Analysis of Energy Efficiency Improvement of LPG Stove

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***Abstract*—India has the second largest population in the world. There are 33.6 million or 17.5% of the households in the country using LPG (Liquefied Petroleum Gas) as their primary cooking fuel. These comprised 7.845 million homes (or 5.67% of the population) in rural areas and 25.752 million (or 47.96% of the population) in urban areas. While the worldwide average growth rate for LPG demand was about 3.7% per year during the 1990s, it is estimated that India's annual growth in LPG consumption was over 11% between 1999 and 2005. The largest growth rates in commercial sector will be in China and India; in 1985, 5% of the total world residential-commercial LPG consumption was in these two countries, but by 2005, this consumption raised to more than 20% of the world total. Existing designs of most conventional LPG stoves have typically relied on open combustion flame, where a large amount of energy loss with the flue gas arises, resulting in relatively low thermal efficiency. The development of combustion equipment (LPG stove) must be directed at environmental compatibility, high efficiency, high intensity, plus low capital and operating costs. In this project work, our aim is to improve the overall efficiency of the stove by recovering waste heat. The stove we have modified which recovers waste heat with the help of water, has a higher overall efficiency than the conventional stove. The modified stove utilizes the empty space to store water which acts as a heat storage medium.**

***Index Terms*—Liquefied petroleum gas (LPG), efficiency, flue gas, air required, propane, design.**

I. INTRODUCTION

LPG stove was found to have one of the lowest thermal efficiency- 40% among various commonly used stoves and the remaining 60% is radiated to the atmosphere. Even though it has a low efficiency, it is being used by a large population for its pollution free and readily atomizing characteristics. LPG is mostly used for cooking in spite of taking more time to cook food compared to electric and induction cooking process. Nowadays people use induction cooker to boil water, since time to heat is lesser and operating cost is lower compared to LPG. LPG poses a major constraint in rural areas due to its high cost and demand. Cooking typically is a small component of the whole energy requirement in a house, which some people typically ignore. Although use of LPG is on the rise, we rarely compare it with other forms of energy. Soaring prices of petroleum based fuels is a great bottleneck for the common people to use these resources. LPG is an important part of our life as 90% of population uses it for cooking purposes but shortage of fuel and high price are problem of concern. This work focuses on effectively minimizing the radiation heat from the stove and thereby improving thermal efficiency of LPG stove. We also try to utilize the empty space present below the LPG stove to absorb the radiation heat losses from the stove. We have tried three modifications which are slightly different from the conventional stove so that they are user friendly and multi-purpose. Our main aim in this project is to utilize the waste heat radiated from the stove maintaining the cooking time as in conventional stove. Prices of petroleum based fuels is a great bottleneck for the common people to use these resources. LPG is an important part of our life as 90% of population uses it for cooking purposes but shortage of fuel and high price are problem of concern. This work focuses on effectively minimizing the radiation heat from the stove and thereby improving thermal efficiency of LPG stove. We also try to utilize the empty space present below the LPG stove to absorb the radiation heat losses from the stove. We have tried three modifications which are slightly different from the conventional stove so that they are user friendly and multi-purpose. Our main aim in this project is to utilize the waste heat radiated from the stove maintaining the cooking time as in conventional stove.

II. LITERATURE REVIEW

Anoopa .P.S, Dayana Scaria, Nithya.N. S and Prajitha. M, Kelappaji College of Agricultural Engineering and Technology, Kerala and K.Madhusoodanan, Energy Management Centre, Kerala - Energy consumption benchmark studies on Parboiled rice cooking in Kerala [1] This paper suggests that efficiency of LPG (η) is lower when compared with other cooking fuels. Thermal efficiency determination of different cooking stoves was studied using various methods. Overall efficiency formulae were obtained for various cooking stoves.

Antonette D'Sa and K.V.Narasimha Murthy, Report on the use of LPG as a domestic cooking fuel option in India, International Energy Initiative, Bangalore, 2004 [2] The report gives a detailed study on the domestic use of cooking fuels in India, particularly that of LPG and the growth in domestic use of LPG in India. The demand for LPG worldwide and other cooking fuels were discussed. Fuel chemical composition, moisture content and net energy of various fuels were given.

Dean Still, Mike Hatfield and Peter Scott, Aprovecho Research Center, Capturing heat two, Lost Valley Publishers, 2000 [3] In this paper, the conventional open type stove is modified into a closed stove. This blocks the passage for escape of flue gases. This paper gives an idea about the use of chimney for the escape of the gases. And the entire heat flow path is insulated, lessening heat absorption into the stove body.

Dr. Mark Bryden, Dean Still, Damon Ogle, and Nordica MacCarty - Designing Improved Wood Burning Heating Stoves [4] This paper suggests that water is a great storage medium for heat. Per pound water stores 5 times more heat than rock. One BTU will raise the temperature of one pound of water through one degree F. For this reason, heating water can be a very efficient way to capture the heat of a fire before it slips away into the sky. The efficiency of heat transfer into large containers of water can be very good. Water stores and holds heat for a long time.

