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Design and Empirical modelling of a waste-heat recovery system in kitchen gas stove

Prakash M[1], Krishnan V.K[2], Siddharth S[3], Senthilkumar T[4]

PG Student, Mechanical, VMKVEC, Salem, India [1]

Professor, Mechanical, VMKVEC, Salem, India [2]

Visiting Faculty, Mechanical, UCE, BIT, Anna University, Tiruchirappalli, India [3]

Dean, Mechanical, UCE, BIT, Anna University, Tiruchirappalli, India [4]

***Abstract*— In this work, a waste-heat recovery (WHR) system was designed and implemented to utilize the waste heat from a cooking stove. The WHR system was designed to preserve maximum thermal energy efficiency, use passive heating, and produce a system that did not alter the body of the cooking stove. The thermal energy of the heated water can be used for domestic and commercial purposes. Dependent variables were the heater temperature and the volume of water. The heater temperature was varied between 230 to 250 °C, and 4.2–7.5 L of water was investigated. At equilibrium, design was used to empirically model the influence of the heater temperature and the volume of water on the economiser. Based on time, more efficiency can be achieved when the WHR system was attached. Here Economiser is used as metal tube container. Water heating is a heat transfer process that uses an energy source to heat water above its initial temperature. Typical domestic uses of hot water include cooking, cleaning, bathing, and space heating. Economizers are mechanical devices intended to reduce energy consumption or to perform useful function such as preheating a fluid. Here metal tubes act as Economizer. This paper shows how efficiently heat energy is transferred or absorbed to metal container during cooking process in a gas stove.**

***Index Terms*— Gas stove, portable water, Waste-heat recovery (WHR) system.**

I. INTRODUCTION

Domestically, water is traditionally heated in vessels known as water heaters, kettles, cauldrons, pots, or coppers. These metal vessels that heat a batch of water do not produce a continual supply of heated water at a preset temperature. Rarely, hot water occurs naturally, usually from natural hot springs. The temperature varies with the consumption rate, becoming cooler as flow increases.

Appliances that provide a continual supply of hot water are called water heaters, hot water heaters, hot water tanks, boilers, heat exchangers or calorifiers. These names depend on region, and whether they heat potable or non-potable water, are in domestic or industrial use, and their energy source. In domestic installations, potable water heated for uses other than space heating is also called domestic hot water (DHW).

Fossil fuels (natural gas, liquefied petroleum gas, oil), or solid fuels are commonly used for heating water. These may be consumed directly or may produce electricity that, in turn, heats water. Electricity to heat water may also come from any other electrical source, such as nuclear power or renewable energy. Alternative energy such as solar energy, heat pumps, hot water heat recycling, and geothermal heating can also heat water, often in combination with backup systems powered by fossil fuels or electricity.

"Empirical" means "based on observation or experience," according to the Merriam-Webster Dictionary. Empirical evidence is information acquired by observation or experimentation. Scientists record and analyze this data. The process is a central part of the scientific method.

In liquids and gases, convection is usually the most efficient way to transfer heat. Convection occurs when warmer areas of a liquid or gas rise to cooler areas in the liquid or gas. As this happens, cooler liquid or gas takes the place of the warmer areas which have risen higher.

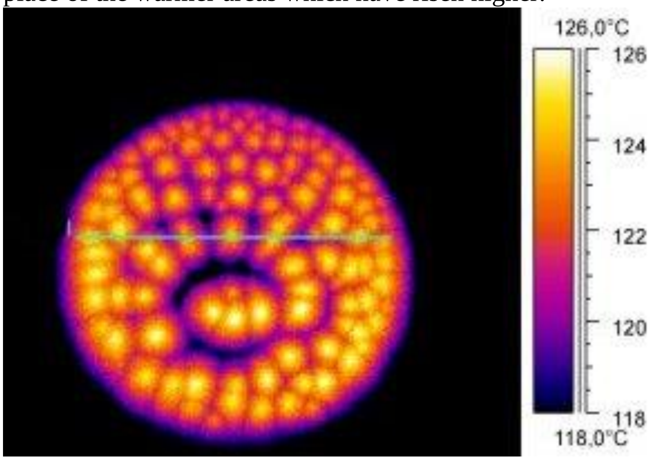

Figure 1. Thermal infrared image indicating hot oil boiling in a pan. (Möllmann et al.)

