Performance Test of Hot Bag: A Pathway to Reduce Cooking Energy Consumption and CO_2 Emission

Principal Investigator: **Prof. Dr. A.K.M. Sadrul Islam**

Investigator: **Sayedus Salehin**

Department of Mechanical and Chemical Engineering
Islamic University of Technology (IUT)
Organisation of Islamic Cooperation (OIC)
Board Bazar, Gazipur-1704, Bangladesh
E-Mail: sadrul@iut-dhaka.edu, sayedus@iut-dhaka.edu

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Executive Summary

Cooking is an essential human need irrespective of race, culture or ethnicity. Cooking of most food item require application of heat which is obtained generally by burning various types of fuels in cooking stoves. The burning of such fuel also releases CO_2 in the atmosphere, responsible for global warming. The families in the urban area and the rural area alike, have to pay for the fuel they use for cooking and this expenditure has a significant market share of their income. The cooking from commonly used open stoves are responsible for indoor air pollution causing severe health hazard for the women. In many rural areas, women have to walk a long distance to collect firewoods for cooking. During the journey, they often confront the risk of attack or physical harassment. The collection of firewood also poses threat to the forest of deforestation leading to increase of greenhouse gas emission and acceleration of climate change impacts.

Retention Heat Cookers (RHC), such as a Hot Bag, is a promising solution to increase the cooking energy efficiency which employs the retained heat for cooking in a rural kitchen or elsewhere. All sort of food items may be cooked in Hot Bags, including rice, potato, chicken, vegetables, and beef etc. which are cooked with water. When the food is heated to its boiling temperature on the cooking stove, the food can be continued to be cooked using Hot Bag by retaining the heat. This option offers several benefits including reduction of fuel usage, reduction of greenhouse gas emission, energy savings for cooking leading to monetary savings, indoor air pollution reduction etc.

The report, '***Performance Test of Hot Bag: A Pathway to Reduce Cooking Energy Consumption and*** CO_2 ***Emission***' provides a detailed quantitative analysis of possible energy savings and CO_2 emission reduction for cooking different food items using Hot Bag. The study has been conducted collaborating with The Programme Sustainable Energy for Development (SED), supported by the Ministry of Power, Energy and Mineral Resources (MPEMR) and the German Federal Ministry for Economic Cooperation and Development through the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The research has been carried out by cooking the food items using Induction cooker and LPG Stove. The food items considered were rice, potato, chicken, mix. Vegetables (Potato, pointed gourd, spinach stem).

The study showed a significant energy savings while cooking with Hot Bag as compared to cooking using traditional method. The tests showed a range of energy savings from 22%-48% for different food items. Also, the CO_2 reduction ranges from 45-189 grams per kg of food items for different food items. Heat retention tests have been carried out for different quantity of water to understand the thermal behavior of the system. The report also presents the thermal analysis of the heat transfer from the Hot Bag and recommendation have been proposed.

Acknowledgement:

The investigation team praise the almighty Allah for enabling them to conduct this study and successfully complete in due time. The team express its heartfelt gratitude to Gesellschaft für Internationale Zusammenarbeit (GIZ) Bangladesh for funding the project and assistance throughout the project. The team thanks the colleagues at the department of mechanical and chemical engineering for their kind cooperation, especially Mr. Abu Hossain and Mr. Mokhtar from MCE department and Mr. Baten Khan for assisting in the experiments.

1. Introduction

In developing countries, household energy use has 10% share in world's primary energy consumption, a total of 1,090 Mtoe. The main use of energy in the households in developing countries is for cooking followed by lighting and heating. And household use of biomass in these countries accounts for almost 7% of world primary energy demand[1].

Cooking of food items involves heating at certain temperature range for a specific duration. This heating can be obtained by various ways, e.g. burning fuel, electricity etc. A significant amount of energy is consumed during the heating process. Even a small percentage of reduction in energy in cooking will contribute to an enormous energy savings since cooking is carried out in every single house. The temperature range and heating duration varies for each food item. In order for the food to be properly cooked, the food item has to be kept at the certain temperature range for a certain time period.

Many of the food items in our country contains starch. This starch has a highly organized structures, known as starch granules. When starch is heated with water, it undergoes a transition process in which the starch granules break down the inter-molecular bond in presence of water and heat, this phenomenon is called gelatinization. Gelatinization temperature is regarded as the temperature at which the phase transition of starch granules from an ordered state to a disordered state occurs[2]. The gelatinization temperature for rice and potato are 66°C-82°C and 55°C-66°C, respectively[3].

Insulating boxes have been used to reduce the energy consumption during cooking in many countries as a tradition. Sarah Collins from South Africa have started an enterprise on WonderBag back in 2006 after the serious power cut problem in her country. This bag makes use of insulation to retain the heat for slow cooking. The Hot Bag used for the study is similar to the WonderBag. The Hot Bag must retain this temperature for slow cooking for a longer duration for slow cooking.

There have been several reports which suggests that using the Hot Bag will lead to a significant amount of energy savings. However, till date, no report has quantified the amount of energy that can be saved by using such bags. Also, the energy savings will be varied for different food items as well as the cooking methods used. In this study, the energy consumption, possible energy savings and CO_2 emission reduction potential by using Hot Bag have been quantified and analyzed.

[1]https://www.iea.org/publications/freepublications/publication/cooking.pdf

[2]Ubwa, S. T., J. Abah, K. Asemave, and T. Shambe. "Studies on the Gelatinization Temperature of Some Cereal Starches." International Journal of Chemistry 4, no. 6 (2012): p22.

[3] Morales-Sanchez, E., J. D. C. Figueroa, and M. Gaytan-Martínez. "Wet method for measuring starch gelatinization temperature using electrical conductivity." Journal of food science 74, no. 7 (2009): E382-E385.

2. General Features of Hot Box

Hot Bag may be considered as Heat Retention Cooker (HRC). It provides the possibility of slow cooking by retaining the heat within the enclosed space using thermal insulation. It also reduces the energy consumption for conventional cooking, thus minimizing the fuel consumption in areas with fuel shortage. In many areas, women have to walk a long distance for collecting fuel for their cooking purpose. This journey are often dangerous posing risks of various kind.

Fig.2.1 Hot Bag used for the tests

The specifications of the Hot Bag in Fig. 2.1 which has been used for the tests are as follows:
Weight = 0.472 kg
Height = 22 cm
Outer Dia (full open) = 95 cm
Outer Dia (full closed with a pan having capacity of 3 liter) = 45 cm
Base Dia = 38 cm
Insulation Thickness = 12 cm
Holding capacity = 6 liter pan

Fig. 2.2 Hot Bag in full open position

Fig.2.3 Hot Bag in full closed position

Insulating material has to be used for retaining heat within the Hot Bag. Polystyrene micro beads have been used as thermal insulating material having a thermal conductivity of 0.03 W/m-K. These micro beads are placed within compartments and then sewed with the bag. The micro beads having diameters of 2-3 mm used in the Hot Bag can be seen in Fig.2.4.

Fig.2.4 Polystyrene micro beads used as insulating material in Hot Bag

3. Method and Material

Cooking stoves have been used to provide heat for cooking and the energy consumption have been measured. This section elaborates the description of the methods and materials employed during the experiments.

Cook Stove details

Although there is a significant number of cooking stoves are present, two different Cooking Stove have been employed for carrying out the experiments.

Induction Cooker: The cooking in Induction cooker makes use of induction heating. The high frequency electromagnet induction element within the cooker generate a magnetic field when electricity is supplied. The cooking vessel has to be of ferromagnetic material e.g. Stainless Steel, cast iron etc. for most of the induction cooker available. The magnetic field generated a loop current flow through the metal of the cooking vessel and this current flow through the resistance of the metal generates heat.

For cooking different food items, SUNLAR-SL-STR Induction cooker has been used with a rated voltage of 220 V at 50 Hz frequency and maximum current flow of 9A. The manual shows that Induction cooker has a maximum power output of 2000W. However, the experiment shows that the maximum power obtained from the Induction cooker is 1400 W. The thermal efficiency of the Induction cooker has been experimentally found to be ~82%. For controlling the power output from the Induction cooker, GGG- TDGC Variac has been used with a capacity of 5KVA and Frequency of 50 Hz.

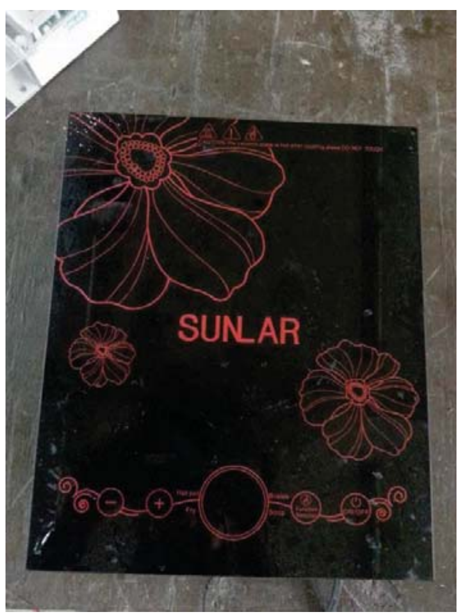

Fig.3.1 Induction cooker used for experiments

LPG Stove: While cooking on a LPG stove, chemical energy is converted to thermal energy and a substantial amount of heat is produced. The energy is released when the gas is combusted in the presence of oxygen. LPG (Liquefied petroleum gas) is a common gaseous fuel being used by urban or rural population who are not connected with the national gas grid. Conventional burners are used along with LPG cylinders for cooking.

For carrying out experiments, Single burner stove has been used bought from the local market. The thermal efficiency has been experimentally obtained. The thermal efficiency of the Induction cooker has been experimentally found to be ~65%. The LPG cylinder was connected with the stove via pipe and the flow of gas can be controlled via knob on the LPG stove. Gas flow rate are controlled at 100% open (~12 gm/min), 50% open (~5.5 gm/min), 25% open (~2.5 gm/min).

Fig.3.2 Single burner stove having LPG as fuel

Measuring method

In order to measure the energy consumed during cooking, an energy meter has been used which shows the power output of the induction cooker, energy being consumed, voltage, and current at regular interval. The energy meter is single phase static kWh meter manufactured by Modern Energy Co. Ltd. '*300'* Thermometer has been used to measure the temperature during cooking. A variac has been used to control the power output for cooking. Fig.3.6 shows the experimental setup for cooking using Induction cooker.

Fig. 3.3 Variac used for varying the power input

Fig. 3.4 Energy meter

Fig. 3.5 Thermometer

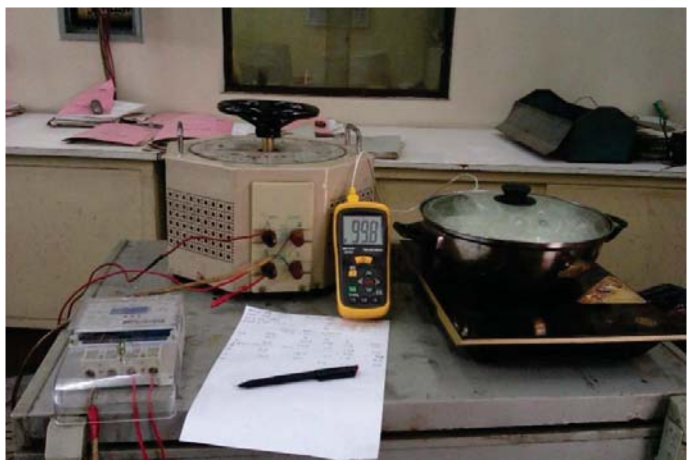

Fig. 3.6 Experimental set up for cooking using Induction cooker

CAMRY Weighing scale has been used to measure the amount of LPG being used with a maximum capacity of 30 kg with sensitivity of 2 gm. The weight of the LPG cylinder has been taken as regular intervals (5 minutes) to determine the amount of gas flow to the burner. The weight is therefore used to determine the energy consumed since the calorific value for LPG is known. Thermometer has been used to measure temperature**.**Fig.3.8 shows the experimental setup for cooking using LPG Stove.

Fig. 3.7 Weighing scale

Fig.3.8 Experimental setup for cooking with LPG Gas Stove.

Energy savings

The energy saving due to the use of Hot Bag has been determined by conducting tests. First, the food material has been cooked using conventional method i.e. heating on the stove or cooker for a duration as needed. Later on a different test, the same food material of same quantity has been heated up to the boiling point, kept at that temperature for a specific time and then placed in the Hot Bag for slow cooking. For both the cases, the energy consumption has been measured. The difference in the energy consumption gives the energy savings.

CO_2 reduction

The cooking employs thermal energy which is originated from fossil fuel sources in most of the cases. The burning of fossil fuel releases CO_2 which is harmful for the environment and also it is one of the main causes of greenhouse emissions. One of the main reasons for global warming is the greenhouse gas emission. As LPG stove makes use of LPG gas, it is possible to determine the amount of CO_2 emission from LPG Stove by measuring the amount of gas flow. The CO_2 emission from LPG[1] is 0.059782 gm/kJ.

[1]http://daq.state.nc.us/monitor/eminv/forms/Stationary_Combustion_Sources.pdf

The electricity is supplied from the national grid which originates from power plants e.g. gas power plants, coal power plants, nuclear power plants etc. and have different CO_2 emission amounts depending on their share in the national grid. For Bangladeshi context, CO_2emission from Induction Cooker which runs on electricity[1] is 0.1425 gm/kJ.