Mohd. Yunus Khan, Anupriya Saxena and Kishan Pal Singh, Performance of Insulated LPG Burner with Ball Bearings as Porous Medium, People's Journal of Science & Technology, ISSN: 2249 –5487 [5] This paper suggests that porous medium combustion technique enhances the rate of heat transfer. It also improves the combustion process. In porous medium combustion technique, the flame can be stabilized over the surface or it can remain fully confined within the porous matrix. Thus, this process is also known as flameless combustion and it has found numerous applications in many areas of applied science and engineering – Filtration, mechanics, acoustics, petroleum engineering, bio remediation, hydrogeology, geophysics, biophysics, biology, material science, fluid flow, poromechanics, capillaries,

Fig 1. Burner with porous medium

Namkhat, S. Jugjai, Primary air entrainment characteristics for a self-aspirating burner, Combustion and Engine Research Laboratory (CERL), Thailand, 2010 [6] From this paper Schematic diagram of LPG stove and burner design were obtained. The ratios of the primary and secondary air compared to the stoichiometric air ratio on the characteristics of flame were discussed. Consumption of LPG was found to be maximum in cooking.

III. LIQUEFIED PETROLEUM GAS

This chapter is concerned with properties of LPG, efficiency, equations to calculate efficiency of various stoves and details about various tests to determine efficiency of stoves. LPG refers to Liquefied Petroleum Gas which is a by-product from the distillation of crude oil.

A. Introduction

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 and the test methods by IS-1448. LPG, which consists primarily of propane and butane, is a "simple" fuel in the hydro-carbon family, and as such, has many significant advantages over other fuels, especially petrol blends which are a long way down the family tree and have highly complex chemicals in them. A major advantage of propane - which has the formula of C_3H_8, meaning that each molecule consists of just three carbon atoms and eight hydrogen atoms - is that it forms very few harmful pollutants. LPG is stored primarily as a liquid at a moderate pressure of 17 – 22 bar, depending only on the ambient air temperature around the cylinder. The pressure does not depend on the amount of liquid LPG in the cylinder. Even if there are only a few drops of liquid LPG in the cylinder, this delicate pressure-temperature relationship applies.

B. Physical properties and characteristics

The Physical properties and characteristics of LPG are as follows –

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 525 to 580 kg/m^3 @ 15°C. Since LPG vapour is heavier than air, it would normally settle down at ground level/ low lying places, and accumulate in depressions.

Vapour pressure: The pressure inside a LPG storage vessel/ cylinder will be equal to the vapour pressure corresponding to the temperature of LPG in the storage vessel. The vapour 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/cm^2 for each ^{0}C. 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 vapour accumulated in low lying area in the eventuality of the leakage or spillage. The auto-ignition temperature of LPG is around 410-580^{o}C and hence it will not ignite on its own at normal temperature. Entrapped air in the vapour 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.

Combustion: The combustion reaction of LPG increases the volume of products in addition to the generation of heat. LPG requires upto 50 times its own volume of air for complete combustion. Thus it is essential that adequate ventilation is provided when LPG is burnt in enclosed spaces otherwise asphyxiation due to depletion of oxygen apart from the formation of carbon-dioxide can occur.

Odour: LPG has only a very faint smell, and consequently, it is necessary to add some odourant, so that any escaping gas can easily be detected. Ethyl Mercaptan is normally used as stenching agent for this purpose. The amount to be added should be sufficient to allow detection in atmosphere 1/5 of lower limit of flammability or odour level 2 as per IS: 4576.

Colour: LPG is colourless both in liquid and vapour phase. During leakage the vapourisation of liquid cools the atmosphere and condenses the water vapour contained in them to form a whitish fog which may make it possible to see an escape of LPG.

Toxicity: LPG even though slightly toxic, is not poisonous in vapour phase, but can, however, suffocate when in large concentrations due to the fact that it displaces oxygen. In view of this the vapour possesses mild anesthetic properties.

Table 1
Properties of LPG

	PROPANE	**BUTANE**
Chemical Formula	C_3H_8	C_4H_{10}
Liquid Density	0.505	0.575
Gas Density	1.5	1.95
Ratio Gas/Liquid	274	230
Atmospheric Boiling point	-42	-2
Specific Heat liquid	0.60 BTU/^{0}C	0.58 BTU/^{0}C
Latent heat of Vapourisation	358 kJ/kg	372 kJ/kg
Flammability Limit	2.2 - 9.5%	1.8 – 8.5%
Auto Temperature Ignition	470 ^{0}C	410 ^{0}C
Mole Weight	44.10 kg/K/mole	58.12 kg/K/mole
Freezing point	-187.7^{0}C	-138.4^{0}C
Critical Temperature	96.7^{0}C	152.1^{0}C
Critical Pressure	42.5 bar	38.0 bar
Litres/tone	1965 – 2019	1723 – 1760
Octane Number	< 100	92
Relative density of Liquid	537 – 543	406 – 431
Maximum Flame Temperature	1980^{0}C	1990^{0}C
Ratio of Gas volume to Liquid Volume	274	233
Soluble in Water	Slight	Slight
Colour	Colourless	Colourless

