# Design and Manufacturing of an Institutional Mirt Stove with Waste Heat Recovery System

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**Abstract.** In the present study the performance of an institutional mirt stove with waste heat recovery system was designed and investigated. The waste heat recovery system is designed to utilize the heat of waste gases of institutional mirt stove as a source of energy for the purpose of injera baking on the secondary mitad. Beside to this main design improvement, adding fuel supporting structure like grates to allow ash falls through it and air to be entered under-neath the fuel and ash collection boxes and ash removal openings below each grate were provided. The performance of the improved stove was compared with that of the existing institutional mirt stove through controlled cooking test method. The result shows that the improved stove saved up to 16% fuel wood and 14% cooking time as compared to the existing institutional mirt stove. During the test a temperature of about 216.3 °C on the surface of a secondary mitad is achieved and injera is baked on this surface. Finally, the techno-economic analysis shows that the improved institutional mirt stove with waste heat recovery for injera baking system is economically feasible.

**Keywords:** Improved institutional mirt stove · Waste heat recovery system · Specific fuel consumption · Total cooking time

## 1 Introduction

Around 90% of the institutional kitchens in Ethiopia depend on biomass for cooking and baking, for which traditional stoves are often used [1]. The three-stone fireplace and many of institutions use pots or mitads which are inbuilt with cement, clay or bricks. However, both of these cooking or baking technologies are thermally as well as environmentally inefficient and hence create higher amount of waste heat and problems for users.

In the mid-1990s the World Bank assisted Cooking Efficiency Improvement and New Fuels Marketing Project implemented by the Ministry of Mines and Energy adopted the improved household "injera" (a traditional flat-bread) baking stove, also known as mirt stove [2]. In the mid-2010s, Energising Development (EnDev) implemented "Efficient stoves for bakeries in Ethiopia project" introduced a different version of modified mirt stoves. Small holding injera bakers use a single stove for their daily baking. Others, such as cooperative micro-enterprises use different versions of modified


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mirt stoves, which cluster two or more stoves so that they use a single chimney, with additional parts for collecting the smoke from the individual stoves, it is called Institutional mirt stove [3, 4].

Even if institutional mirt stove is among the improved designed stove, it has some drawbacks, like high amount of waste heat by the flue gas, difficulty of ash removing system and the radiative heat coming off the chimney cause the bakeries inconvenience, this is because, an experimental study [5] showed, the four-tipped star shape structure for chimney supporting is cracked in the areas where it received high temperature of exhaust flue gasses.

Baking is an essential way of preparing food from raw staple crops. Many different varieties of bread and pastry have emerged from regional traditions around the world. Baking involves very high temperatures (around 180–220 °C) and therefore requires a larger amount of thermal energy input than is required for cooking. The availability and price of fuel is therefore crucial for bakeries, as it constitutes their largest operating cost [6].

Effect of waste heat recovery on different types of biomass stoves was discussed and its impact on efficiency enhancement was determined [7].

Improving stoves is an effective way of improving the environment and serving communities.

Recent field tests have shown that improvements in air control and firebox design is currently the most effective and socially acceptable stove design modification. Waste heat utilization from flue gas is one option to increase the heat transfer efficiency of a stove [8].

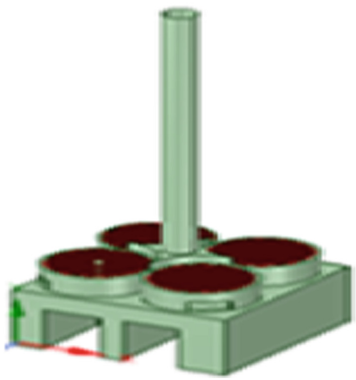
Thus to reduce the problems associated with using institutional mirt stove, in this work institutional mirt stove with waste heat recovery system, which uses waste heat from the exhaust flue gases of institutional mirt stove as the source of energy for secondary injera baking oven is expected to include the following benefits: Saves money and time in acquiring fuel, reduced fuelwood consumption and total baking time.

This work focused on utilizing waste heat as a source of energy for injera baking oven (as recovery device). Because baking injera consumes the largest share of wood fuel and time for bakeries in the institution.