Heat Retention test

Heat retention test was carried out to evaluate the heat retention potential of the Hot Bag. A specific amount of water in a pan is placed in the Hot Bag after heating it to around 100°Cand the Hot Bag is closed. The temperature readings are taken at equal intervals to evaluate the heat retention capacity. The same amount of water in the same pan is kept without the Hot Bag after heating it to the same temperature and the temperature readings are taken. Two results are then compared.

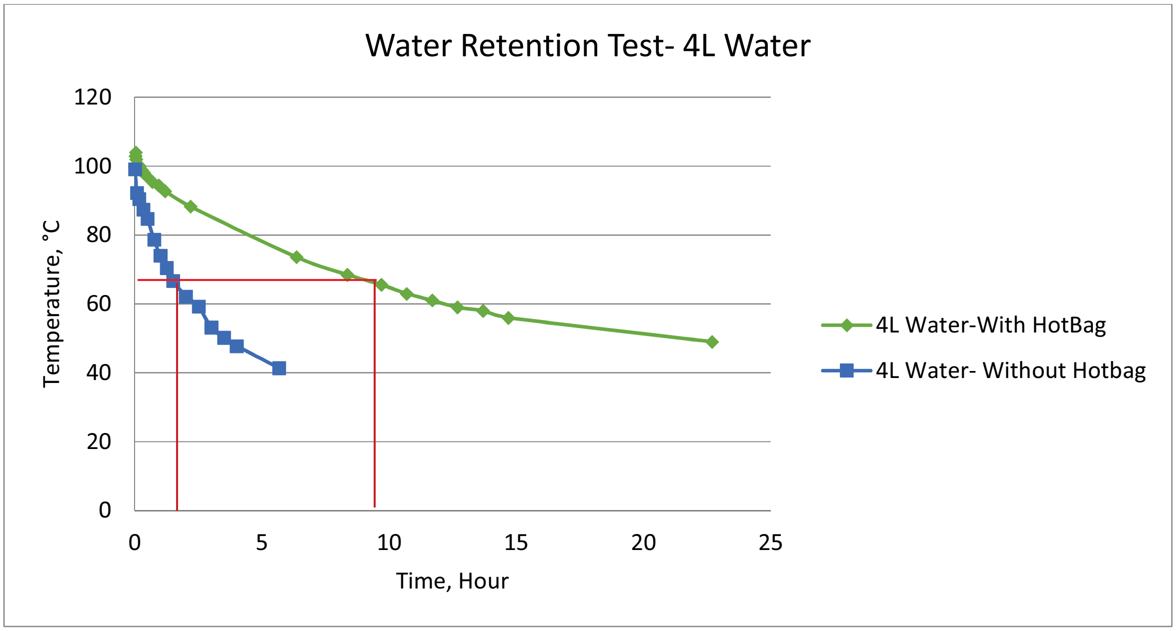

Fig. 3.9 Heat retention test for 4 liter water with and without Hot Bag

Fig.3.9 shows the heat retention test for 4 liter water with and without Hot Bag. The graphs shows that the heat loss rate is higher when Hot Bag is not used. Considering a temperature of 65℃, a temperature many food items are cooked, water reaches to this temperature in around 2.5 hours without Hot Bag where it takes for water to reach the same temperature for around 9 hours with Hot Bag from the same temperature of 100℃.

Modeling of Heat Retention

The heat retention of different capacity of water has been modeled to estimate the thermal behavior of the Hot Bag using appropriate equations. The modeling was carried out to understand the effect of amount of food items and size of the pan.

[1]Technical Report, Solar Bottle Light 'BotolBati': Energy Efficiency Improvement of Baonea-badh Slum, http://www.change.org.bd/Solar%20Bottle%20Light_CHANGE_GIZ.pdf.

4. Tests

For evaluating the performance of the Hot Bag, the following cooking have been undertaken in controlled environment using Induction Cooker and LPG Stove with and without Hot Bag.

- Rice cooking
- Potato boiling
- Chicken cooking
- Mix. Vegetable cooking

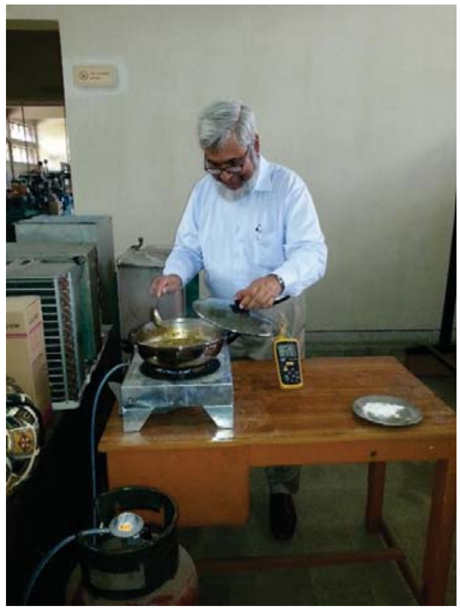

Fig.4.1 The principal investigator is checking the food item being cooked in LPG Stove

Fig. 4.2 The investigator is checking the food item being cooked in induction cooker

Plain Rice Cooking

Bangladesh produces 33889632 Metric tons of rice, being the 6^{th} ranked country in the world[1]. Almost in every household, rice is cooked at least twice daily, for lunch and dinner. Hence, it is of great interest to assess the possible energy savings and CO_2 emission reduction.

[1]http://faostat.fao.org/site/339/default.aspx

Fig.4.3 Cooked rice by conventional method

Fig.4.4 Cooked rice using Hot Bag

Minicate rice has been chosen for the experiments since this type of rice is widely used. 1 kg of rice and 2.5 liters water were put on the cooking pan and cooked using conventional method.

Cooking rice with Induction cooker:

The room temperature and the water temperature were 34.6^0C and 29.5^0C respectively during the test. 1 kg rice was mixed with 2.5 liters of water and put on the pan. The induction cooker was switched on with full power controlled by Variac. A thermocouple has been inserted into the rice-water mixture to measure the temperature throughout the process. The temperature reached the boiling temperature 100°C after 13 minutes. Soon after that, the power input was decreased to 75% (1.06 kW) at 15 minutes. The cooking is completed at 29 minutes, and the induction cooker is switched off. Total energy consumption corresponds to 0.57 kWh. Fig.4.5 shows the temperature profile during the cooking.

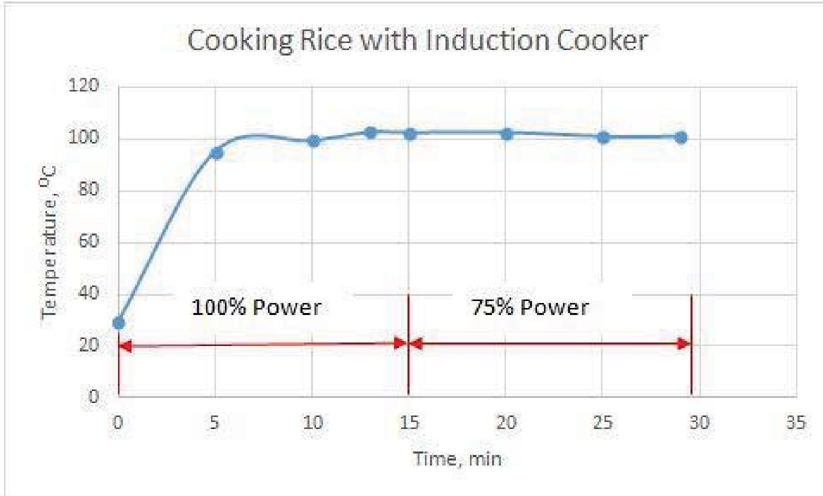

Fig. 4.5 Temperature profile for cooking rice with Induction cooker

Cooking rice with Induction cooker and Hot Bag:

The room temperature and the water temperature were 34.6^{0}C and 32^{0}C respectively during the test. 1 kg rice was mixed with 2.5 liters of water and put on the pan. The induction cooker was switched on with 100% power (1.39 kW) controlled by Variac. A thermocouple has been inserted into the rice-water mixture to measure the temperature throughout the process. The temperature reached the boiling temperature 100°C at 14.5 minutes. Instantly after that the pan was put inside the Hot Bag and sealed off. The pan was kept inside the Hot Bag for 35 minutes. The temperature was 94.7^{0}C when the Hot Bag was opened after 35 minutes. The rice was cooked perfectly. Fig. 4.6 shows the temperature profile during the cooking.

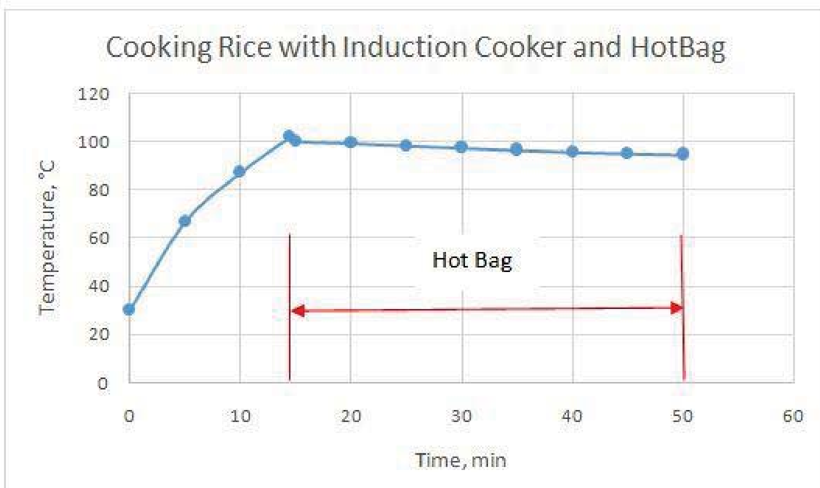

Fig. 4.6 Temperature profile for cooking rice with Induction cooker and Hot Bag

Cooking rice with LPG Stove:

The room temperature and the water temperature were 32^0C and 27^0C respectively during the test. 2.5 liters of water was mixed with 1 kg rice and put on the pan. The LPG Stove was switched on after the LPG supply from the cylinder is ensured. A thermocouple has been inserted into the rice-water mixture to measure the temperature throughout the process. The gas knob was kept full open from 0 to15 minutes, half open from 15 to 25 minutes and quarter open from 25 to35 minutes. The temperature reached the boiling temperature 100°C after 10 minutes. The cooking is completed at 35 minutes, and the LPG stove is switched off. 55 grams of LPG have been consumed during cooking. Fig.4.7 shows the temperature profile during the cooking.

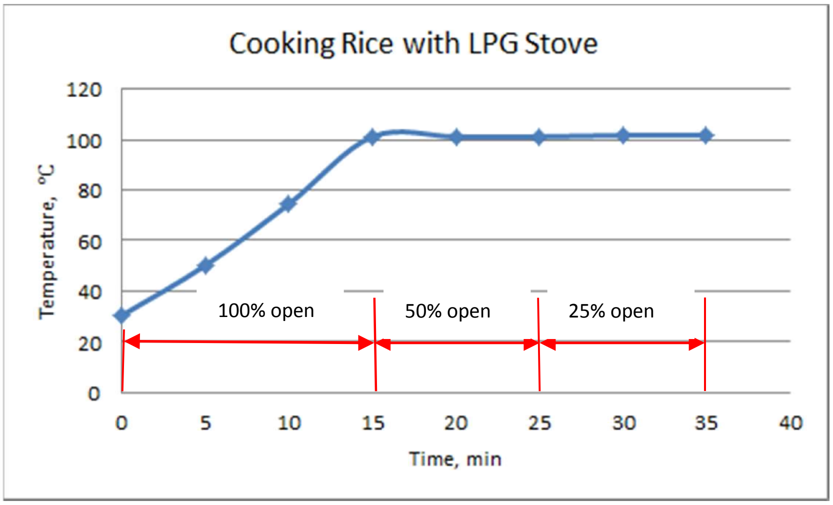

Fig. 4.7 Temperature profile for cooking rice with LPG Stove

Cooking rice with LPG Stove and Hot Bag:

The room temperature and the water temperature were 30.8^0C and 27.5^0C respectively during the test. 2.5 liters of water was mixed with 1 kg rice and put on the pan. The LPG Stove was switched on with gas knob 100% open. A thermocouple has been inserted into the rice-water mixture to measure the temperature throughout the process. The temperature reached the boiling temperature 100°C at 15 minutes. Instantly, the pan is put inside the Hot Bag and kept there for 30 minutes. The temperature of the rice drops down to 94.4^0C during the period.35 grams of LPG have been consumed during cooking. Fig.4.8 shows the temperature profile during the cooking.

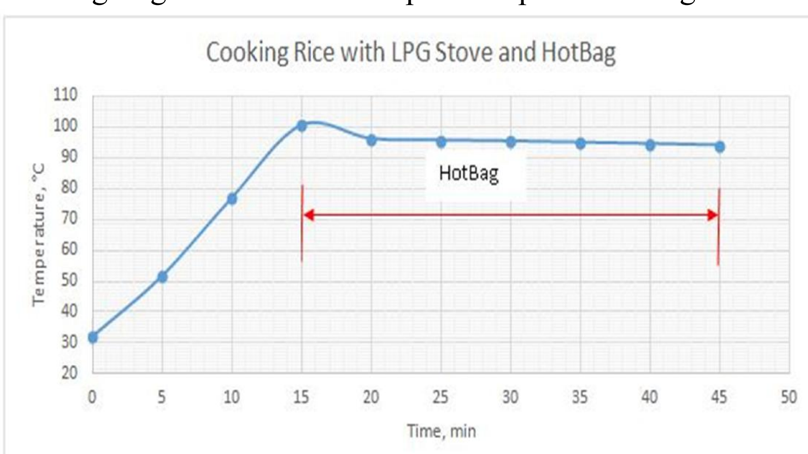

Fig. 4.8 Temperature profile for cooking rice with LPG Stove and Hot Bag

Potato Boiling

Potato is an integrated part to many areas food supply. Bangladesh being the 7^{th} largest potato producer, produces 8205470 metric tons per year.[2]Many household use potato as a food item on a daily basis. In this study, potato has been boiled using Induction cooker and LPG stove, both with and without Hot Bag.