This cycle results in a continuous circulation pattern and heat is transferred to cooler areas. You see convection when you boil water in a pan. The bubbles of water that rise are the hotter parts of the water rising to the cooler area of water at

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the top of the pan. You have probably heard the expression "Hot air rises and cool air falls to take its place" - this is a description of convection in our atmosphere. Heat energy is transferred by the circulation of the air.

II. Materials and Methods

The objective is to design an efficient, cheaper and most of all environment friendly economizer. The design consists of L or U shaped metal tube container as an additional component to the gas stove of single burner. Thus we aim at absorbing the surrounding heat energy which is wasted during cooking process.

The term economizer is used for other purposes as well such as boiler, power plant, heating, refrigeration, ventilating, and air conditioning. In simple terms, an economizer is a heat exchanger.

Single Burner Gas Stove

A Gas stove with single burner of four legs

- Stainless steel stove with square bottom furnace, lighter, regulator and pipe
- Single big spiral burner for wide flame and burner is made of casting iron
- revolutionary burner with more holes
- Silent furnace with no noise at all
- It is a blue flame furnace
- Ideal For Hotels Restaurants & Caterers
- Stainless Steel Body == Stainless Steel Legs
- Overall Height From Bottom – 40 cm == Width X Length = 50cm X 50 Inches == Weight - 5.6 Kg
- The surrounding air temperature varies from 30 to 50 degree Celsius according to the flame temperature of burner.

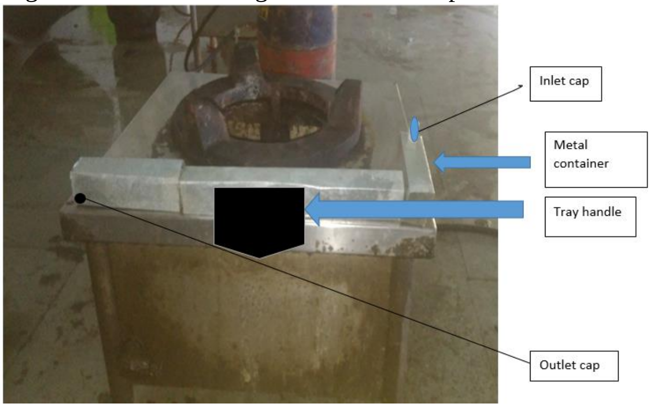

Figure 2. L Shaped Container design

o The inlet cap is located on the top of the container and outlet cap is located on the bottom of the container.

o The container is sealed and outlet cap is closed. Then water is filled in the container via inlet cap at full level.

o Any leakages to be arrested arise from either in outlet cap or in metal container.

o The metal container is fitted with thermoplastic handle for lifting and moving purposes

Figure 3. U shaped Design

Liquefied petroleum gas (LPG)

LPG is a mixture of commercial butane and commercial propane having both saturated and unsaturated hydrocarbons. LPG marketed in India shall be governed by Indian Standard Code IS-4576

Physical properties and characteristics

Density

LPG at atmospheric pressure and temperature is a gas which is 1.5 to 2.0 times heavier than air. It is readily liquefied under moderate pressures. The density of the liquid is approximately half that of water and ranges from 0.525 to 0.580 @ 15 deg. C. Since LPG vapor is heavier than air, it would normally settle down at ground level/ low lying places, and accumulate in depressions.

Vapor pressure

The pressure inside a LPG storage vessel/ cylinder will be equal to the vapor pressure corresponding to the temperature of LPG in the storage vessel. The vapor pressure is dependent on temperature as well as on the ratio of mixture of hydrocarbons. At liquid full condition any further expansion of the liquid, the cylinder pressure will rise by approx. 14 to 15 kg./sq.cm. for each degree centigrade. This clearly explains the hazardous situation that could arise due to overfilling of cylinders.