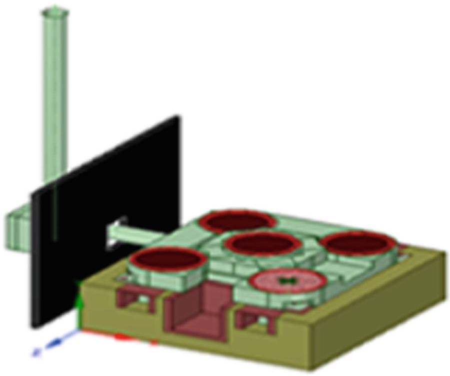
The main objective of this work is to design, manufacture an experimental prototype improved institutional mirt stove with waste heat recovery system that enhances heat transfer from exhaust flue gases to the secondary injera baking oven and to compare the performance of the improved institutional mirt stove with waste heat recovery system and the traditional stove are compared through test.

## 2 Materials and Methods

The commonly used traditional institutional mirt stove does not contain any features that will help in the effectively usage of energy and conversion process as efficient is shown in Fig. 1(a). The proposed model of improved institutional mirt stove with waste heat recovery system design is shown in Fig. 1(b).



**(a).** Model of stoves Existing institutional mirt stove



**(b).** Model of stoves Improved institutional mirt with waste heat recovery system.

**Fig. 1.** **(a).** Model of stoves Existing institutional mirt stove **(b).** Model of stoves Improved institutional mirt with waste heat recovery system.

The main materials that are required for the work are clay plate (mitad), fired brick, cement, construction hollow block, iron rod, red ash and sheet metal. The materials selection is based on local availability and cost affordability.

The main components of the improved institutional mirt stove considered in this model are:-

**Mirt Stoves.** There are four independent mirt stoves. Each stove has four parts fit to make a cylindrically shaped enclosure (about 660 mm in diameter and 240 mm high). The cylindrical enclosure of each mirt stoves has two openings. The first opening, which has a semi-elliptic shape, is at the lower front of the enclosure and is about 240 mm wide and 110 mm high. It is used as fuel and air inlet. The second is at the rear up, where the enclosure is fitted with the inlet duct of exhaust flue gas to the flue chamber of the secondary injera baking mitad, as smoke outlet. This opening is of rectangular cross section and has a dimension of 190 mm width and 70 mm height.

**Structure:** The stoves supporting structure was designed to have 2290 mm × 2290 mm overall dimensions in ordered to support four independent mirt stoves and secondary injera baking assembly of 660 mm diameter which located at the center of the top platform. The height of the structure was designed to be 700 mm.

**Mitad:** It is a flat and circular pan commonly about 500 to 600 mm in diameter and traditionally used over large clay hearths to bake injera. The secondary baking mitad is considered to be 20 mm thick and 580 mm in diameter, which is equivalent to the size of primary baking mitads and also available in the local market.

**Flue Chamber:** The flue chamber is basically cylindrically shaped enclosure whose axis is vertically oriented. The cylindrical enclosure is made when four identical mating pieces of walls match together to form a cylindrically shaped enclosure. Its outer diameter was designed to be 660 mm and 60 mm wall thickness and 140 mm high.

The top part of the walls of the enclosure was provided 20 mm slotted rim for resting the secondary mitad.

**Ducts:** Four flue gases inlet ducts between each mirt stoves and flue chamber were constructed by maintaining constant cross sectional area of smoke outlets of each mirt stoves 190 mm by 70 mm and.one flue gases outlet duct opening was built with cross sectional area of 180 mm by 180 mm, that was considered to be equivalent to the chimney internal area, at the center of the housing of the flue chamber. The height of the outlet duct inside the flue chamber was considered to be 100 mm.