C. *Process of LPG Extraction*

LPG which is produced from straight distillation and it consists of saturated hydrocarbons, i.e. propane and butane, whereas LPG which is produced by both cracking and reforming processes has, in addition to hydrocarbons, some quantities of unsaturated hydrocarbons also (i.e. propylene and butylene).There is also moisture and some impurities (such as sulphur compounds) that are removed by suitable treatment at the refinery. LPG burns cleanly, producing no particulate matter, with low emissions of CO, unburned hydrocarbons and NOx, and less CO_2. The exact composition of LPG can vary but it usually consists predominantly of propane (C_3H_8) and butane (C_4H_{10}), with a small proportion of propylene (C_3H_6) and butylene (C_4H_8). Commercial LPG also contains traces of lighter hydrocarbons like ethane (C_2H_6) and ethylene (C_2H_4) and heavier hydrocarbons like pentane (C_5H_{12}). LPG at about 45.5GJ/tonne, has a higher energy content than the fuels currently in use for cooking – kerosene (43.2 GJ/tonne), fuel-wood (about 15 GJ/tonne), crop residues (13 – 14 GJ/tonne) and dung (12.5 – 13 GJ/tonne).

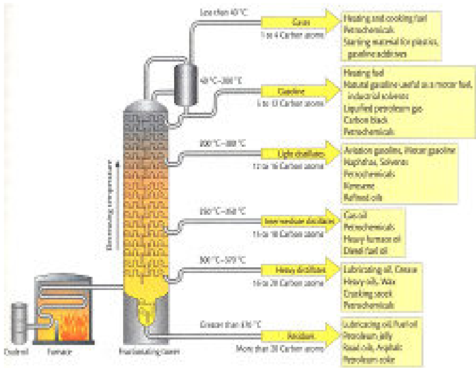

Fig 2. Distillation process of Crude oil

D. *Hazardous Nature of LPG*

LPG may be defined as those hydrocarbons, which are gaseous at normal atmospheric pressure, but may be condensed to the liquid state at normal temperature, by the application of moderate pressures. Although they are normally used as gases, they are stored and transported as liquid.

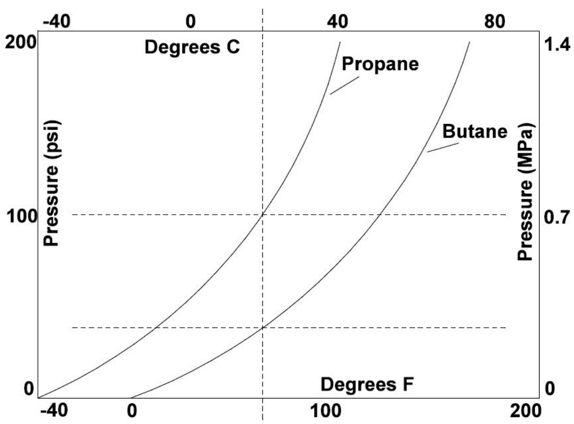

Fig 3. Pressure Vs Temperature relationship for Propane and Butane

From this graph, we infer that propane has higher pressure than butane at same temperature. Rate of pressure rise is higher in propane than butane for a given temperature difference. For this reason, the proportion of propane is higher than butane in LPG. For safety reasons, an LPG cylinder is only filled to 80% with liquid; the remaining 20% volume of the cylinder contains gaseous LPG. The 80:20 ratio gradually changes towards 0:100 as the fuel is used.Liquid LPG expands when heated, i.e., about 1.5% increase for each 6^0C increase in temperature - and requires an expansion volume so as not to over-stress the cylinder. Liquid LPG evaporates to produce about 250 times volume. LPG vapour is denser than air. Escape of even small quantities of the liquefied gas can give rise to large volumes of vapour / air mixture and thus cause considerable hazard.

IV. CONVENTIONAL LPG STOVE

The stove is made up of stainless steel body for use with liquefied petroleum gases sold in refillable tanks at 17 – 22 bar pressure. A tap is provided in the stove to control the pressure. If the tap is turned “full on” the intensity of the flame is high. A detachable metal frame is provided to support the pan. The stove connected to the gas cylinder with rubber tubing. A detachable regulator is provided at the end of the tube to connect the stove to the cylinder. There is a knob in the regulator to control the supply of gas from the cylinder to the stove.