Flammability

LPG has an explosive range of 1.8% to 9.5% volume of gas in air. This is considerably narrower than other common gaseous fuels. This gives an indication of hazard of LPG vapor accumulated in low lying area in the eventuality of the leakage or spillage. The auto-ignition temperature of

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LPG is around 410-580 deg. C and hence it will not ignite on its own at normal temperature. Entrapped air in the vapor is hazardous in an unpurged vessel/ cylinder during pumping/ filling-in operation. In view of this it is not advisable to use air pressure to unload LPG cargoes or tankers.

Fuel Calorific Values

The calorific value of a fuel is the quantity of heat produced by its combustion – at constant pressure and under "normal" (standard) conditions (i.e. to 0°C and under a pressure of 1,013 mbar).

The combustion process generates water vapor and certain techniques may be used to recover the quantity of heat contained in this water vapor by condensing it.

- Higher Calorific Value (or Gross Calorific Value – GCV, or Higher Heating Value – HHV) – the water of combustion is entirely condensed and that the heat contained in the water vapor is recovered;
- Lower Calorific Value (or Net Calorific Value – NCV, or Lower Heating Value – LHV) – the products of combustion contain water vapor and that the heat in the water vapor is not recovered.

Energy is often expressed as the calorie (cal.), which is the amount of heat needed to raise the temperature of one gram of water by one degree Celsius. One calorie is equal to 4.184 joules.

Table 1. Calorific value of various fuels:

Fuel	Calorific Value (kJ/kg)
Cow dung cake	6000-8000
Wood	17000-22000
Coal	25000-33000
Petrol	$45x10^3$
Kerosene	$45\ x10^3$
Diesel	$45\ x10^3$
Methane	$50\ x10^3$
CNG	$50\ x10^3$
LPG	$55\ x10^3$
Biogas	$35\text{-}45\ x10^3$
Hydrogen	$150\ x10^3$

Boiling stage

The boiling point of a substance is the temperature at which the vapor pressure of the liquid equals the pressure surrounding the liquid and the liquid evaporates resulting in an abrupt change in vapor volume. Saturation temperature means boiling point. The saturation temperature is the temperature for a corresponding saturation pressure at which a liquid boils into its vapor phase. The liquid can be said to be saturated with thermal energy. Any addition of thermal energy results in a phase transition.

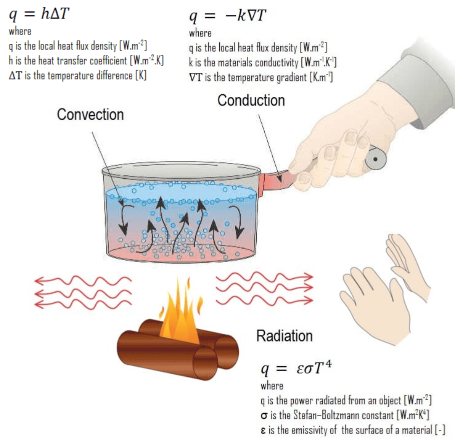

Figure 3. Heat exchange mechanism

At standard atmospheric pressure and low temperatures, no boiling occurs and the heat transfer rate is controlled by the usual single-phase mechanisms. As the surface temperature is increased, local boiling occurs and vapor bubbles nucleate, grow into the surrounding cooler fluid, and collapse. This is sub-cooled nucleate boiling, and is a very efficient heat transfer mechanism. At high bubble generation rates, the bubbles begin to interfere and the heat flux no longer increases rapidly with surface temperature (this is the departure from nucleate boiling, or DNB).

At similar standard atmospheric pressure and high temperatures, the hydro-dynamically-quieter regime of film boiling is reached. Heat fluxes across the stable vapor layers are low, but rise slowly with temperature. Any contact between fluid and the surface that may be seen probably leads to the extremely rapid nucleation of a fresh vapor layer ("spontaneous nucleation"). At higher temperatures still, a maximum in the heat flux is reached (the critical heat flux, or CHF).