Fig.4.9 Boiling potato

Boiling Potato with Induction Cooker:

The room temperature and the water temperature were 31.4^0C and 26.3^0C respectively during the test. On a pan, 1 kg potato was partially submerged in 1.5 liter water. The induction cooker was switched on with 100% power (1.68 kW) being controlled by Variac. A thermocouple has been inserted into water to measure the temperature continuously. The temperature reached the boiling temperature 100 °C at 10 minutes. The power input was decreased to 50% (0.85 kW) at 12 minutes. At equal intervals, it has checked whether the potato is boiled. The boiling is completed in 39 minutes, and the induction cooker is switched off. Total energy consumption corresponds to 0.7 kWh. Fig.4.10 shows the temperature profile during the boiling.

Boiling Potato with Induction Cooker and Hot Bag:

The room temperature and the water temperature were 34.6^0C and 32^0C respectively during the test. 1 kg potato (Big size: 3, Medium size: 4, Small size: 15). The induction cooker was switched on with 100% power (1.39 kW). A thermocouple has been inserted into water to measure the temperature during the boiling process.

[2]http://faostat.fao.org/site/339/default.aspx

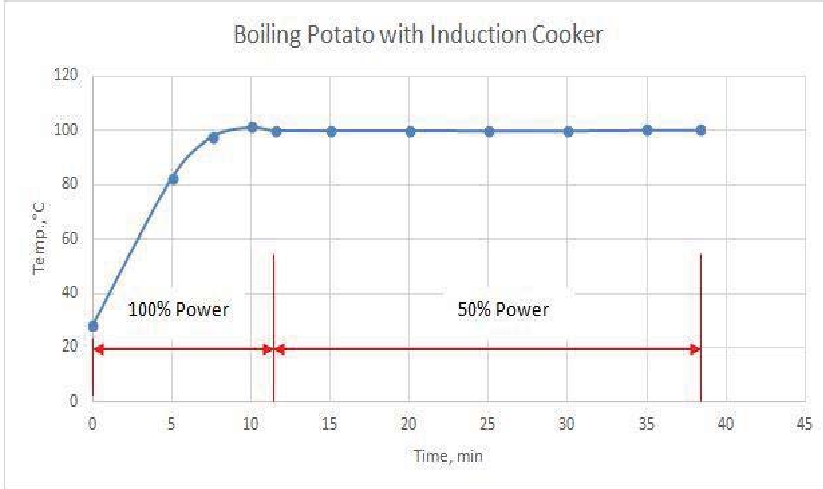

Fig.4.10 Boiling Potato with Induction Cooker

The temperature reached the boiling temperature 100℃ at 8 minutes. The pan was kept on the cooker for 10 more minutes. Then, the pan was put inside the Hot Bag and sealed off. The pan was kept inside the Hot Bag for 120 minutes. The temperature was 78.6^{0}C when the Hot Bag was opened after two hours. The potatoes were cooked perfectly. Fig. 4.11 shows the temperature profile during boiling.

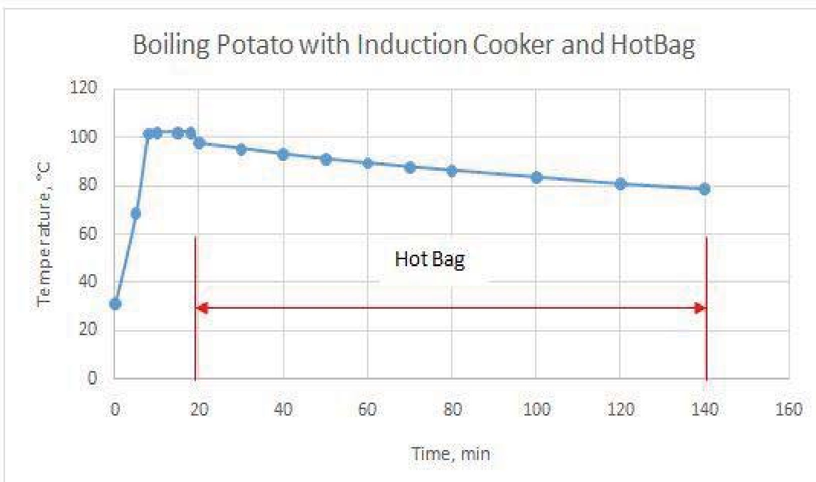

Fig.4.11 Boiling Potato with Induction Cooker and Hot Bag

Boiling Potato with LPG Stove:

The room temperature and the water temperature were 32^{0}C and 27.4^{0}C respectively during the test. 1 kg potato (big size: 4 pcs, medium size: 7 pcs, small size: 9 pcs). The LPG Stove was switched on after the LPG supply from the cylinder is ensured. A thermocouple has been inserted into water to measure the temperature throughout the process. The gas burner was kept full open from 0 to15 minutes, half open for rest. The temperature reached the boiling temperature 100℃ after 8 minutes. The boiling is completed at 55 minutes, and the LPG stove is switched off. 84 grams of LPG have been consumed during boiling. Fig.4.12 shows the temperature profile during the boiling.

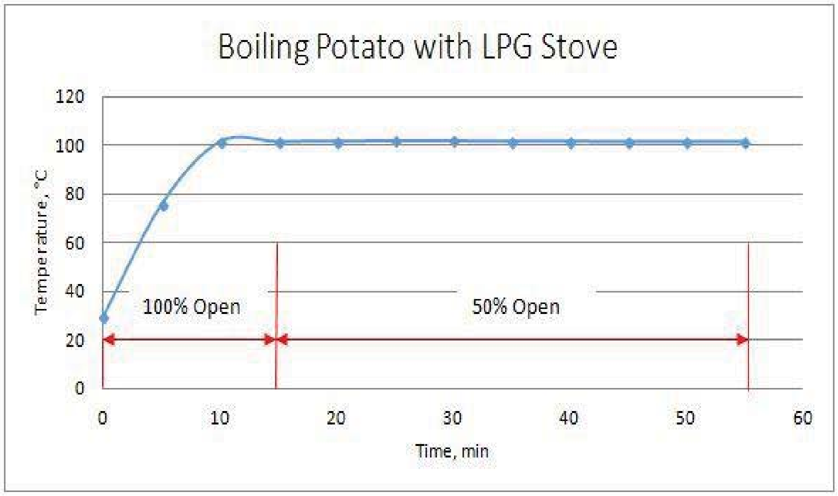

Fig.4.12 Boiling Potato with LPG Stove

Boiling Potato with LPG Stove and Hot Bag:

The room temperature and the water temperature were 31.5^{0}C and 27^{0}C respectively during the test. On a pan, 1 kg potato (Big size: 3 pcs, medium size: 12 pcs, small size: 10 pcs) was submerged on 1 liter water. The LPG Stove was switched on with gas burner 100% open. A thermocouple has been inserted into water to measure the temperature. The temperature reached the boiling temperature 100°C at 8 minutes. The pan was kept on the cooker for 10 more minutes. Then, the pan was put inside the Hot Bag and the bag was sealed off. The pan was kept inside the Hot Bag for 120 minutes. The temperature was 85.1^{0}C when the Hot Bag was opened after two hours. The potatoes were boiled perfectly. Fig.4.13 shows the temperature profile during boiling.

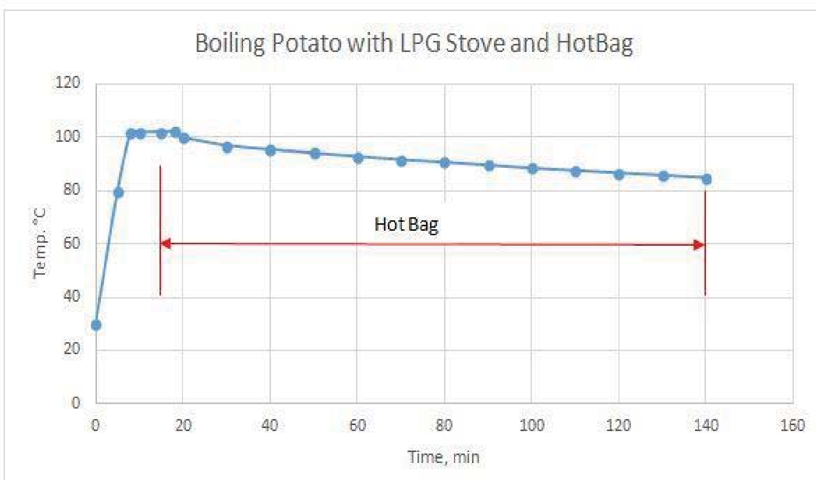

Fig.4.13 Boiling Potato with LPG Stove and Hot Bag

Chicken Curry

Chicken meat is widely consumed in lunch and dinner meals in Bangladesh. The country has a significantly large number of poultry firms from where the chicken are distributed to the local market. In this study, chicken has been cooked with traditional Bangladeshi method by mixing with hot spices, onions and green chili. Chicken was cooked using Induction cooker and LPG Stove, with Hot Bag and without Hot Bag.

Fig.4.14 Preparation of chicken before cooking

Fig.4.15 Cooked chicken following traditional style

Cooking Chicken with Induction Cooker:

The room temperature and the water temperature were 32.5^0C and 27^0C respectively during the test. Chicken was cut into small pieces beforehand and mixed up with, oil, salt, hot spices (ginger paste, garlic paste, turmeric powder, red chili powder, cumin powder, coriander powder, and cardamom), onions and green chili. The mass of the mixture was 1.38 kg. Initially, around 75 ml of water is poured to ensure that the mixture don’t stick to the surface while heated up. A thermocouple has been inserted into the mixture to measure the temperature continuously. The mixture is occasionally stirred to avoid sticking, otherwise the cover was put at all times.

Fig.4.16 Cooked chicken with Hot Bag

The temperature reached the boiling temperature 100℃ at 15 minutes.250 ml water was added at 55 minutes, and an additional 250 ml was added at 78 minutes for proper cooking. The cooking is completed in 90 minutes, and the induction cooker is switched off. Total energy consumption corresponds to 0.9 kWh. Fig.4.17 shows the temperature profile during the cooking.

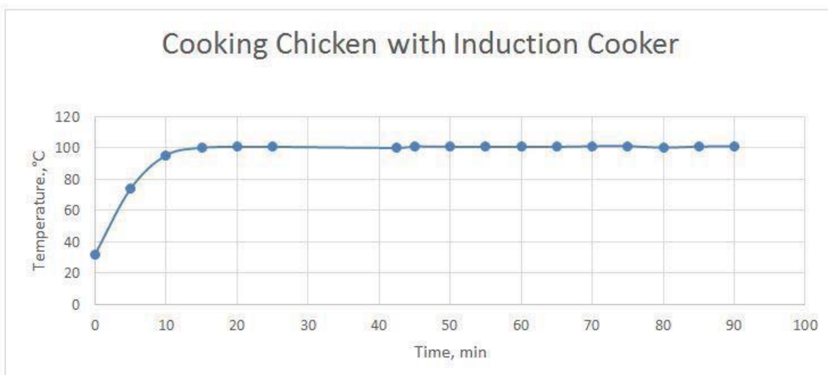

Fig.4.17 Cooking Chicken with Induction Cooker

Cooking Chicken with Induction Cooker and Hot Bag:

The room temperature and the water temperature were 32.1^{0}C and 27^{0}C respectively during the test. Chicken was cut into small pieces beforehand and mixed up with, oil, salt, hot spices, onions and green chili. The mass of the mixture was 1.11 kg. Initially, around 100 ml of water is poured to ensure that the mixture don't stick to the surface while heated up. A thermocouple has been inserted into the mixture to measure the temperature continuously. The cover is put on at all-time except for stirring. The temperature reached the boiling temperature 100℃ at 15 minutes. An additional 250 ml was added at 30 minutes for proper cooking. The stove was switched off at 45 minutes and the pan was transferred to the Hot Bag and kept there for 4 hours. The temperature drops to 60.5^{0}C after 4 hours.Fig.4.18 shows the temperature profile during the cooking.