Fig 4. Conventional LPG stove (Double Burner)

A. *Parts of the Stove*

Conventional LPG stove is widely used for cooking and the double burner type stove is commonly used. The parts of the stove are –

BURNER: A burner is a mechanical device that -

1. supplies required amount of fuel and air
2. creates condition for rapid mixing of fuel and air
3. produces a flame which transfers thermal energy to the vessel

A gaseous fuel burner is of diffusion type in which fuel and some amount of air is mixed and the mixture is passed through the burner. Rest air for combustion is supplied above the stove. Combustion of fuel is controlled by the rate of mixing of air and fuel. In these burners small portion of air is mixed with fuel as primary air and the rest amount, known as secondary air is supplied above the stove.

Fig 5. Burner (Side View)

NOZZLE:

Fig 6. Nozzle

A jet is produced when a fluid (LPG) is discharged through the nozzle. In the jet the velocity of the fluid is accelerated. Free jet is produced when the fluid is discharged in the surrounding with no confinement. High pressure fluid inside the cylinder gets reduced to low pressure when passed through the nozzle. This creates vacuum leading to suction effect. Due to this effect the surrounding air is sucked in and this part of the air is called primary air.

Thus in the design of burner for gaseous fuel it is important to design the primary air depending on the requirement. Since the amount of air is many times greater than the fuel. The primary air controls the fuel /air mixing rate. In designing a gaseous fuel burner total mass flow rat of air is subdivided into primary, secondary. Whereas primary air is mixed with fuel, secondary air is introduced through the opening above the burner.

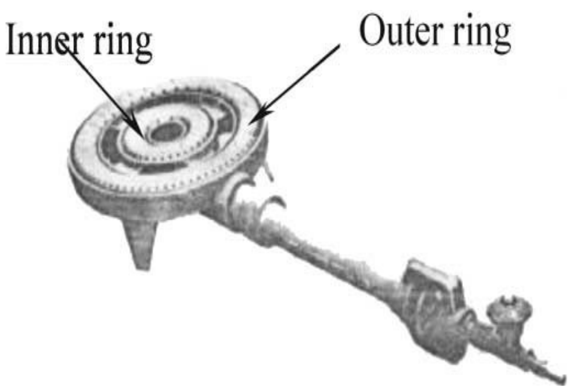

Fig 7. Nozzle - Burner setup

There is a mixture of air and LPG in the burner head. The air is supplied as both primary and secondary air which is essential for combustion. Primary air is small when compared to secondary air as most of the volume at throat is occupied by LPG. The flow of LPG is controlled by a control valve also called as knob which can be adjusted to low or high flame.

B. *The Role of Oxygen*

Fig 8. Yellow Flame

Fig 9. Blue Flame

In a laboratory under normal gravity conditions and with a closed oxygen valve, a Bunsen burner burns with yellow flame (as shown in Fig 4.5) also called as safety flame at around 1000°C. This is due to incandescence of very fine soot particles which are produced in the flame. With increasing oxygen supply less black body radiating soot is produced, due to more complete combustion and the reaction creates enough energy to excite and ionize gas molecules in the flame, leading to a blue appearance (as shown in Fig 4.6). Blue flame can be inferred as a result of proper mixing leading to complete combustion.

V. SURVEY

There are 3 types of cook-tops available in market, they are:

Gas: This type of cooktop has a burner on top and uses gas (LPG) to burn a flame that is used to cook food.

Electric: This type of cook-top has a coil that heats up due to resistance when current passes through it. As its name, it uses electricity to generate heat and cook food.

Induction: Although this type of cook-top uses electricity but it uses magnetic property of steel to directly heat the cooking vessel. Unlike other cooking methods it does not use flames or red-hot element to cook. Thus it is considered more energy efficient. Also it only heats the vessel in contact thus reduces possibility of injury.

Based on boiling water tests the efficiency of various stoves were: [8]

1. Gas - 40%
2. Electric – 74%
3. Induction – 84%

The efficiency mentioned above is based on the heat transferred to the vessel kept on top of it. It also depends on the size of vessel used compared to the size of flame/heating surface. From the boiling water test, we can note that efficiency of the LPG stove is one of the lowest when compared to induction and electric stoves. We can find that efficiency of LPG stove is lower due to radiation losses.

LPG is being used widely by household people for cooking and survey helps in understanding the importance of a LPG stove and a better system is in need to utilize the waste heat radiated to the surrounding

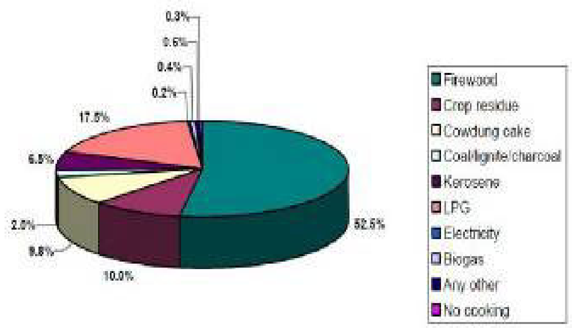

Fig 10. All India household dependent on various cooking fuels

The Pie chart shows that the usage of LPG is second largest (about 17.5%) next to firewood (52.5%).