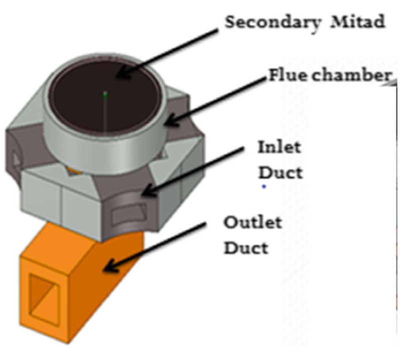
**Grates:** Four rectangular plates, made of 10 mm dia. MS iron rods were designed for holding fuel wood and allowing ash to be fall through to ash collector boxes. Each rod was welded 10 mm apart from others. The overall dimensions of each grate were considered to be 360 mm by 360 mm.

**Ash Collector Boxes and Ash Outlets:** Ash collector boxes and ash removal openings have been introduced below each grate. The size of each ash collector is 380 mm × 380 mm and 250 mm height. Each ash outlet ports of size 200 mm × 200 mm is used to dispose the ash from the ash collector box of each independent mirt stoves.

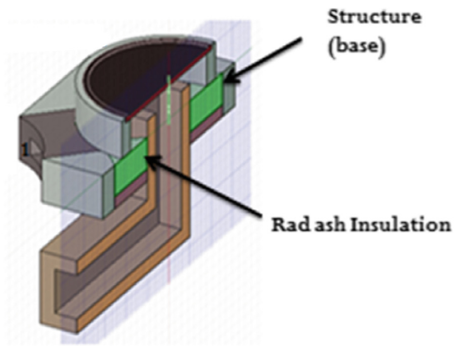
**Chimney:** The chimney, made of sheet metal of 1.5 mm thickness, has circular cross section about 200 mm in diameter and 2 m in height which is equivalent to the existing institutional mirt stove chimney size.

## 2.1 Model of Waste Heat Recovery System Components

The main components of the waste heat recovery system for injera baking considered in this model are as shown in the Fig. 2 below.




**(a)** 3D model of waste heat recovery System




**(b)** Cross sectional view of 3D model of waste heat recovery system

**Fig. 2.** **(a)** 3D model of waste heat recovery System **(b)** Cross sectional view of 3D model of waste heat recovery system

## 2.2 Working Principle of the Experimental Model

The working principle of the experimental model as can be observed from Fig. 3; Fuel wood was burnt in each independent mirt stove combustion chambers over their grates and baking on each primary mitads is done by direct flame produced from fuelwood, while baking on the secondary mitad is done by the heat of hot exhaust flue gases coming out from each independent mirt stoves.

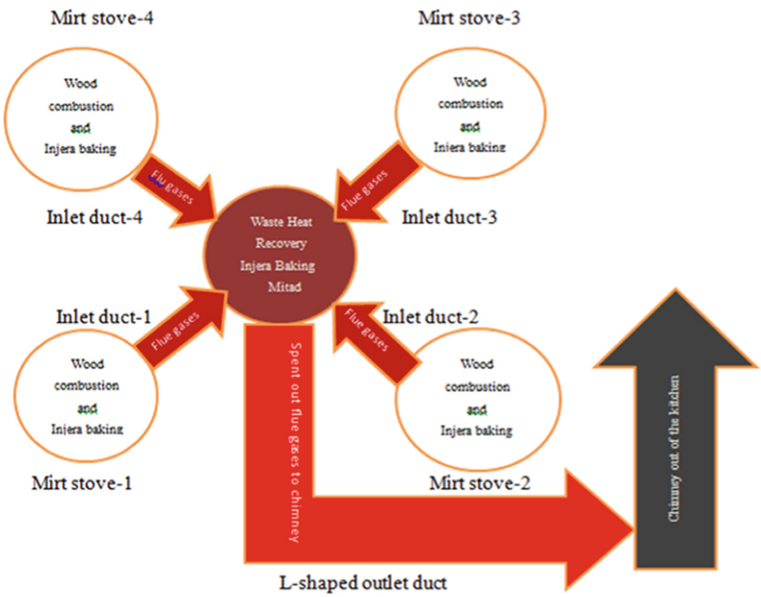



**Fig. 3.** Working principles and flue gases passage of the experimental model.

The bottom of the secondary baking pan was exposed to the hot flue gases. Thus heat was transferred from the hot flue gases to the baking pan by convection and conduction heat transfer mechanisms. After giving the energy to the baking mitad the spent flue gases are led out of the kitchen through the L- shape rectangular duct to chimney and finally to the environment through chimney stack.