Figure 4. High Flame temperature in single burner gas stove

Heat transfer by high flame

Heat transfer is the process of transfer of heat from high temperature reservoir to low temperature reservoir. In terms of the thermodynamic system, heat transfer is the movement of heat across the boundary of the system due to temperature difference between the system and the surroundings. Waste heat refers to loss of heat in surroundings during cooking process at high flame temperature.

Figure 5. High flame temperature in various stoves

Figure 6. Model box as movable tray

III. RESULTS AND DISCUSSION

Excess heat energy generated from the burner is wasted usually. This can be used for useful applications. If we create a metal container of tank and placed near combustion chamber, so that the heat radiated into the atmosphere can be absorbed by the water inside the tank surrounding it. This hot water can be utilised for making tea for the same heating function. This will save heat energy and increase the efficiency of cooling. The room temperature in the kitchen will be reduced, so the exhaust air condition expense and cost will be less. Human effort and hardness will be reduced. Adjustable closed steel water container is used with the cooking stove or burner to use the wasted flame and heat radiation. Water is filled in the steel container, so that the hot water can be for various purposes like cleaning, bathing, cooking, making tea etc. In Big kitchens and auditorium, the stoves of the burner have large diameter with more opening of the holes for the internal orifice. Then only move gas comes out and more combustion takes place and more heating occurs rapidly.

In these cases, the wasted flames will also be released. So this attachment's (metal container) can be used in outside of burner and the vessel forming a closed system, so that the whole flame is utilized properly. For small stove, the number of holes will be less and the size will also be small. So the need for their mechanisms is minimum. Two closed C-shaped hollow stainless steel containers should be used so that as the size of vessel increases or decreases, the container can be pulled back and pulled in to match the shape of the vessel. And also to block the escape of outside flame.

Just grab a thermometer and measure water temperature for tea with extreme precision. Water for black and green teas should generally be between 30 to 40 degrees Celsius. The preheated water is readily available from WHR without losing time. By this, sufficient amount of preheated water can be transfer to the milk for tea preparation. Time is precious Tea making process for 10 members, In practical we have to heat water at certain level for 10 min and milk at 15 min totally 25 min. By using WHR method we can able to save heated water of 10 min and energy of LPG gas

Advantages in daily life

To heat water at initial level will be reduced during Rice cooking. Cooking time is will consume less. For cleaning vessels, clothes of born child. Cleaning for instruments in Hospitals. Drinking purposes. Bathing purposes. Small quantity can be used for face wash and hand wash during winter season.

Model preparation of sheet metal

A blank sheet metal of two pieces for L shaped container of length 50 cm.

Figure 7. SHEET METAL BENDING PROCESS FOR MODEL CONTAINER

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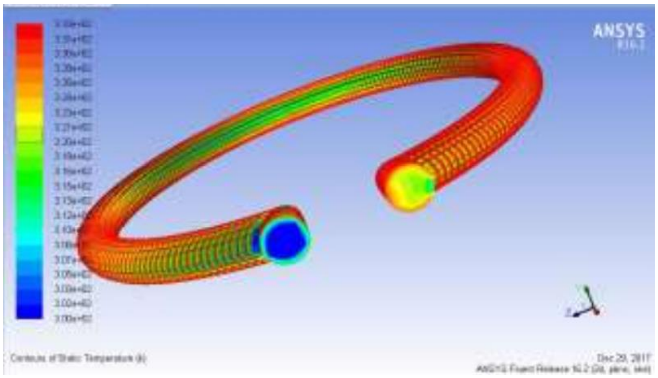

Figure 8 – Waste Heat Recovery Ansys Evaluation

It could be observed that a significant increase in the heat utilization could be observed on modification of the existing gas stove. AS the waste heat passing through the atmosphere got decreases, a significant increase in the efficiency of the combustion system could be obtained.

IV. CONCLUSION

In this paper, by modification of the existing kitchen stove design, a significant change in the output characteristics was observed. As the rate of waste heat flow was reduced by a significant percentage, a measurable increase in the overall efficiency of the stove was observed. The modifications in the design helped in achieving the conversion of the losses into useful heat.

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