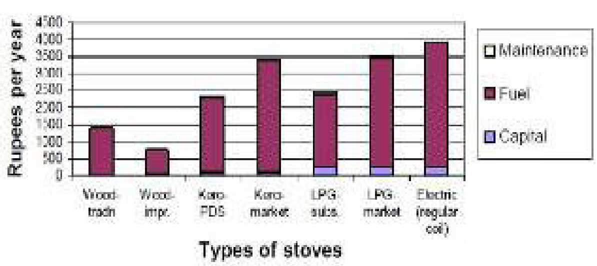

Fig 11. Comparison of annualized costs of stoves

The bar graph implies that LPG is one of the costliest products used for cooking which has one of the lowest efficiency.

VI. PROBLEM DESCRIPTION

The efficiency of a conventional LPG stove is 40% and the remaining 60% is radiated to the surrounding. The losses in conventional burners are:

1. Convection loss (air entering the combustion region, absorbs heat and escapes the spot as hot air) which is unwanted.
2. Flame rolling out of the vessel is greatly lost to the surrounding.
3. Heat is lost to the stand of the burner stove.

The other disadvantages of LPG stove are:

1. Inflammable and thus dangerous. Can cause burns.
2. Heats up the surroundings as well. Can increase the cooling bills if the environment is air conditioned.
3. Ceiling Fans cannot be used along with it.
4. Flames do produce CO_2.

It has been proved by experiment that the efficiency of the conventional burners is around 40%. By numerical values in the standard tables it has been found that the energy released during the combustion of LPG is 45,837 kJ/kg. Therefore the availability (useful amount of work) is less than 18,334 kJ/kg remaining heat is lost to the atmosphere which is undesirable. In spite of its low efficiency it is been used widely for cooking.

Thus we try to fabricate a stove which utilizes the radiated heat in doing some useful work and hence recovering waste heat. The modification of the conventional LPG stove on a large scale will help both in waste heat recovery and reducing pollution.

Fig 12. Radiation loss in the stove

Our objective is to improve the efficiency of the LPG stove. We try to model and fabricate the LPG stove which utilizes the radiated waste heat resulting in recovery to reduce excess heat wastage. We also try to do a comparative experimental analysis of existing and modified LPG stoves.

Based on the results of the analysis, further modifications will be done to reduce heat loss. The conventional stove was studied in detail and the flow of LPG, the air required for complete combustion, the nozzle effect, various heat losses in stove, Primary and Secondary air required, pressure of LPG stored in cylinder were found and was used for designing our new stove.

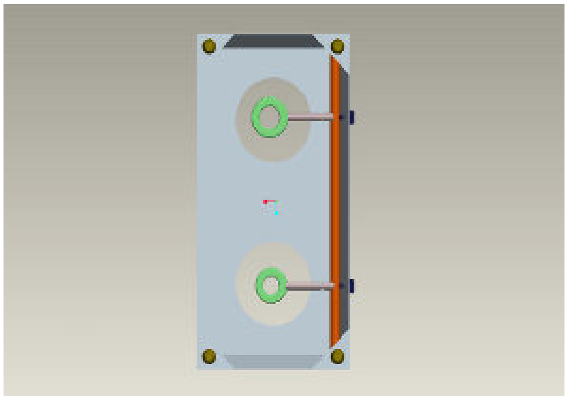

Fig 13. PRO-E model of conventional stove

VII. METHODOLOGY

The major heat loss in the stove occurs due to radiation. We are trying to design a system to recover the radiated heat. To achieve this, the burner is lowered and is enclosed by heat resistant material like ceramic so that all the heat from the burner gets absorbed by the food. The stove is designed in such a way that the exhaust flue gas which is at high temperature is passed through a water chamber and is finally let out through a chimney. This design recovers waste heat.

The water chamber is used to absorb the waste heat from the exhaust. The lower empty space is utilized for the water chamber and a heat flow path for flue gas is provided.