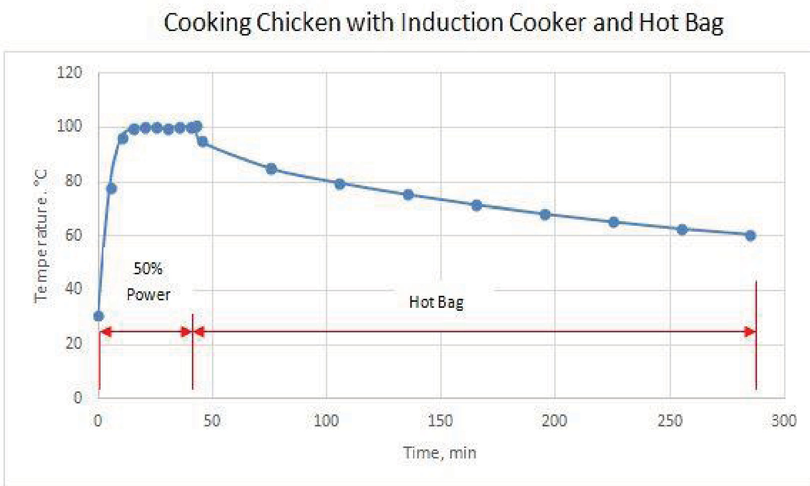

Fig.4.18 Cooking Chicken with Induction Cooker and Hot Bag

Cooking Chicken with LPG Stove:

The room temperature and the water temperature were 32^{0}C and 28^{0}C respectively during the test. Chicken was cut into small pieces and mixed up with, oil, salt, hot spices, onions and green chili. The mass of the mixture was 1.15 kg. Initially, around 75 ml of water is poured to ensure that the mixture don't stick to the surface while heated up. A thermocouple has been inserted into the mixture to measure the temperature continuously. The mixture is occasionally stirred to avoid sticking, otherwise the cover was put at all times. After 25 minutes, the gas flow rate is halved. The temperature reached the boiling temperature 100°C at 10 minutes. After 25 minutes, the gas flow rate is halved. 225 ml water was added at 12 minutes, and an additional 50 ml was added at 30 minutes for proper cooking. The cooking is completed in 35 minutes, and the burner was switched off. The chicken was perfectly cooked. Total gas consumption corresponds to 71 gm. Fig.4.19 shows the temperature profile during the cooking.

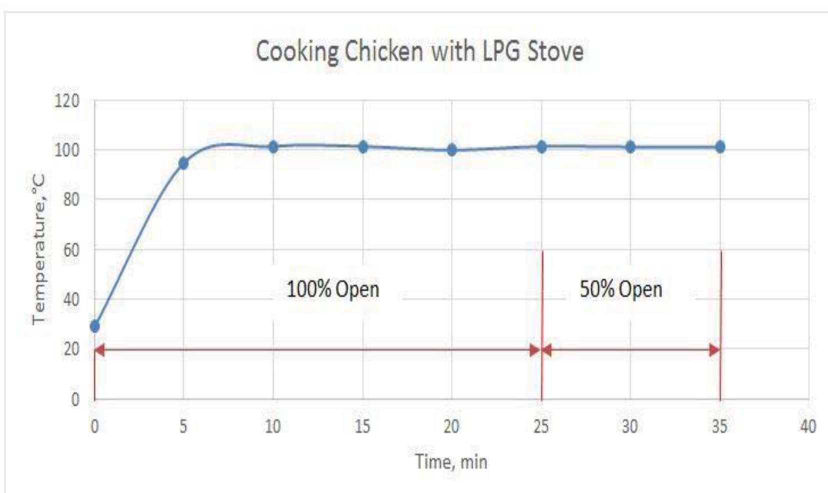

Fig. 4.19 Cooking Chicken with LPG Stove

Cooking Chicken with LPG Stove and Hot Bag:

The room temperature and the water temperature were 34.6^{0}C and 29.5^{0}C respectively during the test. Chicken was cut into small pieces and mixed up with, oil, salt, hot spices, onions and green chili. The mass of the mixture was 1.08 kg. Initially, around 75 ml of water is poured to avoid sticking to the surface while heated up. A thermocouple has been inserted into the mixture to measure the temperature throughout the process. A spoon is used to stir the contents occasionally. The temperature reached the boiling temperature 100℃ at 7 and ½ minutes, then 250 ml water was added. The pan was put in the Hot Bag after 20 minutes and kept for 2 hours. The temperature reading was 71.3^{0}Cafter 120 minutes in the Hot Bag. The chicken was perfectly cooked. Fig.4.20 shows the temperature profile during the cooking.

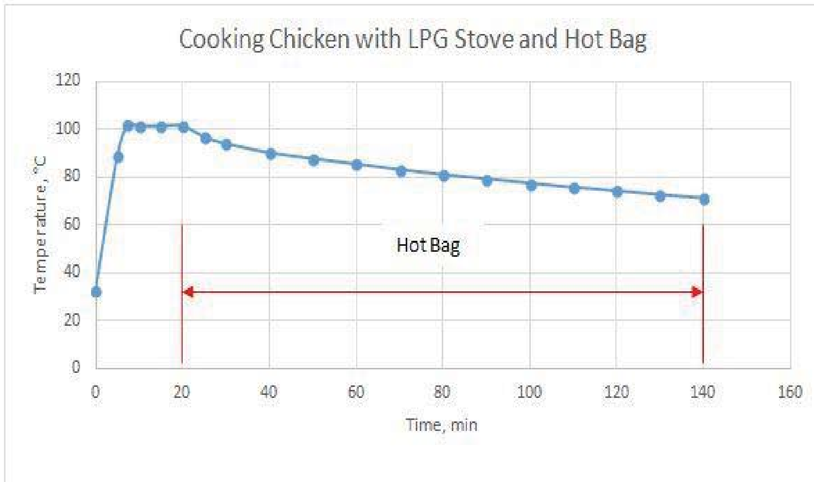

Fig. 4.20 Cooking Chicken with LPG Stove and Hot Bag

Vegetable Curry

Vegetable are very important sources of nutrients including different vitamins, potassium etc. It is essential for human health to consume vegetables. Usually, a common practice in Bangladesh is to serve a dish of vegetable in every meal. There are varieties of vegetables available in local markets with seasonal variation. In this study, three common used vegetables have been considered namely pointed gourd, potato and spinach stem. Fig.4.21 shows the vegetable cooked.

Fig.4.21 Raw vegetables used for cooking

Fig.4.22 Preparation of spices, onions and vegetables for cooking

Cooking Mixed vegetable with Induction Cooker:
The room temperature and the water temperature were 34.6^{0}C and 27.5^{0}C respectively during the test. All three vegetables ware cut into small pieces beforehand and mixed up with, oil, salt, hot spices (ginger paste, garlic paste, turmeric powder, red chili powder etc.), onions and green chili. The mass of the mixture was 952 grams. Initially, around 50 ml of water is poured to ensure that the mixture don't stick to the surface while heated up. A thermocouple has been inserted into the mixture to measure the temperature continuously. The mixture is occasionally stirred to avoid sticking, otherwise the cover was put at all times. The temperature reached the boiling temperature 100℃ at around 4 minutes. 50 ml water was added at 9 minutes, and an additional 250 ml was added at around 12 minutes for proper cooking. The cooking is completed in 30 minutes, and the induction cooker is switched off. The induction cooker was given 100% power from the beginning to 10 minutes, 80% power from 10 minutes to 25 minutes and 45% power till the end. Fig.4.23 shows the temperature profile during the cooking.

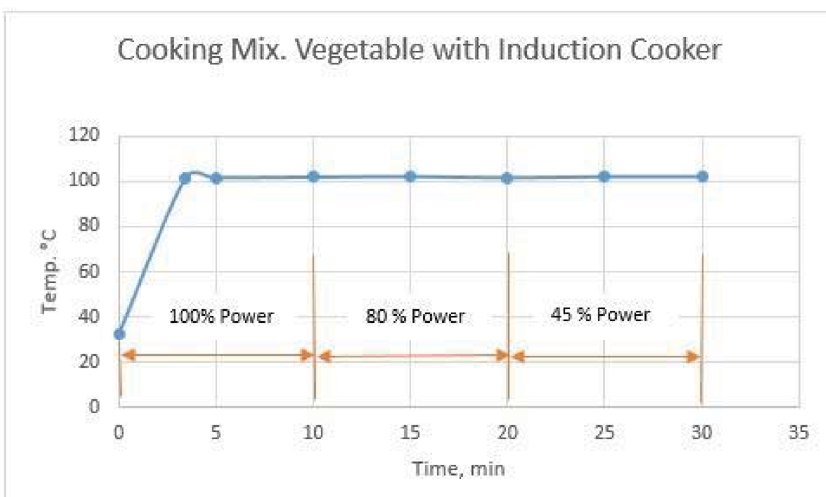

Fig.4.23 Cooking Mix. Vegetable with Induction Cooker

Cooking Mixed vegetable with Induction Cooker and Hot Bag:

The room temperature and the water temperature were 36.9^{0}C and 31.4^{0}C respectively during the test. All three vegetables ware cut into small pieces beforehand and mixed up with, oil, salt, hot spices, onions and green chili. The mass of the mixture was 716 grams. Initially, around 50 ml of water is poured to ensure that the mixture don't stick to the surface while heated up. A thermocouple has been inserted into the mixture to measure the temperature throughout the process. The mixture is occasionally stirred to avoid sticking; otherwise the cover was put at all times. The temperature reached the boiling temperature 100°C at around 2.30 minutes. 200 ml water was added at 3 minutes. The pot is put in the Hot Bag after 10 minutes for 35 minutes. The cooking is completed in total of 45 minutes. The temperature drops to 86.4^{0}C after 45 minutes. Fig.4.24 shows the temperature profile during the cooking.

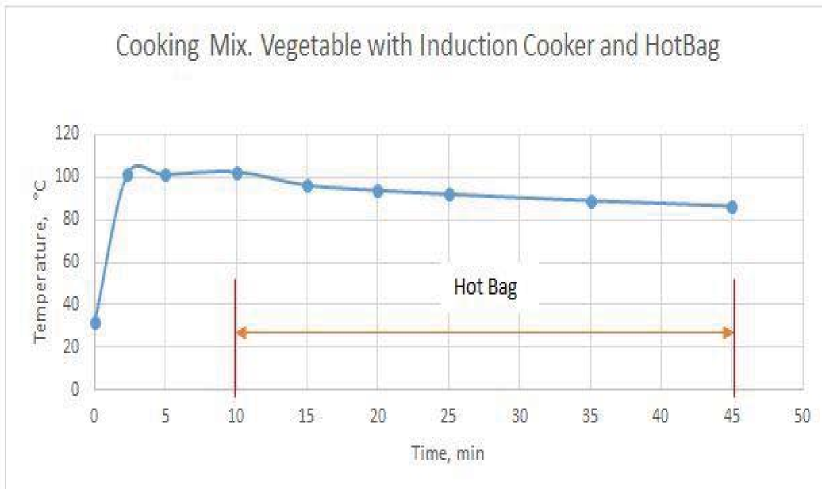

Fig.4.24 Cooking Mix. Vegetable with Induction Cooker and Hot Bag

Cooking Mixed vegetable with LPG Stove:

The room temperature and the water temperature were 36.5^{0}C and 26.5^{0}C respectively during the test. All three vegetables ware cut into small pieces beforehand and mixed up with, oil, salt, hot spices, onions and green chili. The mass of the mixture was 721 grams. Initially, around 50 ml of water is poured. A thermocouple has been inserted into the mixture to measure the temperature continuously. The mixture is occasionally stirred to avoid sticking. The temperature reached the boiling temperature 100°C at around 5 minutes. The gas flow rate is halved after 10 minutes. An additional 150 ml was added at around 23 minutes for proper cooking. The cooking is completed in 33.5 minutes. The vegetable was perfectly cooked. Fig.4.25 shows the temperature profile during the cooking.

Cooking Mixed vegetable with LPG Stove and Hot Bag:

The room temperature and the water temperature were 36.3^{0}C and 32^{0}C respectively during the test. All three vegetables ware cut into small pieces beforehand and mixed up with, oil, salt, hot spices, onions and green chili. The mass of the mixture was 721 grams. Initially, around 50 ml of water is poured. A thermocouple has been inserted into the mixture to measure the temperature continuously. The mixture is occasionally stirred to avoid sticking.150 ml water added at 5 minutes after boiling starts at 100^{0}C. The pot was placed inside the Hot Bag after 13 minutes and kept there for 37 minutes. The temperature drops to 89.6^{0}C after 50 minutes. The vegetable was perfectly cooked. Fig.4.26 shows the temperature profile during the cooking.

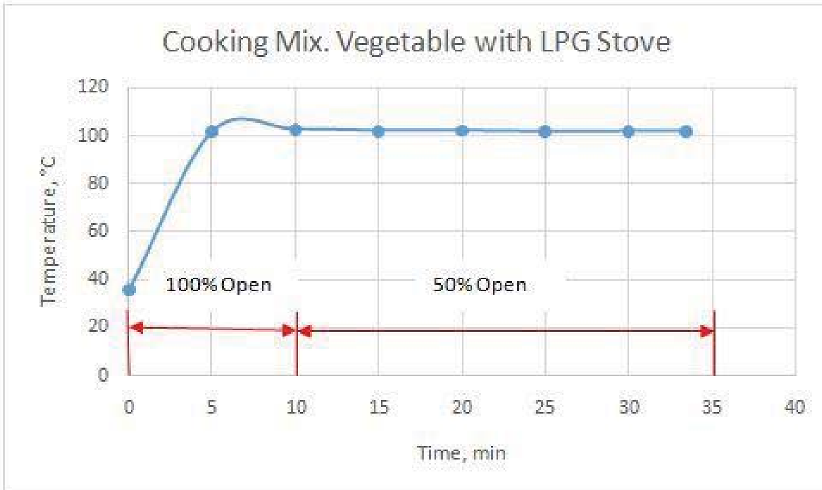

Fig. 4.25 Cooking Mix. Vegetable with LPG Stove

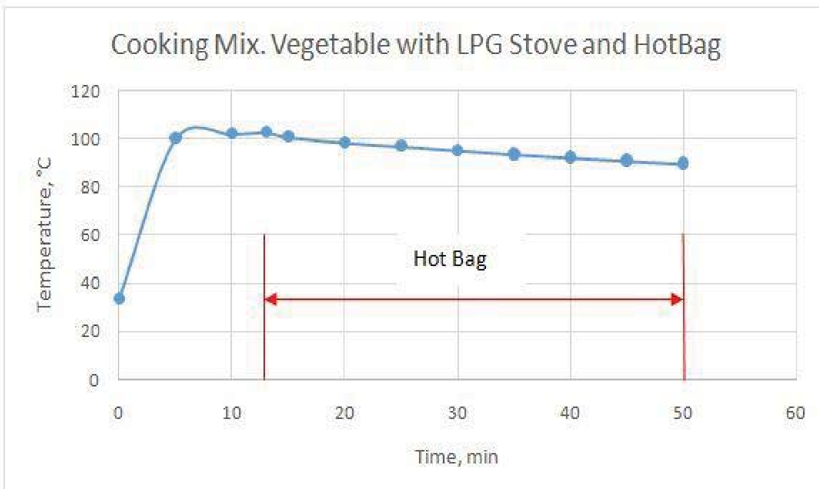

Fig. 4.26 Cooking Mix. Vegetable with LPG Stove and Hot Bag

5. Results and Discussion

The energy consumption has been calculated for cooking different food items with and without Hot Bag. For Induction cooker, energy meter reading shows the energy in kWh which is then converted to kJ (1 kWh = 3600kJ).For LPG Stove, the LPG consumption has been measured by employing a weighing scale. The mass of LPG is then converted to kJ (1 gm of LPG is equivalent to 46.607 kJ) [1].