## 2.3 Manufacturing of Stove Model

As per the design of improved Institutional mirt stove model shown in Fig. 4. for manufacturing the stove Bahir Dar University (BIT Campus) injera baking kitchen and the Research workshop is sufficient enough.

**Fig. 4.** Improved institutional mirt stove prototype

## 2.4 Performance Testing of Improved Stove

The CCT is a standard cooking test which is designed for field test that measures the performance of improved stove relative to the common or traditional stoves when cook prepares a local meal. It analyzes how the improved stove performs to save fuel and time compared to common or traditional cooking methods [9].

Controlled cooking test (CCT) [9], according to the protocol of the University of California-Berkeley (UCB), is employed here in the test. The corresponding data entry and calculation spreadsheets were utilized. The goal of such test is basically to get the value of specific fuel consumption of a stove, which is the amount of fuel used to produce a unit amount of food expressed in units of g/kg. This is the main parameter used for comparing the improved stove against the baseline stove. The total time of producing a certain amount of food is also a measure of stove performance. Therefore total time of production of injera was recorded for each of the baking sessions.

During the test, the amount of batter, the weight of the fuel used, the elapsed time, the weight of charcoal and container, the weight of a cooking pot, total weight of cooked food, the total number of injera baked, the equivalent dry wood consumed, moisture content of the wood, air temperature of the day and the surface temperature of the secondary mitad were recorded.

Instruments used for performing CCT are balance; stopwatch; thermometer; a handheld moisture tester.

### 2.5 Economic Analysis

The benefit-cost and payback period analyses were used to determine the economic acceptability of the improved stove.

Payback period is the number of years required to recover the initial investment in full with the help of the stream of annual cash flows generated by the project. The cash flow is assumed to be constant throughout their useful life time of the improved stove. Payback period can be calculated using Eq. 1 [10].

$$Payback = \frac{Annual\,Cash\,flow}{Initial\,Investment} \tag{1}$$

Benefit-cost Ratio: is the ratio of the net benefits to costs of the project. If the benefit-cost ratio is greater than or equal to one, accept the project as economically justified for the estimates and discount rate applied. The conventional benefit/cost ratio is calculated by Eq. 2 [10].

$$Benefit/cost = \frac{present\,Worth\,of\,Cost}{Present\,Worth\,of\,Benefit} \tag{2}$$

The cost of the project is in present worth. The benefits gain by the improved stove throughout their useful life time is future worth and should be converted into present worth by Eq. 3 [10].

$$P = F \times (1+i)^{-n} \tag{3}$$

Where: p is the Present worth; F is the future worth; i-is interest rate in percent, and n is the number of useful life years of the stove.

## 3 Results and Discussion

### 3.1 Equivalent Dry Wood Consume

A comparison of institutional mirt stove and improved stove has been made with their respective average equivalent dry wood consumed during the test. The results obtained are presented in Fig. 5.