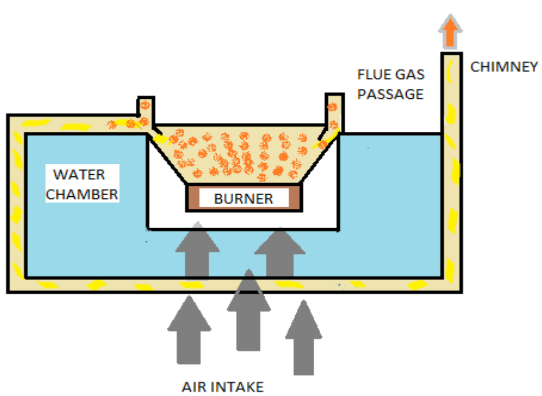

Fig 14. Prototype diagram of the fabricated model

A. *Thermal Efficiency Determination of Different Cook Stoves*

Thermal efficiency indicates the performance of cooking stoves. It is the ratio of energy absorbed by the food to the total energy supplied by the fuel. Different methods available for thermal efficiency determination are discussed below -

Water Boiling Test: In this study the water boiling test method was used for thermal efficiency determination. The equipments used in this test are-

1. A stainless steel pot with lid having a capacity of 5 litres.
2. Electronic weighing balance.
3. Fuels like L.P.G, Kerosene
4. Water
5. Temperature Indicator

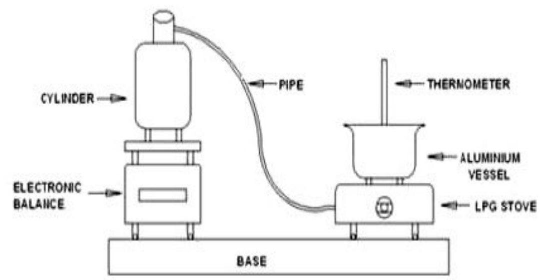

Fig 15. Water boiling test setup

The experimental setup consists of LPG stove, a LPG cylinder, a vessel and a stirrer. A Temperature indicator is used to measure the water temperature during experimentation. A stirrer is used for stirring the water for uniform distribution of heat. An electronic balance is used for weight measurement of water and LPG cylinder.

Conventional LPG stove and modified LPG stove is used for testing. The value of thermal efficiency with conventional stove is taken as reference value. The weight of vessel with its lid and the weight of water used in the vessel are noted. Initial temperature of water (T_1) is also noted. The weight of cylinder (W_1) is noted. The stove is lighted and water is warmed up to 80°C and stirred continuously for uniformity of temperature. When final temperature of water (T_2) reaches 80°C, the stove is put off. Again, the weight of cylinder (W_2) is recorded.

The difference in the weight of cylinder (W_2-W_1) gives the mass of fuel consumed for heating water by temperature (T_2-T_1). By dividing the difference in the weight (W_1-W_2) by time taken in heating gives fuel consumption rate. The thermal efficiency of the stove is expressed as follows:

$$\eta = \frac{(W_W \times C_W + W_{SS} \times C_{SS}) \times (T_2 - T_1)}{(W_1 - W_2) \times CV} \quad (1)$$

Where,

W_W is the quantity of water (in kg) in the vessel,
W_{SS} is weight of the vessel (in kg),
C_W is specific heat of water (in kJ/kg-K),
C_{SS} is specific heat of Stainless steel vessel (in kJ/kg-K),
CV is the calorific value of the LPG (in kJ/kg).

Constant Heat Output Method: It consist in bringing a definite quantity of water to high temperature such as 96°c and repeating it with successive batches of water in similar vessel, presumably till all lpg is used up. the heat absorbed by the water is simple to calculate, if the initial temperature and mass of water is known.

The amount of LPG used can be measured and if one knows the moisture content and calorific value of LPG used, the heat input for accomplishing the job can be calculated leading to an efficiency value.

Constant Temperature Rise Method: This is a modified version of the Indian Standard for electric stoves and is suitable for constant power output stoves. A fixed quantity of water is heated through a temperature rise of, say 20 or 30°C and the time to accomplish this is noted. The test is repeated several times and an average time to accomplish the task is computed. Since the power and time is known one can compute the energy input. The heat absorbed by the water is easy to evaluate and the efficiency is calculated.

Constant Time Method: In this method, a fixed quantity of water is heated over a fixed interval of time and the temperature rise is noted. The experiment is repeated several times and an average temperature rise is computed.

Indirect Method: In large scale cooking establishments, it is not feasible to estimate the efficiencies easily. The energy input is estimated by performing the task on either scaled version or full-scale on the electric stove .From the users of such stoves, fuel consumption is obtained. Comparison of energy consumption in the electric stove test with the latter gives an estimate of efficiency of the large stove.

Approximate Method: This is generally called “quick and dirty method”. This is applicable to large installation where the stove is in continuous use. A known quantity of water is heated for a 15 minutes and temperature rise of the water is noted.

Flow rate of L.P.G using the large and small burner were:

For large burner

1. At Max. position = 144gm/hr
2. At Sim position = 45gm/hr

For small burner

1. At Max. position = 133gm/hr
2. At Sim position = 34gm/hr

We chose the Water boiling test method for calculating the efficiency and comparative analysis with conventional stove.

VIII. FABRICATED MODEL

The stove which we fabricated was aimed at recovery of waste heat. We did three different stoves with slight modifications.