Plain Rice Cooking

Plain rice has been cooked using Induction cooker both with Hot Bag and without Hot Bag and then the energy consumption has been compared. For cooking rice with Induction cooker alone, 0.57 kWh, equivalent to 2052 kJ, has been consumed. The cumulative energy consumption profile can be seen in Fig.5.1.

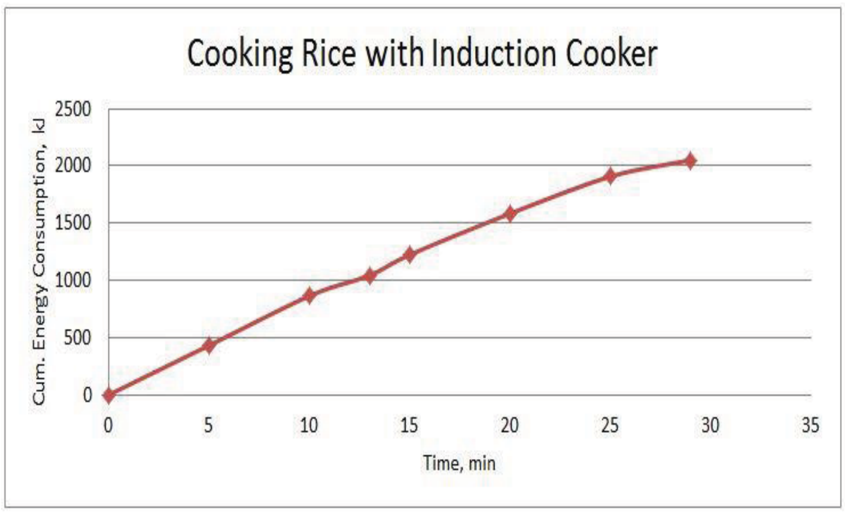

Fig. 5.1 Energy consumption profile for cooking rice with Induction Cooker

Same amount of rice was cooked with Induction cooker and Hot Bag. The pot was put instantly in the Hot Bag after reaching the boiling temperature and kept there for 35 minutes. The total energy consumption was 1188 kJ yielding 42% energy savings. The cumulative energy consumption profile is shown in Fig.5.2 The savings of 864 kJ leads to 123 grams of CO_2 emission. The cooking with Hot Bag required additional 20 minutes as compared to cooking Induction cooker alone.

The same type of rice has been cooked using LPG Stove both with Hot Bag and without Hot Bag and then the energy consumption has been compared. For cooking rice with LPG stove alone, 55 grams of LPG, equivalent to 2563 kJ, has been consumed. The cumulative energy consumption profile can be seen in Fig.5.3.

[1]GREET, The Greenhouse Gases, Regulated Emissions, and Energy Use In Transportation Model, GREET 1.8d.1, developed by Argonne, National Laboratory, Argonne, IL, released August 26, 2010.

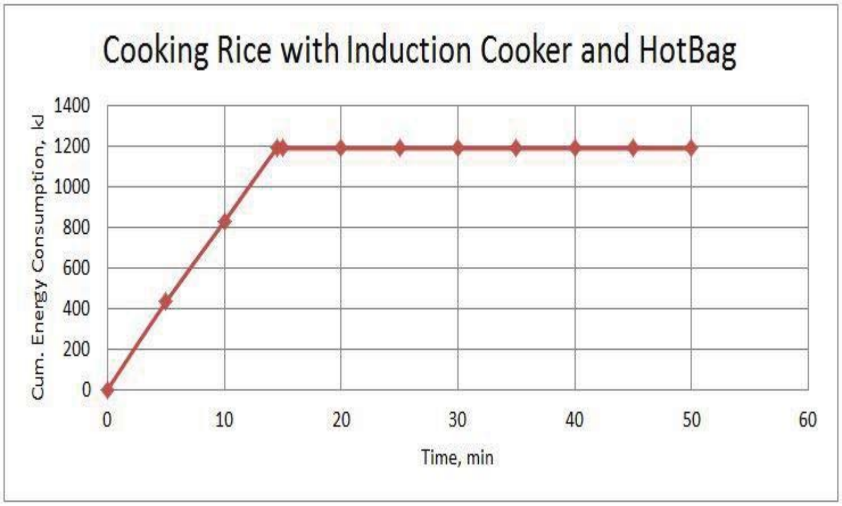

Fig. 5.2 Energy consumption profile for cooking rice with Induction Cooker and Hot Bag

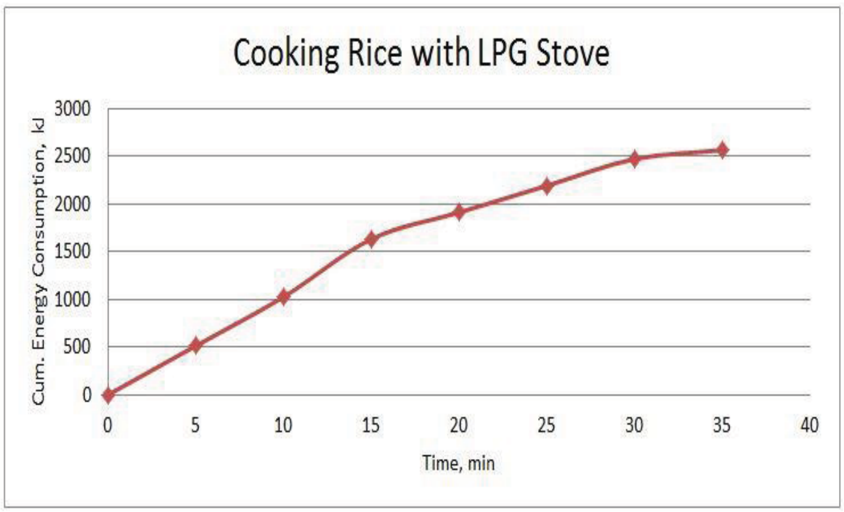

Fig.5.3 Energy consumption profile for cooking rice with LPG Stove

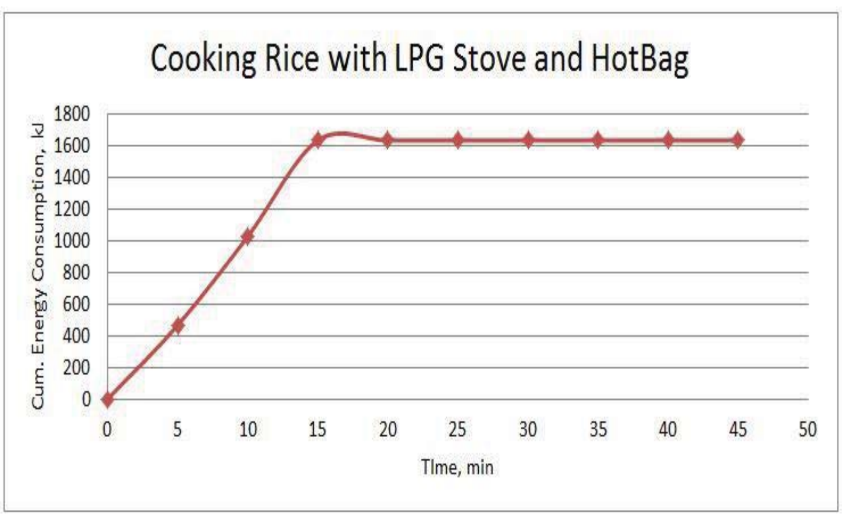

Fig.5.4 Energy consumption profile for cooking rice with LPG Stove and Hot Bag

Same amount of rice was cooked with LPG Stove and Hot Bag. The pot was put instantly in the Hot Bag after reaching the boiling temperature and kept there for 30 minutes. The total energy consumption was 1631 kJ yielding 36% energy savings. The cumulative energy consumption profile is shown in Fig.5.4. The savings of 932 kJ leads to reduction of 56 gram CO_2 emission. The cooking with Hot Bag required additional 10 minutes as compared to cooking LPG stove alone.

Potato Boiling

Potato has been boiled using Induction cooker both with Hot Bag and without Hot Bag and then the energy consumption has been compared. For boiling potato with Induction cooker alone, 0.7 kWh, equivalent to 2520 kJ, has been consumed. The cumulative energy consumption profile can be seen in Fig.5.5.

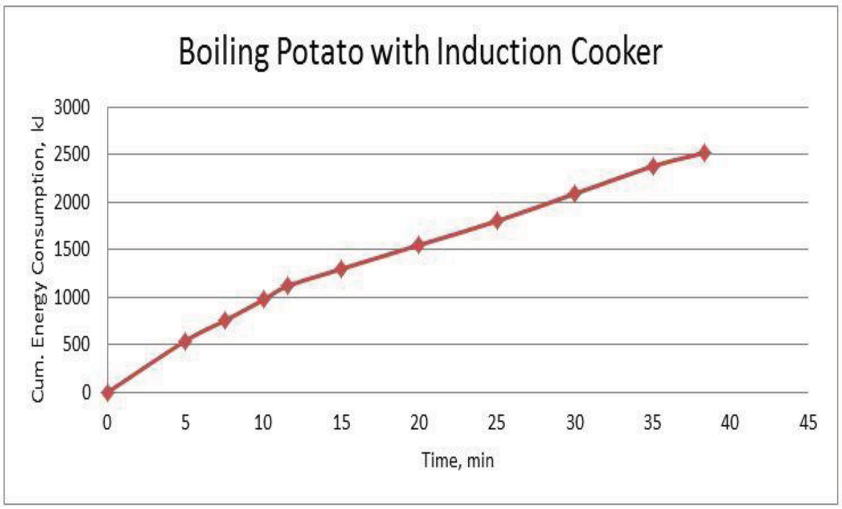

Fig.5.5 Energy consumption profile for boiling potato with Induction Cooker

Same amount of potato was boiled with Induction cooker and Hot Bag. The pot was put in the Hot Bag10 minutes after reaching the boiling temperature and kept there for 120 minutes. The total energy consumption was 1476 kJ yielding 41% energy savings. The cumulative energy consumption profile is shown in Fig.5.6The savings of 1044 kJ leads to reduction of 149 grams CO_2 emission. The boiling with Hot Bag required additional 100 minutes as compared to boiling with Induction cooker alone.

The same type of potato has been boiled using LPG Stove both with Hot Bag and without Hot Bag and then the energy consumption has been compared. For boiling potato with LPG stove alone, 84 grams of LPG, equivalent to 3915 kJ, has been consumed. The cumulative energy consumption profile can be seen in Fig.5.7

Same amount of potato was boiled with LPG Stove and Hot Bag. The pot was put in the Hot Bag 10 minutes after reaching the boiling temperature and kept there for 120 minutes. The total energy consumption was 2051 kJ yielding 48% energy savings. The cumulative energy consumption profile is shown in Fig.5.8The savings of 1864 kJ leads to reduction of 111 gram CO_2 emission. The cooking with Hot Bag required additional 80 minutes as compared to boiling with LPG stove alone.

