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Development of A Work-Input Free, Waste-Heat Based System for Water Heating

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Abstract

This Paper Summarizes components, functionality, calculations, & challenges faced by an on-going project on water heating system utilizing waste-heat. The Source & the Sink of the system are also outlined. The structural integrity aspects are highlighted. Moreover future dimensions of the project are discussed as well
Keywords: Work-input free System, Waste-Heat, Water heating System, Cooking Stove

1 Introduction

Historically the considerations made on utilizing that heat, which was being wasted in atmosphere or environment(i.e. Rivers, Lakes etc) has given us the concepts of cogeneration[1], regeneration[2], Combined-Cycle Power Plant[3] (Waste-heat Recovery Unit) & so on[4, 5], So moving on the parallel lines, we are going to Design & Fabricate a Waste-Heat based water heating system. The design will ensure that there won't be any need of work-input, so its operating cost may be considered as zero.

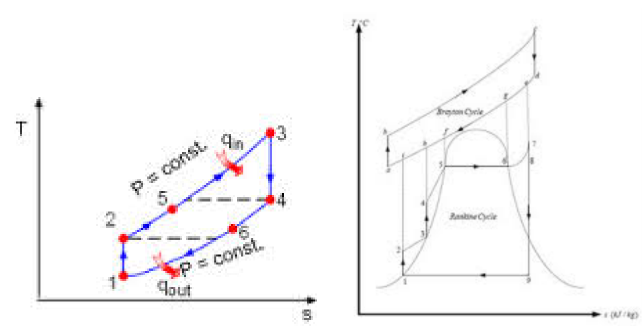

Figure 1: Ts diagrams of Regeneration & CCPP

1.1 Work-input free System

The first nominating thing about our project is, it's actually a work-input free system & to make it possible we are actually manipulating two naturally occurring phenomenons of Convection cell (Liftng up of less dense & warmer fluids), free of gravitational effects[6], second one is gravitational force of earth & the third one is a common practice of placing water reservoir at a certain head, from where it is to be extracted, which will serve as the link between the first two phenomenon's. However their combined effect is to eradicate any kind of need of work-input device(i.e. pump or compressor).

1.2 Source

Being a cyclic process & in compliance with laws of Thermodynamics, there must a heat-input source of our system. And the available research[7] , our daily life observation & the calculations we made doing some experiment, direct us to use waste-heat available in the domestically used gas-fired cooking stove to serve for us as the heat-input source of our system.

Figure 2: Domestic Gas Cooking Stove

1.3 Calculations

We actually performed an experiment, we took 1 litre of water at temperature 22°C and boiled it completely on the cooking stove with all water evaporated (i.e. steam quality = 1), we also noted the amount of gas consumed from the meter of gas. We assumed the pressure to be 1 atm
Taking $\rho = 1000\ kg/m^3$, the energy required to raise its temperature to saturation temperature is given as

$$E_{sat} = m \cdot c \cdot (T_{sat} - T_{in}) = 335\ kJ/kg$$

where $m = mass = 1kg$
c = specific heat of water = 4.190 kJ/kg·K
T$_{sat}$ = $100°C$ and $T_{in} = 22°C$

And the latent heat of vaporization at 1 atm Pressure & $100°C$ is (h_{fg}) 2257 kJ/Kg[8]. Adding both of these to determine the energy utilized.

$$E_{total,Consumed} = E_{sat} + m \cdot h_{fg} = 2592kJ$$

Now below is how we determined the available energy from the natural gas in stove. The amount of energy given as the natural gas is burnt is as follows

$$1ft^3 = 1000BTU = 1000kJ$$ [9]

Actually we noted the consumption of gas while boiling the water completely, the readings are as follows

$$Before = 03029815m^3 \text{ and } after = 03029999m^3$$

the difference is

$$V = 0.184m^3 = 6.49ft^3$$

And using the above relation we can calculate the energy produced as

$$E_{produced} = 6855\ kJ$$

Now we can have idea how much energy was Utilized to evaporate water.