A. *Theoretical Calculation Of Air Required*

Theoretical air requirement calculation depends on proportion of propane and butane in LPG. LPG contains 70% propane and 30% butane which are used in combustion equation of LPG. For complete combustion of LPG,

PROPANE **(**C_3H_8**):**

$$C_3H_8+5O_2 \rightarrow 3CO_2+4H_2O$$

44g of propane requires 160g of O_2 which means 800g of air. 1g of propane requires 18.18g of air. 22.4l of propane requires 112l of O_2 which means 533.12l of air. 1l of propane requires 23.8l of air.

BUTANE **(**C_4H_{10}**):**

$$2C_4H_{10}+13O_2 \rightarrow 8CO_2+10H_2O$$

58g of butane requires 208g of O_2 which means 990.47g of air. 1g of butane requires 17.07g of air. 22.4l of butane requires 145.6l of O_2 which means 693.05l of air. 1l of butane requires 30.94l of air.

LPG (70% PROPANE AND 30% BUTANE): 1g of LPG requires ([18.18*0.7] + [17.07*0.3]) = 17.84g of air. 1l of LPG requires ([23.8*0.7] + [30.94*0.3]) = 25.94l of air. Energy density of LPG 46.4 MJ/kg. Assuming 14kg cylinder, Total energy = 46.4*14 = 649.6MJ/cylinder Considering, that the stove is used for 3 hours a day every month (considering 30 days per month), Energy usage per hour = 649.6 / (30*3) = 7.217 MJ/hr = 7217 kJ/hr = 2.004 kJ/s = 2004W

Specific heat of water = 4.186 J/g^{0}C. Energy required to boil water :

$$W_w C_w (T_2-T_1) \quad (2)$$

= 1000g * 4.186 * (100 – 35) = 272090J. Time required to boil water = 272090/1030 = 264.16s = 4.40 min.

I. LPG FLOW

Energy density of LPG = 46400J/g. The total amount of energy released from LPG = 2004J/s. LPG flow per second = 2004/46400 = 0.043 g/s = 43 mg/s

PROPANE (C_3H_8)**:** 44g of propane corresponds to 22.4l according to mole concept. 0.00221 g of LPG corresponds to 0.0011l. 1l of LPG requires 23.8l of air. So 1.1ml of LPG requires 26.18ml of air. 1g of LPG requires 18.18g of air. So 0.00221 g of LPG requires 0.0401g of air.

BUTANE (C_4H_{10})**:** 58g of butane corresponds to 22.4l according to mole concept. 0.00221g of LPG corresponds to 0.0011l. 1l of LPG requires 30.94l of air. So 1.1ml of LPG requires 34.03ml of air. 1g of LPG requires 17.07g of air. So 0.00221g of LPG requires 0.0377g of air.

LPG (70% PROPANE AND 30% BUTANE): Thus 1.1ml of LPG requires 28.535ml of air. 2.21mg of LPG requires 39.38mg of air.

B. *Pressure Inside The Cylinder*

The pressure of LPG inside the cylinder is calculated. Total vapour pressure of LPG:

partial pressure of propane (70%) + partial pressure of butane(30%)

(8.2)

Total vapour pressure of LPG = (0.7*1550) + (0.3*520) = 1241kPa. Total vapour pressure of LPG = 12.41bar @ 40^0C
(Vapour pressure of propane = 1550kPa @ 40^0C, Vapour pressure of butane = 520kPa @ 40^0C)

C. *Stove Design*

As discussed in the problem description, the waste heat is recovered using water which is a great storage medium for heat. We have modeled two stoves which helped us in achieving the goal

Model I (Fig 8.1) consists of a water chamber with flue gas passage. It utilizes the bottom space for storing water which acts as a medium for heat recovery. In this model the open type burner is completely closed when vessel is placed over it. And hence flue gases which are trapped are let out through a passage which is made of copper pipe of diameter ¼ inch. The sides of the burner are closed using a ring of diameter larger than the burner so that the flue gases passes only through the copper pipes. The copper pipes were designed such that the flue gases heats up the water in the chamber resulting in heat recovery.

But, there was very little space for flue gas to pass through, since only two holes were provided in the ring. Most of the flue gases passed through gaps in the stove and hence it did not effectively heat the water, there were also problems as the gases came in contact with the ring and top sheet metal covering leading to unwanted heating.

Due to the failure of the first model, we made few changes to it resulting in model II. Model II (Fig 8.3) had a larger copper pipe of diameter 1 inch. And instead of a ring, a grill of rectangular shape (Fig 8.2) was made which had several holes so that the flue gases had a lot of gap to escape through and not accumulate. It also had the problem of unwanted heating of the grill and the top sheet metal covering, as the gases came in contact with them.

To overcome the problem of flue gases coming in contact with the top sheet metal covering, the sheet metal covering is to be lowered below the burner. Finally we have modified the stove which is similar to the conventional stove. It has a grill of larger rectangle which coincides with the size of the stand on which the vessel is kept. The flue gas passage remains unchanged.