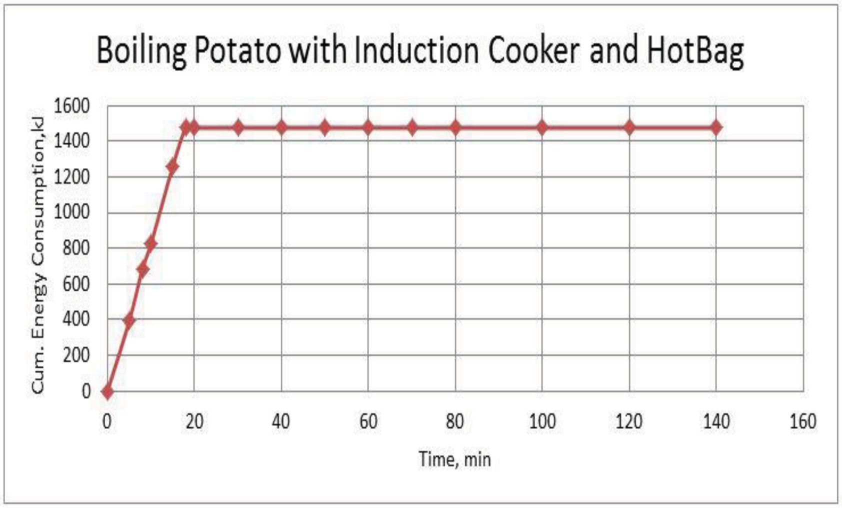

Fig.5.6 Energy consumption profile for boiling potato with Induction Cooker and Hot Bag

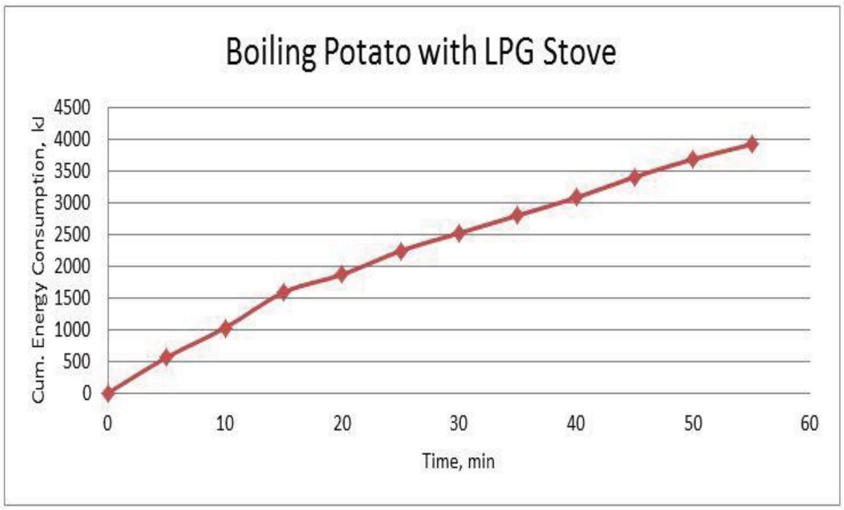

Fig.5.7 Energy consumption profile for boiling potato with LPG Stove

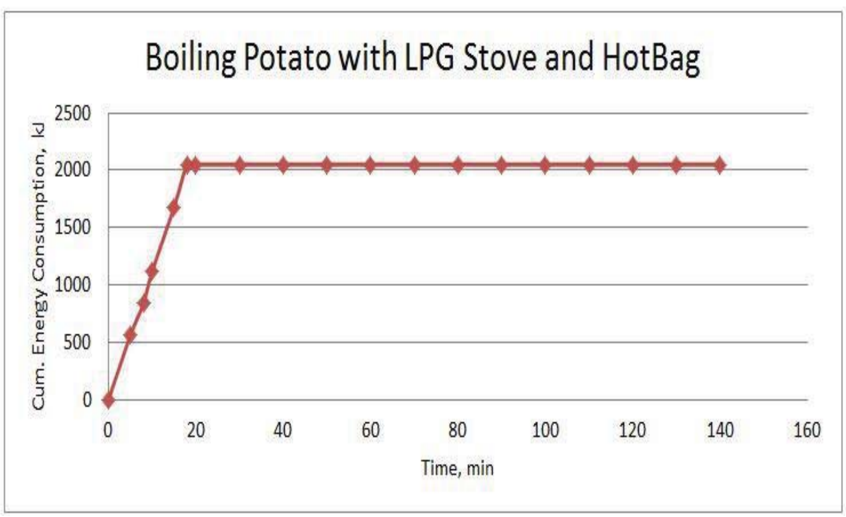

Fig.5.8 Energy consumption profile for boiling potato with LPG Stove and Hot Bag

Chicken Curry

Chicken has been cooked after mixing with hot spices, onions, green chili following traditional cooing style. It has been cooked using Induction cooker alone as well as using Hot Bag. While cooking with Induction cooker alone, 0.65 kWh, equivalent to 2346 kJ, has been consumed per kg of the mixture. The cumulative energy consumption profile can be seen in Fig.5.9.

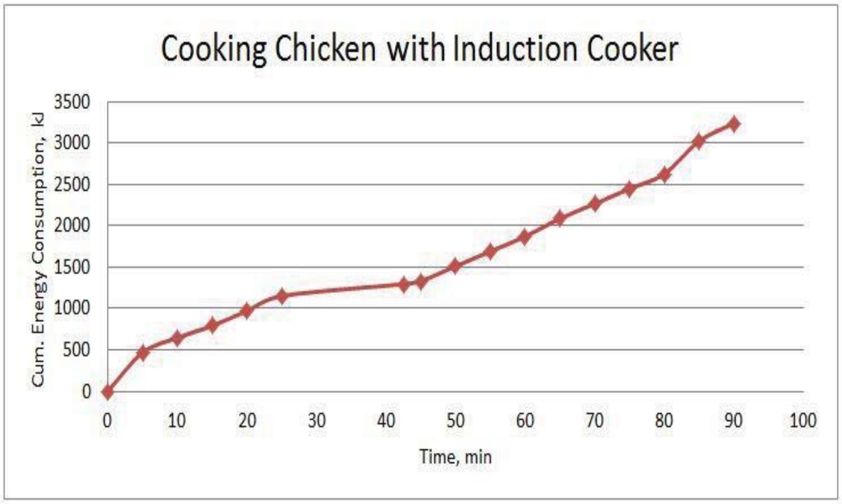

Fig.5.9 Energy consumption profile for cooking chicken with Induction Cooker

The similar type of chicken has been cooked employing same traditional style using Induction cooker and Hot Bag. The pan containing the chicken mixture was put in the Hot Bag 30 minutes after boiling temperature has been reached and kept there for 4 hours. However, later experiments suggests that keeping the pan inside the Hot Bag for 2 hour would also serve the purpose.

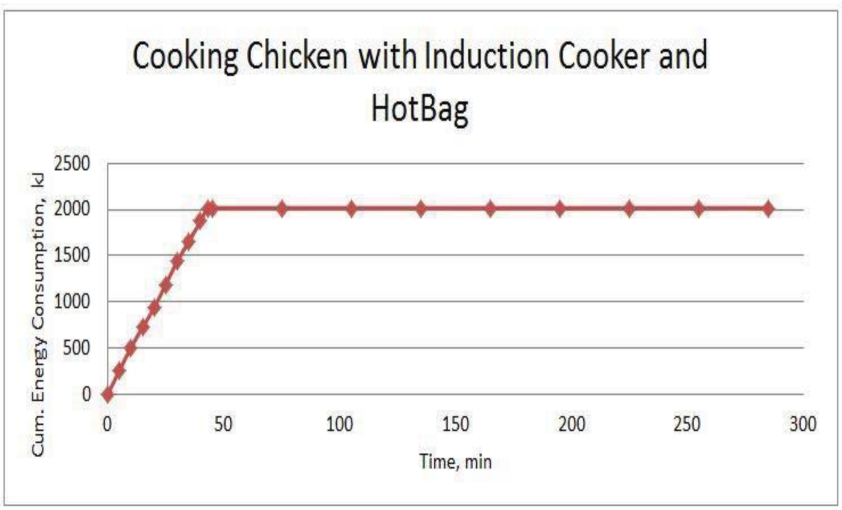

Fig.5.10 Energy consumption profile for cooking chicken with Induction Cooker and Hot Bag

The total energy consumption was 1819 kJ per kg of chicken mixture yielding 22% energy savings. The cumulative energy consumption profile is shown in Fig.5.10. The savings of 527 kJ leads to reduction of 75 grams CO_2 emission. The boiling with Hot Bag required additional 195 minutes as compared to cooking with Induction cooker alone.

1.15 kg of chicken was cooked using LPG stove following the same cooking style as carried out using Induction cooker. The test has been carried out with and without Hot Bag. While cooking with LPG stove alone, 61.6 grams per kg of chicken mixture, equivalent to 2873 kJ, has been consumed. The cumulative energy consumption profile can be seen in Fig. 5.11.

The similar type of chicken has been cooked using LPG stove and Hot Bag employing same traditional style. The pan containing the chicken mixture was put in the Hot Bag 12.30 minutes after boiling temperature has been reached and kept there for 2 hours.

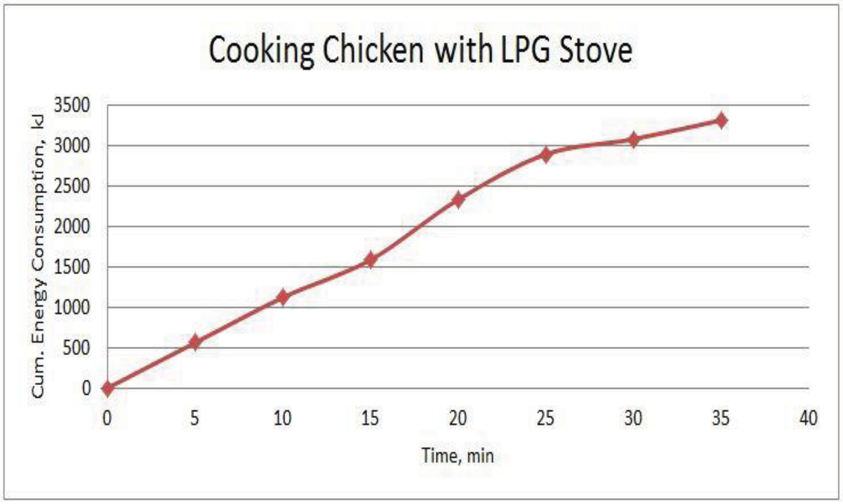

Fig.5.11 Energy consumption profile for cooking chicken with LPG Stove

The total energy consumption was 2115 kJ per kg of chicken mixture yielding 26% energy savings. The cumulative energy consumption profile is shown in Fig.5.12. The savings of 758 kJ leads to reduction of 45 grams CO_2 emission. The boiling with Hot Bag required additional 105 minutes as compared to cooking with LPG stove alone.

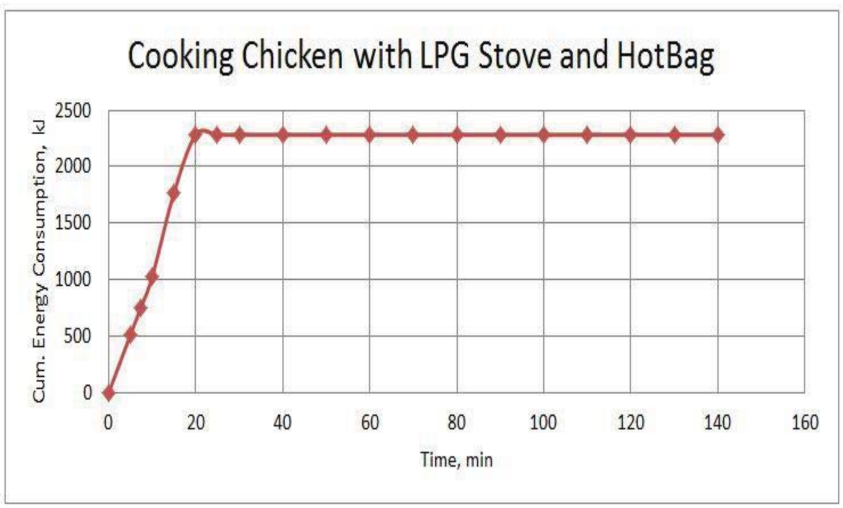

Fig.5.12 Energy consumption profile for cooking chicken with LPG Stove and Hot Bag

Vegetable Curry

Mixed vegetable was cooked with spices using native traditional cooking style. Potato, Pointed gourd and spinach stem were used after cutting into small pieces. It has been cooked using Induction cooker alone as well as using with Hot Bag. While cooking with Induction cooker alone, 0.56 kWh, equivalent to 2004 kJ, has been consumed per kg of the mixture. The cumulative energy consumption profile can be seen in Fig.5.13.

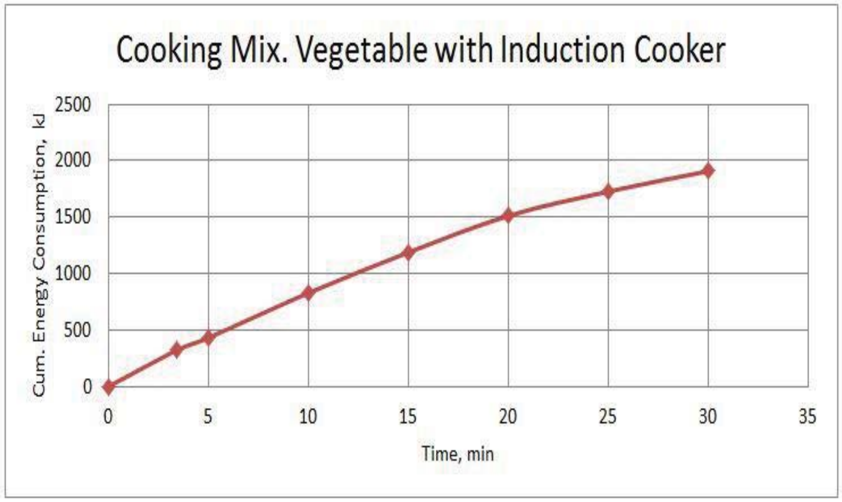

Fig.5.13 Energy consumption profile for cooking mix. Vegetables with Induction Cooker

The similar type of vegetables with same proportion has been cooked employing same traditional style using Induction cooker and Hot Bag. The pan containing the vegetable mixture was put in the Hot Bag7.30 minutes after boiling temperature has been reached and kept there for 35 minutes.

