a boilerwhere heat is fed by continuous pressure that converts water into steam.

This high temperature steam rotates the turbine. This increase in steam occurs entropically. Now the heat is rejected in the condenser by continuous pressure which converts to water. Now this water is again pumped into the boiler naturally ending the cycle. This cycle continues continuously producing energy.

The basic and fundamental difference between the Carnot and Rankine cycles is that in the Carnot cycle the heat is added and rejected at constant temperature and in the combination of the Rankine cycle temperature and rejection occurs at constant pressure. Another major difference is that the Rankine cycle uses water as an active substance and the Carnot cycle uses air as an active substance. There are many other variations described below in the form of a table.

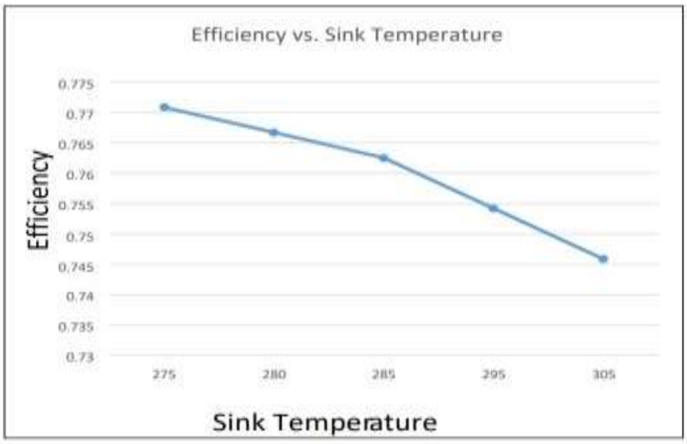
Sr. No.	Carnot Cycle	Rankine Cycle
1.	It is a theoretical cycle. . It gives maximum efficiency between two temperature difference	This one is a practical cycle of steam engine and turbine.
2.	Heat is added and rejected at constant temperature.	Heat is added and rejected at constant pressure.
3.	It has highest efficiency between two temperature differences.	Rankine cycle has lower efficiency than Carnot cycle.
4.	Carnot cycle uses air as the working substance.	Rankine cycle uses water as working substance.
5.	Carnot cycle is an ideal cycle for heat engine.	It is an ideal cycle for vapor power engine.

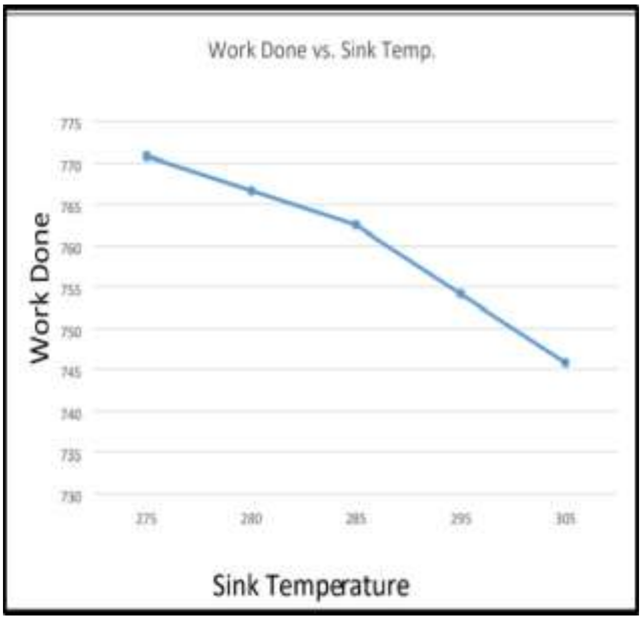
Results and Discussion

On observing the above tables and plotting the graphs for both Heat Engine and Reverse Carnot Engine, we get the followingresults.

First consider the graph for Heat Engine when the SourceTemperature (T_1) is kept constant and Sink Temperature (T_2) is varied.

First observing the plot between **Efficiency** vs. **SinkTemperature**.