Fig 16. Fabricated water chamber with flue gas passage (Stove I)

Fig 17. Grill with flue gas passage

Fig 18. Fabricated stove II

Fig 19. Fabricated Stove III

The dimensions of the water chamber is -
Height = 12 cm
Length = 63 cm
Width = 31 cm

Volume of water chamber:
height * length * width (3)
= 0.12 * 0.63 * 0.31 = 0.023 m^3 = 23 litres (including burner area). Excluding burner area, volume = 18 litres

Table 2
Specification of stove used

Make Of Stove	Surya Home Appliances
Type	Double Burner
Weight Of Burner	0.5kg
Burner Material	Brass
Design Fuel	LPG

IX. RESULTS & DISCUSSION

The water boiling test was conducted for the various fabricated models and compared with the conventional stove.

The calculations for Model III stove compared with conventional stove are –

For small burner: At Maximum position = 133gm/hr. For large burner: At Maximum position = 144gm/hr

For conventional stove, temperature difference, T_2-T_1 = 20°C. Weight of LPG consumed, W_1-W_2 = 5.2 g/min. Quantity of water in the vessel, W_W = 1.15 kg. Weight of the vessel, W_{SS} = 0.15 kg. Specific heat of water, C_W = 4.186 kJ/kg-K.

Specific heat of Stainless steel vessel, C_{SS} = 0.502kJ/kg-K.

Calorific value of LPG, CV = 45,837 kJ/kg

From equation (7.1),

$$\eta = \frac{(W_W \times C_W + W_{SS} \times C_{SS}) \times (T_2 - T_1)}{(W_1 - W_2) \times CV}$$

η = 40.90%

For Model stove III, temperature difference, T_2-T_1 = 20°C. Weight of LPG consumed, W_1-W_2 = 5 g/min. Mass of water in the water chamber = 18 kg

$$\eta_0 = \frac{[(W_W \times C_W + W_{SS} \times C_{SS}) \times (T_2 - T_1)] + [m \times C_W \times \Delta T]}{(W_1 - W_2) \times CV} \quad (4)$$

η_0 = 42.62 %

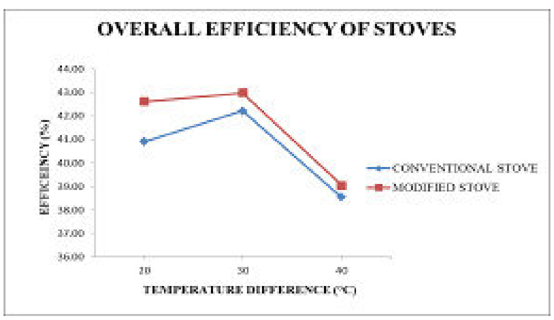

Fig 20. Graph – Efficiency (%) Vs Temperature difference (°C)

From the comparison of the efficiencies we see that Model stove III has better efficiency that conventional stove and it also recovered the waste heat by increasing the temperature of water in the water chamber. We achieved a temperature rise of 15°C for cooking time of 20 minutes

X. CONCLUSION

From the results derived we can note that the modified stove had better efficiency than the conventional stove and also waste heat is recovered using water chamber. We are planning to modify the fabricated stove to improve the efficiency as well as reduce the cooking time by adding porous medium technique.

Table 3 Cost Break - up

COMPONENTS	COST (Rs.)
Conventional Stove	900
Water Chamber	300
Flue gas passage	400
Other expenses (Sheet-metal work)	200
Total cost	1800

A. *Advantages ff LPG Stove*

1. Gas stoves provide better cooking control. One does not have to worry too much about position and size of the utensil kept on it.
2. One does not have to depend on power cuts for cooking.
3. No specific requirement for utensil type.

   It is possible to save upto 30% of LPG fuel by following good cooking practices. The following tips could be followed to minimize losses on LPG -

1. Pressure cooking saves fuel and time
2. Reduce the flame when boiling starts
3. Soak before cooking
4. Shallow, wide vessels save fuel

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APPENDIX

A. LIST OF SYMBOLS

SYMBOL	DESCRIPTION
F	Fahrenheit
BTU	British Thermal Unit
η	Efficiency (%)
W_W	Quantity of water in vessel (kg)
C_W	Specific heat of water (kJ/kgK)
W_{SS}	Weight of the stainless steel vessel (kg)
C_{SS}	Specific heat of stainless steel (kJ/kgK)
T_1	Initial temperature of water (^{0}C)
T_2	Final temperature of water (^{0}C)
W_1	Weight of the cylinder before the test (kg)
W_2	Weight of the cylinder after the test (kg)
CV	Calorific value of LPG (kJ/kg)
ΔT	Temperature difference (^{0}C)
m	Mass of water in the water chamber (kg)
η_o	Overall efficiency (%)

B. LIST OF FIGURES

C. LIST OF TABLES