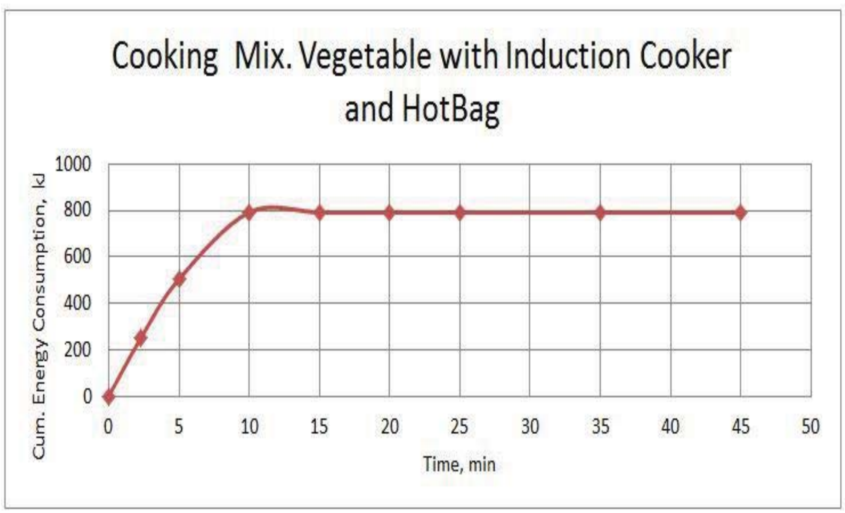

Fig.5.14 Energy consumption profile for cooking mix. Vegetables with Induction Cooker and Hot Bag

The total energy consumption was 1819 kJ per kg of chicken mixture yielding 45% energy savings. The cumulative energy consumption profile is shown in Fig.5.14. The savings of 898 kJ leads to reduction of 128 grams CO_2 emission. The cooking with Hot Bag required additional 15 minutes as compared to cooking with Induction cooker alone.

LPG Stove was used to cook mixed vegetable using native traditional cooking style with and without Hot Bag. While cooking with LPG Stove alone, 68grams, equivalent to 3167 kJ, has been consumed per kg of the mixture. The cumulative energy consumption profile can be seen in Fig.5.15.

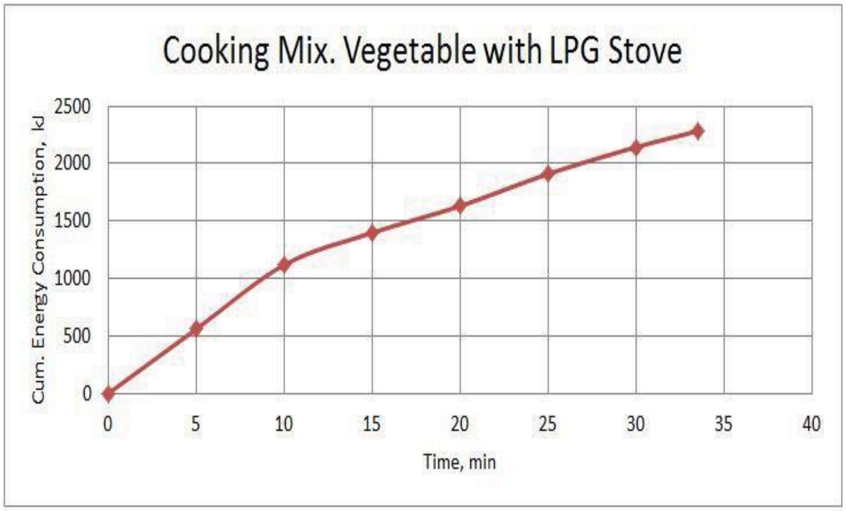

Fig.5.15 Energy consumption profile for cooking mix. Vegetables with LPG Stove

The vegetables with same proportion has been cooked employing same traditional style using LPG stove and Hot Bag. The pan containing the vegetable mixture was put in the Hot Bag 8 minutes after boiling temperature has been reached and kept there for 37 minutes.

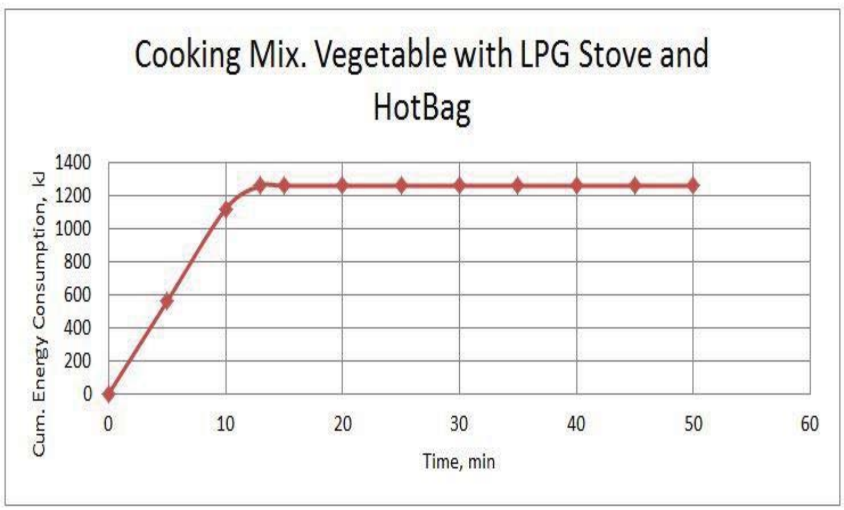

Fig.5.16 Energy consumption profile for cooking mix. Vegetables with LPG Stove and Hot Bag

The total energy consumption was 1745 kJ per kg of mixture yielding 45% energy savings. The cumulative energy consumption profile is shown in Fig.5.16. The savings of 1422 kJ leads to reduction of 85 grams CO_2 emission. The cooking with Hot Bag required additional 17 minutes as compared to cooking with LPG stove alone.

Table 5.1 shows the summary of the energy consumption for different tests, energy savings and CO_2 emission reduction.

Table 5.1: Energy consumption, energy savings and CO_2 emission reduction for food items

Item	Cooking method	Amount	Energy Needed Without Hot Bag, (kJ*)	Energy Needed With Hot Bag, (kJ*)	Savings (kJ*)	Savings, %	CO_2 savings, (gm)	Time when the pan is placed in the Hot Bag after boiling, (min)
Rice	Induction Cooker	1 kg + 2.5 lit	2052	1188	864	42%	123	0
	LPG Stove	1 kg + 2.5 lit	2563	1631	932	36%	56	
Potato	Induction Cooker	1 kg + 1.5 lit	2520	1476	1044	41%	149	10
	LPG Stove	1 kg + 1 lit	3915	2051	1864	48%	111	
Chicken	Induction Cooker	1 kg + 0.25 lit	2346	1819	527	22%	75	18
	LPG Stove	1 kg + 0.250 lit	2873	2115	758	26%	45	10
Vegetable	Induction Cooker	1 kg + 0.20 lit	2004	1106	898	45%	128	5
	LPG Stove	1 kg +0.20 lit	3167	1745	1422	45%	85	

*per kg of food item

Tasting of food items cooked:

The investigation team has tasted the food item cooked with and without the Hot Bag. The food cooked with Hot Bag showed better taste and texture as compared to the food cooked without Hot Bag. Fig.5.17 show the team is evaluating the taste and quality of the cooked food.

Fig.5.17 Investigation team tasting the cooked food items

6. Thermal Analysis

In cooking of food materials, the heat transfer is often in transient state, where the temperature changes over time. While the food material is kept inside Hot Bag, the heat transfer phenomena can be explained by Lumped Heat Capacity method. In this analysis, it is assumed that the internal thermal resistance can be neglected as compared to the external thermal resistance. The convective heat transfer from the Hot Bag can be expressed as

$$q = hA\,(T - T_{\infty}) = c\rho V \frac{dT}{dt} \qquad \text{(Eq. 6.1)}$$

Where,

q = Heat transfer rate, W

h = Convective heat transfer coefficient, W/m^2K

A = Surface area for convection, m^2

T = Temperature of the Hot Bag, ^0C

T_∞ = Room temperature, ^0C

V = Volume, m^3

c = Specific heat, kJ/kg-K

ρ = Density, kg/m^3

t = time.

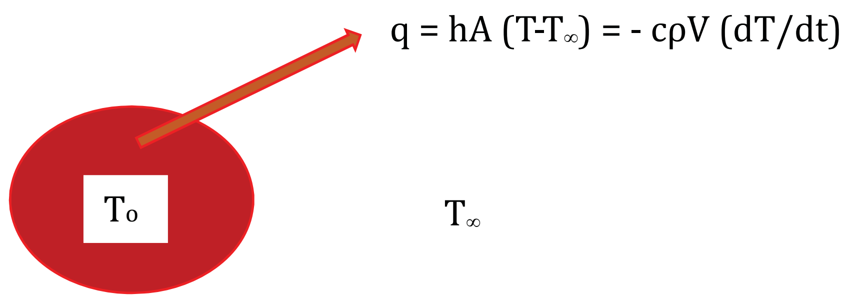

Fig. 6.1 Heat transfer phenomena from Hot Bag

When $T=T_0$ at t=0, the solution to Eq. 6.1 can be expressed as,

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-\left[\frac{hA}{\rho \mathrm{cV}}\right]\mathrm{t}} \qquad \text{(Eq. 6.2)}$$

$$\theta = e^{-mt} \qquad \text{(Eq.6.3)}$$

Here m is defined as, $m = \frac{hA}{\rho \mathrm{CV}} = \frac{1}{\frac{1}{hA}\rho cV}$, Where, $\frac{1}{hA}$ is the thermal resistenace and ρcV is the thermal capacitance.

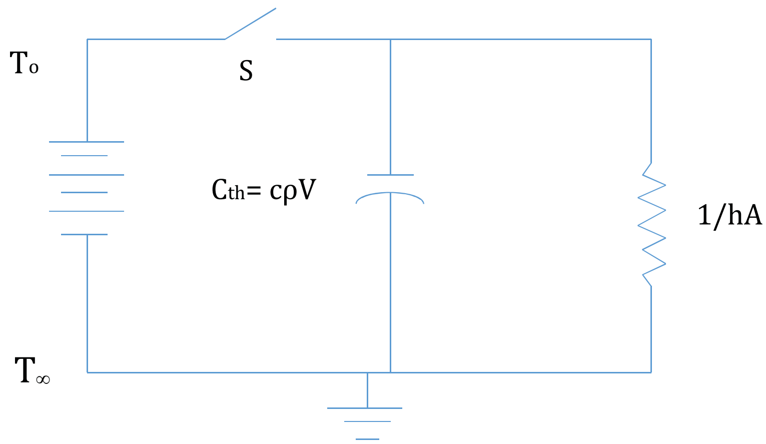

Fig. 6.2 Analogous electric circuit for heat transfer

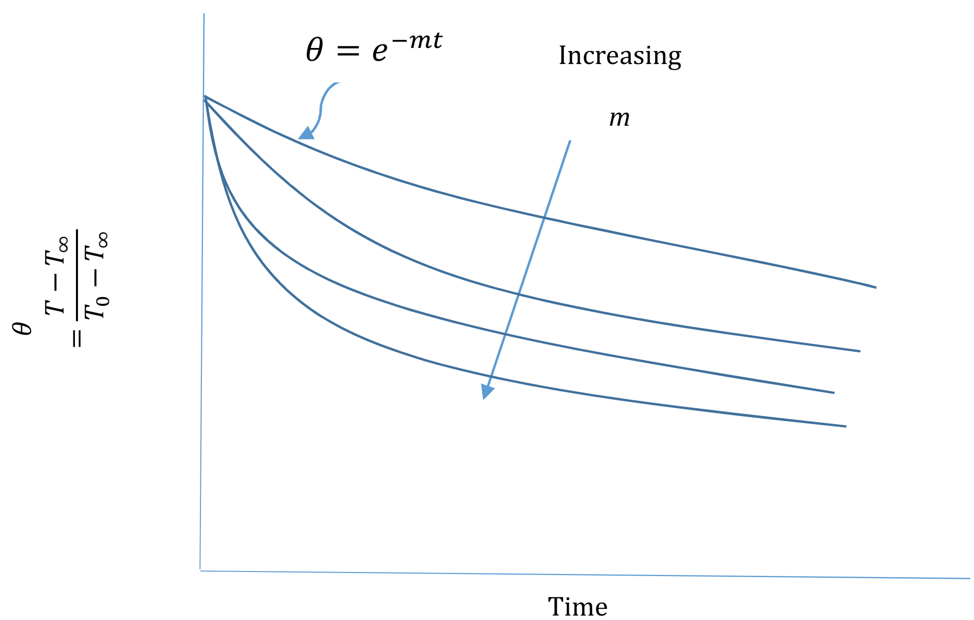

Fig. 6.3 Dimensionless temperature as a function of time

Fig.6.2 shows an analogous electrical circuit for the phenomena. It is noticed that the thermal capacity of the system is charged initially at potential T_0 by closing the switch S. When S is opened, the energy stored in the thermal capacitance is dissipated through the resistance *1/hA*.

A graph of the dimensionless temperature as a function of time can be seen in Fig.6.3.With time, the temperature decays exponentially. The time constant *m* determines the shape of the curve. Here m has the dimension of $(\text{time})^{-1}$. As the value of m increases, the curves become steeper which indicates that the value of m will cause the solid to respond faster to a change in ambient temperature. The definition of *m* reveals that increasing the surface area for a given volume and the heat transfer coefficient increases *m*.

For thermal analysis of the problem, three different pots have been used for heat retention test with the following capacity. Fig.6.4 shows the pans used.

Table 6.1: Capacity of the pans used

Pan	Capacity
Pan 1	5.5 liters
Pan 2	3 liters
Pan 3	2 liters

Fig.6.5 shows the experimental set up for the heat retention test without Hot Bag. The pan was covered all the time while it was kept in the open atmosphere.Fig.6.6 shows the set up for heat retention test with Hot Bag.