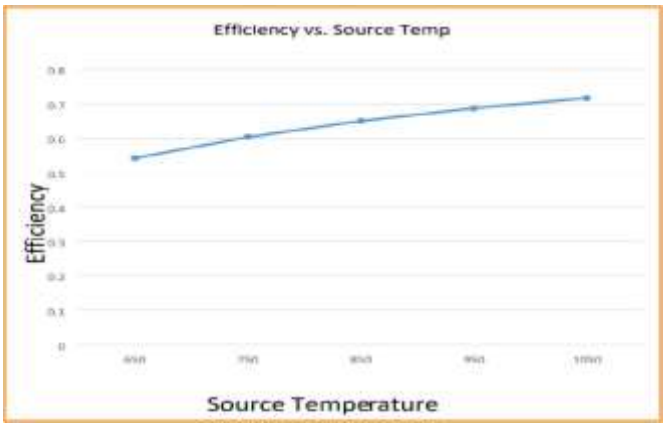


As we can clearly see from the graph, the **Efficiency (n) decreases** as **Sink Temperature (T_2) increases**.

Now taking the plot between **Work Done** and **SinkTemperature**.

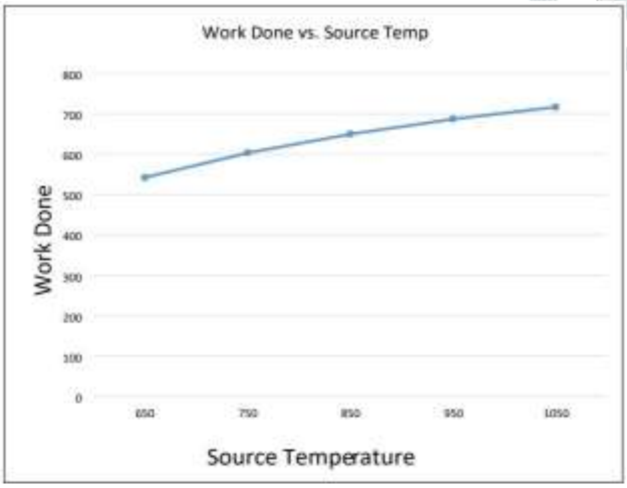
From the graph we can see that the

Work Done (W) decreases as the **Sink Temperature (T2) increases**. Now taking the graph where the **Sink Temperature (T2)** is takenconstant as the **Source Temperature (T1) is varied**.



The first plot is again taken between **Efficiency (n)** and **Source Temperature (T_1)**.

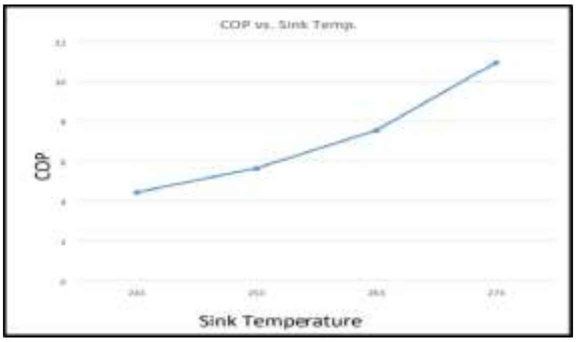
We can see from the graph that the **Efficiency (n)** slowly **increases** as the **Source Temperature (T_1) increases**. Taking the Plot between **Work Done (W)** and **Source Temperature (T_1)**



The same can be seen from the graph of **Work Done (W)** vs. **Source Temperature (T_1)**. As the Efficiency **increases** so does the **Work Done** as the **Source Temperature increases**.

Now in the case of the Reverse **Heat Engine** we plot the graph between the **COP** and **Work Done** against the Sink Temperature(T2).

So first taking the plot of **COP vs. Sink Temperature.**



It is clearly evident from the graph that the **COP of the Reverse Heat Engine increases** as the **Sink Temperature is increasing**. Going to thenext plot of Work Done and Sink Temperature (T2).

Since the **COP and Work Done** are **inversely proportional** thus weget a **decreasing curve** in the plot of **Work Done and Sink Temperature**.

The Carnot cycle is useful to compare the efficiency of any cycleunder consideration with the efficiency of a reversible cycle operating between the same temperatures.

Conclusion

The Thermodynamic study on Heat Engine, Carnot cycle, Rankine cycle and Reverse Heat Engine has been completed and their respective Efficiencies, COP and Work Done have also been calculated.

Various graphs have also been plotted to show their Efficiency curves with respect to the increase of Sink and the Source Temperatures.

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