$$\%\text{ age of energy used} = (E_{(Total,Consumed)}/E_{(produced)}) \times 100 = 38\ \%$$

Hence

$$\text{Waste energy} = 62\%$$

1.4 Our Target, The Sink

A small level survey conducted by ourselves revealed that 27 litre of water is required at 40°C Temperature to take bath for a single person in the winters. Hence, using density as mentioned earlier, we can conclude. the mass of water of our sink is

$$m_{sink} = 27kg$$

And throughout the year, the water available from the earth being good insulator is constant[10], which is in our case 22°C. So We are targeting to raise the temperature of this much water from 22°C to 40°C from the waste heat in the cooking stove

1.5 Components of Our system

The suggested system consists of three components

- Collector
- Condenser
- Reservoir

These components are connected via piping. The attributes and detail functioning of each component will be given in later sections.

1.6 Working Principle:

The working principle of this system is similar to solar water heateing systems. A working fluid takes thermal energy from stove and boils. Vapor formed move via convection through the piping to condenser. These vapors transfer heat condenser where vapors get condensed. The liquid working fluid flows through reservoir to move towards collector again in order to complete the cycle and start again.

1.7 System Layout:

The simplest system layout is given as following:

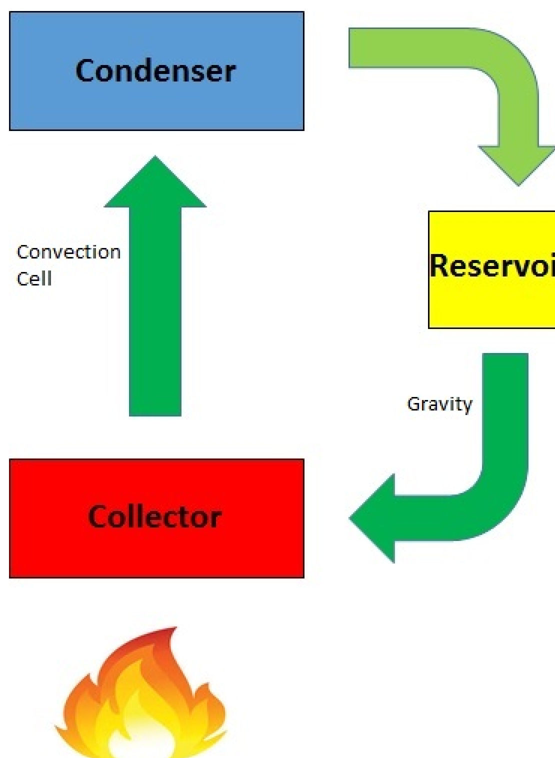

Figure 3: System Layout

The detailed description of each part and its application is given as following:

1.7.1 Collector:

The collector, as shown in the figure 3, is a hollow structure. The working fluid from the reservoir flows in it it via gravity. It basically serves in two ways. Firstly its hollow cavity allows wokring fluid to pass through it and boils it using the waste heat in the stove. Secondly it serves as the support stand of the stove where the cooking pots are placed. The cross section view of our designed collector is given as following:

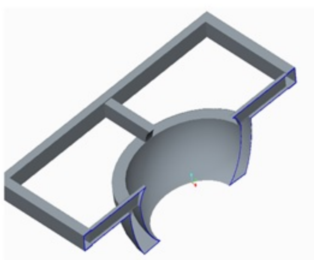

Figure 4: The cross section view of collector

1.7.2 Condenser:

It is a heat exchanging component that condenses the vapors by rejecting its heat to water i.e. sink. The system demands that the height of the water reservoir(in other words condenser) must be higher than all other components so that we can ensure the flow of working fluid from condenser to all other components without requiring the external work done.

1.7.3 Reservoir:

The reservoir is basically a tank that holds working fluid. It ensures that amount of fluid is available to the system.