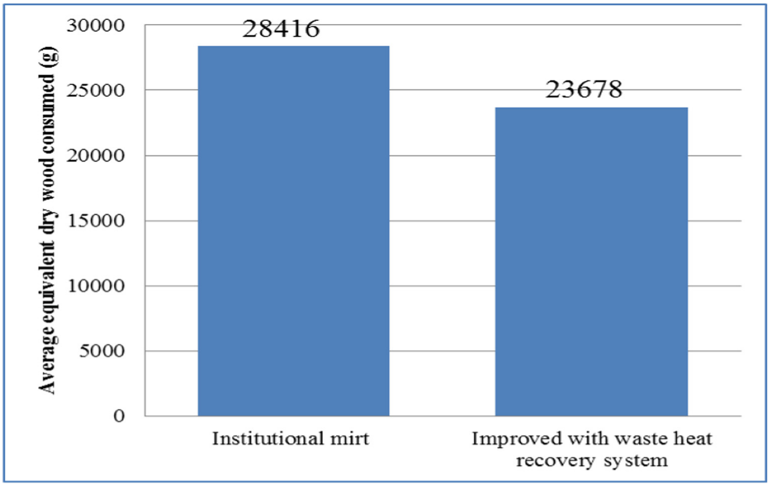



**Fig. 5.** Equivalent dry wood consumed by each stove.

As shown in Fig. 5, the amount of fuel wood to bake 117 injera was relatively low for improved stove as compared to institutional mirt stove. Institutional mirt stove registered a higher average fuel wood consumption, which is 28416 g and improved stove with 23678 g of fuel wood consumption. The equivalent dry fuel consumed per injera was 202 g with improved stove and 243 g with Institutional mirt stove. Fuel consumption is reduced by 41 g per injera as a result of using improved stove. This indicates that improved stove has fuel saving potential over institutional mirt stove by 16.9%.

## 3.2 Specific Fuel Consumption

As it can be seen in Fig. 6, Institutional mirt stove has the higher average specific fuel consumption of 625 g/kg. Improved stove was found 525 g/kg average specific fuel consumption. The direct output of CCT version 2.0 software results showed that there is a significant difference between the stoves at 95% confidence interval. Institutional mirt stove and improved stove was significant with percentage difference of 16%. This suggests that improved stove was 16% more efficient or saved up to 16% of the fuel wood per kg of Injera.

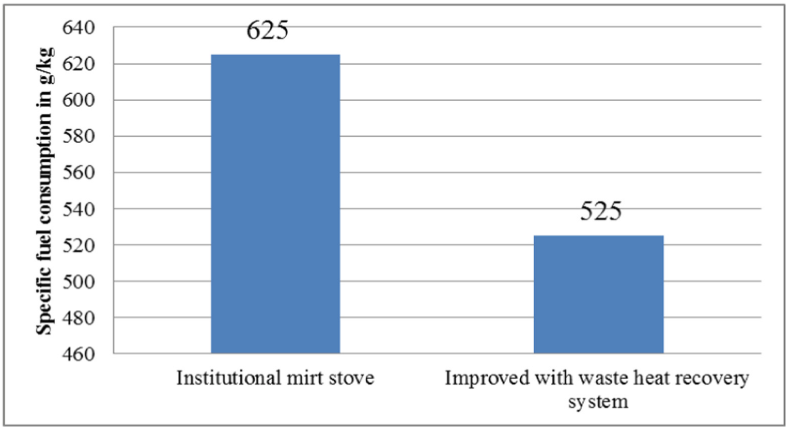



**Fig. 6.** Specific fuel consumption of the two stoves

## 3.3 Cooking Time

From the result shown in Fig. 7, it was observed that improved stove was found to have low mean cooking time. Institutional mirt stove had an average cooking time of 111 min as compared to 96 min of the improved stove. The difference in cooking time between stoves was statically significant at 95% confidence interval. This indicated that improved stove is saved up to 14% cooking time. Therefore, the improved stove gives lower cooking time than institutional mirt stove.

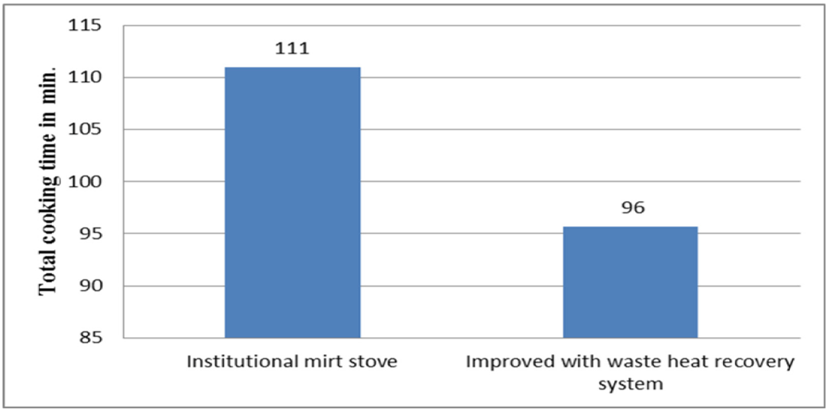



**Fig. 7.** Average cooking time of stoves

### 3.4 Baking of Injera on Secondary Mitad

The activities during injera baking on the secondary mitad were shown in the Fig. 8.