*Fig. 6.4*Pans used for thermal analysis

*Fig. 6.5*Heat retention test without Hot Bag

Fig.6.7 shows the modeling for heat retention test for 4 liters of water with Hot Bag whereas Fig.6.8 shows the modeling for heat retention test for the same quantity of water. The value of m has been estimated to be m = 0.00002 for test with Hot Bag and m = 0.0001 for test without Hot Bag after fitting with the experimental values.

The modeling of heat retention test for 2 liters water with and without Hot Bag is shown in Fig.6.9 With Hot Bag, the value of m has been fitted as m = 0.00005 and without Hot Bag, the value of time constant is, m = 0.00014.

In both tests, it is seen that the value of m is lower when the Hot Bag was used. As the time constant *m* determines the shape of the curve, it is seen that with the increased value of m while no Hot Bag was used, the curve is steeper which indicates that the content in the pan responds faster to a change in ambient temperature, loosing heat at a faster rate.

Fig. 6.6 Heat retention test using Hot Bag

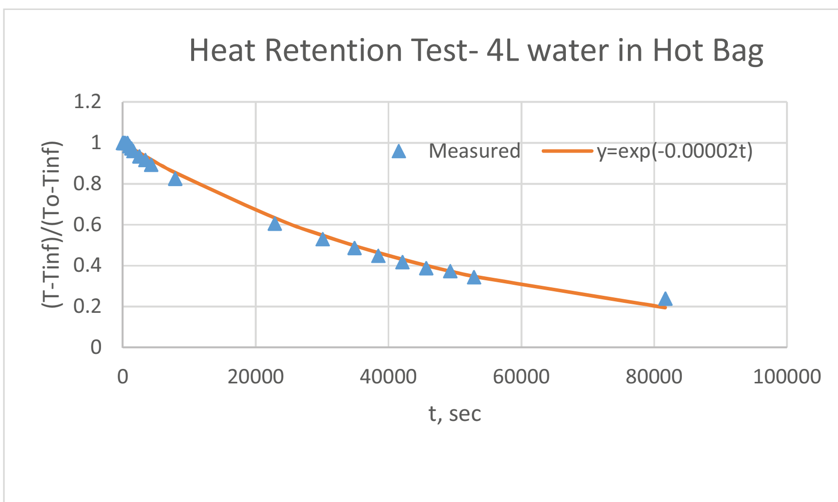

*Fig. 6.7*Heat retention test for 4 liters with Hot Bag

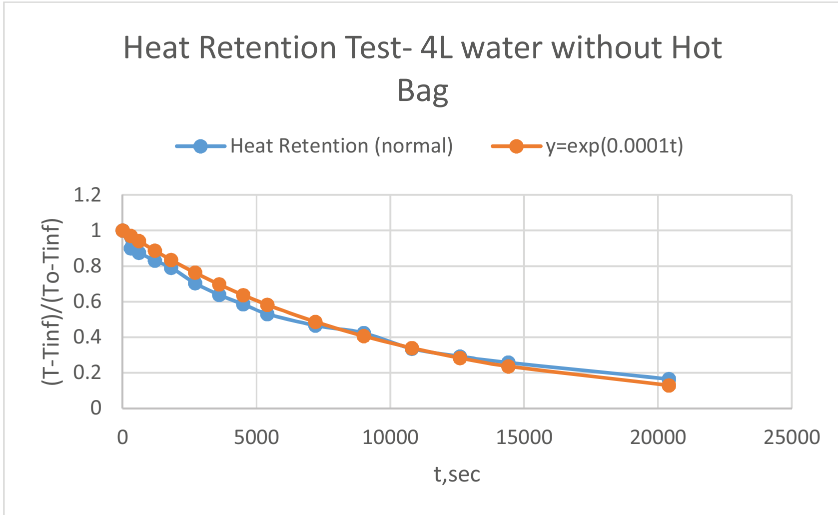

Fig. 6.8 Heat retention test for 4 liters without Hot Bag

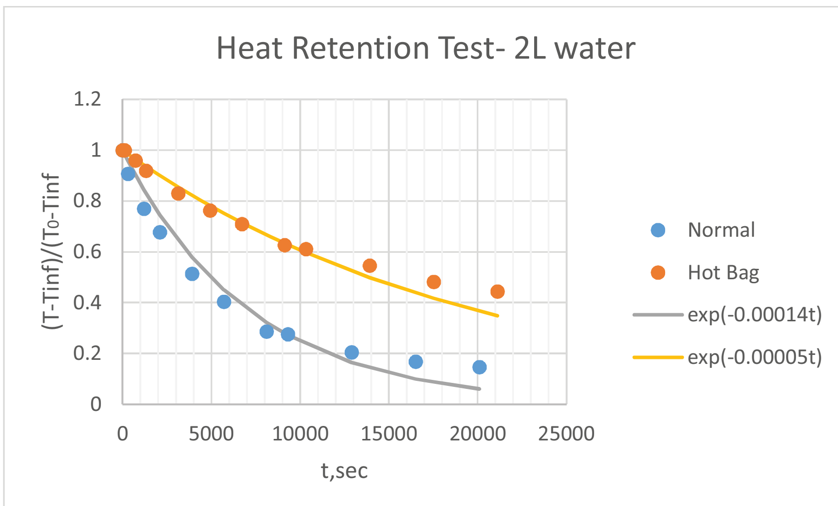

Fig. 6.9 Heat retention test for 2 liters water with and without Hot Bag

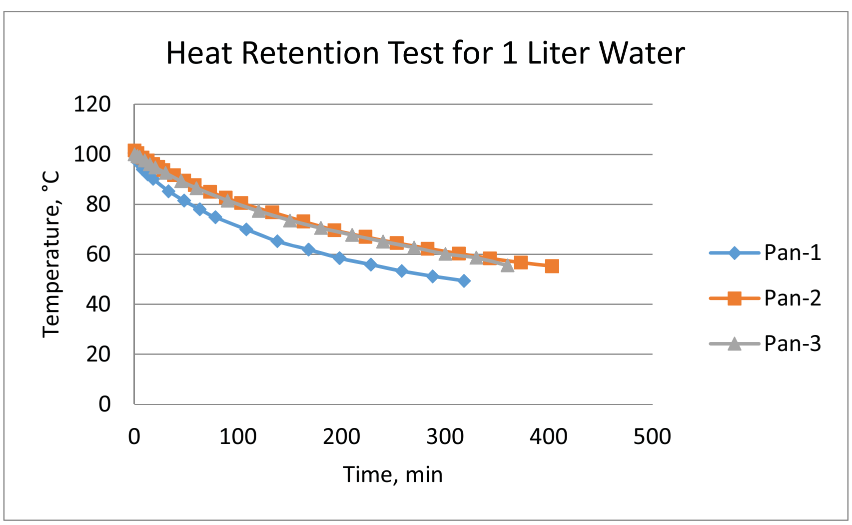

Fig. 6.10 Heat retention test for 1 liter water in three different pans

Heat retention test for 1 liter water has been carried out using all three pans and the temperature profile has been analyzed. Although, the same quantity of water have been used in all three pans, the temperature decreases at faster rate for Pan 1 as seen in Fig.6.10. Hot Bag with Pan-2 and Pan-3 show similar temperature profile while Hot Bag with Pan-1 shows heat loss at a faster rate. The modeling of heat transfer characteristics can be seen in Fig. 6.11.

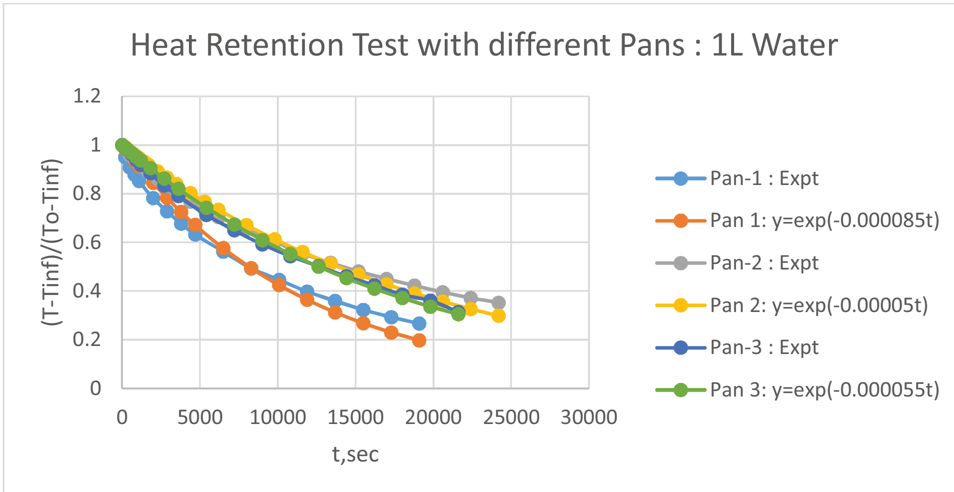

Fig. 6.11 Modeling for heat retention test for 1 liter water in three different pans

By modeling heat transfer, time constants for different pans have been found as 0.000085, 00005, 000055 for pan 1, pan 2 and pan 3, respectively. The value of time constant, m is very close for pan 2 and pan 3 whereas pan 3 shows higher time constant. This phenomenon can be explained with the surface area increase of the Hot Bag with Pan-1. From the definition of time constant, $= \frac{hA}{\rho CV}$, it can be seen that with the increase of surface area the value of m increases. As the value of m increases, the heat is lost at a faster rate.

Fig. 6.12 Measurement of peripheral length horizontally

Fig. 6.13 Measurement of peripheral length vertically

The peripheral length of the Hot Bag was measured horizontally and vertically for all three pans. Table 6.2 lists all the values which shows that the peripheral length of the Hot Bag with Pan 2 and Pan 3 is same whereas the peripheral length with Pan 1 is much higher. Surface area of the Hot Bag with Pan 1 ~ 0.55 m^2 and with Pan 2 & 3 ~ 0.5 m^2.

Table 6.2 Peripheral length measurement of the Hot Bag

Peripheral length	**Pan 1**	**Pan 2**	**Pan 3**
Measured horizontally	150.5 cm	141 cm	140 cm
Measured vertically	119.5 cm	114.5 cm	115.5 cm

Table 6.2 shows values of time constant m for different capacity. It is seen that as the water content decreases, the value of time constant increases. The value of time constant m has been found as 0.00002, 0.00005, 0.000085 for 4 liters, 2 Liters, 1 Liter water, respectively.

Table 6.3: Value of time constants for different capacity with Hot Bag

Test	***Value of time constant, m (1/sec)***
4L water	0.00002
2L water	0.00005
1L water	0.000085

Based on the findings from the tests, the performance of Hot Bag is better when large amount of food items is cooked and placed in the Hot Bag. Also, it is recommended to cook smaller amount of food items in smaller pans such that the food item fills at least 80% of the pan.

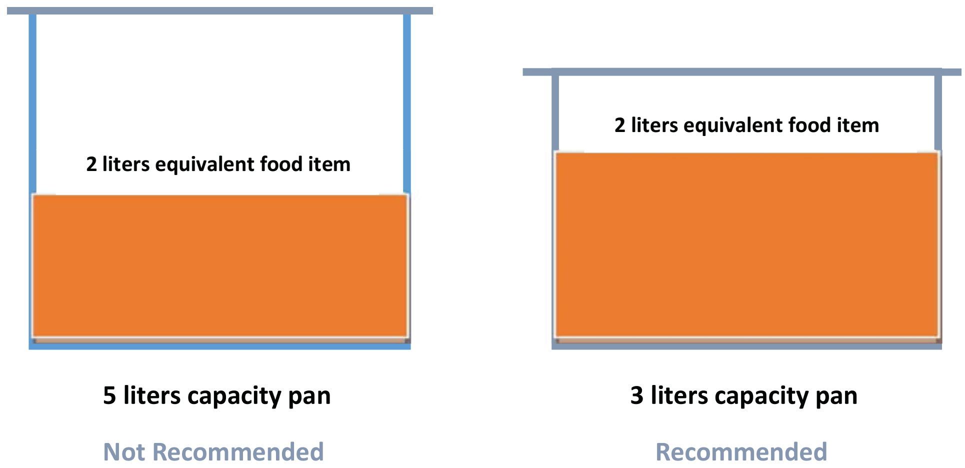

Fig. 6.14 Choosing the right size for the pan

7. Conclusions

The study comprehensively analyzed the performance of the Hot Bag for energy savings and CO_2 savings. Induction cooker and LPG stove have been used for cooking different food items. Rice, potato, chicken and mixed vegetable (potato, spinach stem and pointed gourd) have been cooked for measuring the energy consumed. The study reveals that the Hot Bag reduces a significant amount of energy consumption in both modes, i.e. Induction Cooker and LPG Stove. The tests showed a range of energy savings from 22%-48% for different food items. The Hot Bag will also help reducing the impact on Carbon footprint. The CO_2 emission can be reduced 45-189 grams per kg of food items for different food items. The study also presented the results of heat retention tests for different quantity of water and the thermal behavior of the system have been explained. The thermal analysis of the heat transfer from the Hot Bag have been analyzed. The food cooked during the tests have been tasted and it has been found that the texture of the food items cooked using Hot Bag was better.

8. Recommendation

For further work, the following recommendations are suggested.

- Preparation of technical standard and testing procedures for performance evaluation of Hot Bags manufactured.
- Further testing by cooking different food items with and without Hot Bag.
- Performance evaluation of the Hot Bag by cooking food items using Kerosene stove and Improved Cook Stove (Biomass Stove).