1.7.4 Piping:

Piping connect all components together. Piping will be insulated in between condenser and collector to minimize heat loss. In order to transfer maximum heat from source to sink there must be least possible turns/contours in the piping

1.7.5 Working Fluid:

This section describes the criteria for selecting a working fluid and also a way to calculate the amount of working fluid required. At present we are proposing the water to be our working fluid because of the following characteristics

- Easily available for testing purpose
- Low Cost
- More Energy carrying capacity i.e. greater specific heat c_p

The amount of working fluid required can be determined from the energy balance in the condenser.

$$m_{wf} \cdot c_p \cdot (T_i - T_{eq}) = m_{sink} \cdot c_p \cdot (T_{eq} - T_{ii})$$

Where T_{eq} is the thermal equilibrium temperature which would be 40°C, T_i is the steam temperature, ideally 100°C and T_{ii} will the be initial sink temperature which would be 22°C. Specific heat will vanish from the relation because it is same for the given scenario. And hence this is how we can determine the quantity of our working fluid required for our objective to be fulfilled.

1.7.6 Auxiliary Components:

The valves may be required at different places to regulate the functionality of the system effectively.

2 Thermodynamic Cycle:

Following T-v diagram shows what is happening in the system thermodynamic-ally. Since we are not sure about suitable fluid for our system this diagram shows a general behavior of any fluid that might be used.

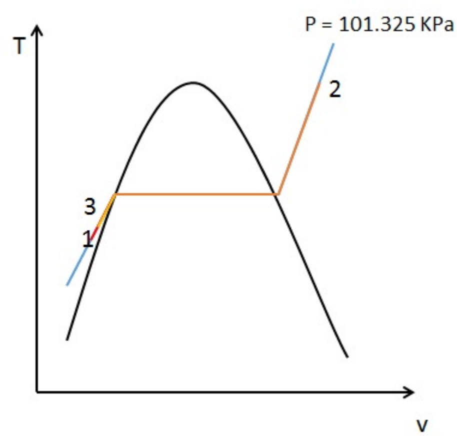

Figure 5: T-v diagram of the system

- **Process 1-2:**Constant pressure heat addition in collector.
- **Process 2-3:**Constant pressure heat rejection in condenser.

One thing is notice able that T_3 is equal to T_1.

3 Structural Integrity

In our potential design the boiler (collector) around the stove burner must be with as less as possible thickness in order to transfer the maximum heat. But the boiler is also serving as the supporting stand which may be then modeled as a cantilever beam, because one of its end is fixed while other with load of cooking pot. So it will be subjected to bending phenomena.

Also Being exposed to a high temperature and the constant loading this may be subjected to phenomena of Creep i.e A time dependent strain.

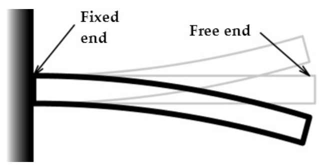

Figure 6: Cantilever Beam

4 Challenges & Future Aspects

Initially we are having the sink sufficient for only one person to take bath. However making the system hybrid by utilizing exactly similar system but the other source of heat, being the solar radiations, more water can be heated in lesser time.

Moreover Engineering Software Would be employed to Simulate our system under working conditions So that the functionality of the system is assured as well as the structural integrity is supplemented.

The other factors increasing the heat transfer would be studied as well i.e. Reducing the velocity at inlet of boiler, Using the internal fins and external fins in boiler & condenser respectively in order to enhance the heat transfer.

Moreover the selection of material for the components as well as the insulation for the piping is also another challenge to implement the maximum possible efficiency and keeping in mind safety standard

5 Conclusion

Since no law of physics is violated in the above discussion as well as the calculations made are rationale so it appears to be a promising effort to yield the required results efficiently once it has developed completely. It will also serve as a new field of study and an engineering application. As mentioned earlier it is based on waste heat and no work-input is employed so it will be a cheaper solution to water heating rather the gas fired water geyser.

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