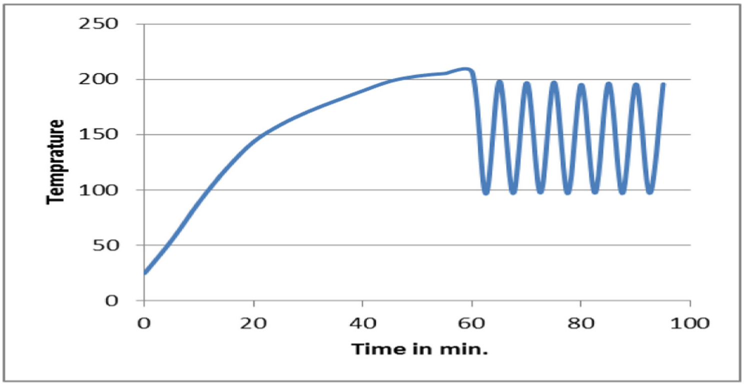



**Fig. 8.** Temperatures of secondary baking pan surface during baking cycles

### 3.5 Techno-Economic Evaluation of Improved Institutional Mirt Stove

The amount of fuel wood saved during baking process using the improved stove was the benefits gain from the project. The initial investment cost of the improved stove is taken as costs of the project. Considering the durability of materials used to manufacture the stove it was estimated to have a life span of 7 years.

The Initial investment of improved stove was the sum of raw material cost, machining cost and labor cost. The cost of manufacturing of the improved stove is found to be 10,496.63 ETB.

The amount of wood fuel consumption per injera with institutional mirt stove was obtained to be 0.243 kg per injera while it was 0.202 kg for an improved stove. The difference in the consumed fuel wood was about 0.041 kg per injera. From the survey conducted, the price of fuel wood at Bahir Dar town was found 3.21 ETB per kg and the daily average number of injera baked on one institutional mirt stove is 1200. The annual fuel wood saved per one stove is 17,958 kg. Hence the bakers save 57,645 birr per year and the cost saved through the useful life time (7 years) was ETB 403,515.26.

The benefit gain from improved stove was the cost saved from fuel wood purchase. Therefore, the benefit gain from improved stove was 403,515.26 ETB. This value was future worth and should be converted to present worth by the current saving interest of the country which is 5%. Thus, the present worth of benefit was ETB 316,165.55. Therefore, the benefit/cost ratio of improved stove was 30.12. This indicates that the project was economically feasible.

The annual cash flow for improved stove was the cost of fuel wood saved from purchase per year which is obtained ETB 57645.18 per year. Therefore, the payback period of improved stove was found 0.18 year or 2.2 months only.

## 4 Conclusions

A country's socio-economy cannot show progressive development unless energy is explored, developed, distributed and utilized in an efficient and appropriate way. Therefore, this work introduced the utilization of waste heat from exhaust flue gases of institutional mirt stove and recovered for the purpose of injera baking process in order to improve the performance of the stove. In this experimental study a more efficient and improved institutional mirt stove with waste heat recovery system was de-signed, manufactured and the performance of improved institutional mirt stove was compared with that of traditional institutional mirt stove through controlled cooking test method.

Based on the results obtained during the experimentation following conclusions could be drawn:

The surface temperature of the secondary baking mitad in the experiment was measured and about 216.3 °C was registered; so that it was possible to bake nice injera. The baking cycle took about five minutes. It could be inferred that it was possible to bake injera using the heat of exhaust flue gases from institutional mirt stove as energy source.

The controlled cooking test of the improved stove revealed that the time required for baking 117 injera was 15 min and 4.797 kg less fuel than traditional institutional mirt stove thus 14% time and 16% fuel saved in the improved stove.

The kitchen environment was free from radiative heat coming out of the chimney. The stove was easy to operate (bake) on it and also to remove ash.

The estimated cost of the system was ETB 10,496.63 with 0.18 year payback period and benefit cost ratio of 30.12. It could be inferred that the improved stove is technically as well as economically feasible in the present energy context.

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