DEVELOPMENT AND EVALUATION OF A BACK-UP STOVE FOR SOLAR "KILISHI" DRYER

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ABSTRACT

The back-up stove is used as a back-up heat source for solar "Kilishi" Dryers in the night or when there is low solar radiation. The stove is made up of the following parts: Burner, Ash-tray, Heat-exchanger and Chimney. Hot air from the burner entered the heat-exchanger through one end of the shell side and leave at the other end to the chimney. Fresh air is blown into the heat-exchanger through one end of the tube side and leave at the other end to the drying chamber. Each component of the stove was designed using appropriate design equation. 2 mm thick galvanizes steel sheet was used for the construction. The stove was tested and the following parameters were measured and recorded: The relative humidity and temperature of air at the inlet, inside and outlet of the drying chamber at 1 hour interval. The meat was weighted at 2 hours interval from which the moisture content of the meat was calculated. These results were used to evaluate the performance of the stove and the average efficiency was found to be 8.8% and the drying time was eight hours.

SIGNIFICANCE: In this research a stove was developed, and it provides a heat energy as a back- up to Solar "Kilishi" dryers, which can be used during rainy season, in the night and when there is low solar radiation. Therefore, "Kilishi" can be dried anytime throughout the year.

KEYWORDS: Mix-powder solution, "Kilishi", Chimney, Heat-exchanger, burner and ash-tray

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NOMENCLATURE

$M_w = Mass\ of\ water\ removed (kg)$; $M_c = Mass\ of\ charcoal\ (kg)$; $A = Area\ (m^2)$;

$C.V._c = Lower\ calorific\ value\ of\ charcoal (J/kg)$; $m_c = Mass\ flowrate\ of\ cold\ fluid (kg/s)$;

$h_{fg} = Latent\ heat\ of\ vaporisation\ of\ water (kJ/kg)$; $Q_c = Heat\ gain\ by\ cold\ fluid (kJ)$;

$cp_c = Specific\ heat\ capacity\ of\ cold\ fluid (J/kgs°C)$; $T_{c1} = Cold\ fluid\ inlet\ temperature (°C)$;

$T_{c2} = Cold\ fluid\ outlet\ temperature (°C)$; $Q_h = Heat\ loss\ by\ hot\ fluid (kJ)$;

$m_h = mass\ flowrate\ of\ hot\ fluid (kg/s)$; $cp_h = Specific\ heat\ capacity\ of\ hot\ fluid (J/kgs°C)$;

$T_{hi} = Hot\ fluid\ inlet\ temperature (°C)$; $T_{h2} = Hot\ fluid\ outlet\ temperature (°C)$;

$U_o = Overall\ heat - transfer\ coefficient (W/m^2°C)$.

1.0 INTRODUCTION

The back-up charcoal stove consists of the burner, ash-tray, shell and tube heat-exchanger and chimney. The burner is pyramidal and it is connected to the heat-exchanger for hot air delivery. Grates at the bottom of the burner allows for air circulation. The ash-tray is used to collect ashes. The heat-exchanger is shell and tube type. The chimney has rectangular cross-section, it is connected to one end of the shell side of the heat-exchanger. A rectangular hole at the upper end of the chimney serves as an exit for flue gases from the burner. The back-up stove operates as follows: a fan located at the ash- tray door blows air through the grates at bottom of the burner which forced hot air to pass through a pipe located on the slanted side of the burner into the shell side of the heat-exchanger. In the heat-exchanger, heat is exchanged between the hot air in the shell and ambient air in the tube. The ambient air gain heat and flow to the drying chamber for meat drying.

Improved charcoal stoves (ICS) development originated from traditional charcoal stove which was introduced by Indian traders since 1900's in Tanzania. "Sazawa" is a charcoal stove developed by Tanzania Traditional Energy Development and Environmental Organization (TaTEDO), it is made of metallic part called cladding, two clay liners and binding materials (mainly mixture of cement, water and vermiculate). Binding materials are used to bind together the two clay liners and the cladding. Other parts of "Sazawa" include a bent round bar that acts as pot rests. Legs handles, metallic belt, ashes collector and door for primary air inlet (Pasambili, 2003).

"Toyola" cooking stove is another type of charcoal stove which was developed to improve fuel efficiency by 50% in comparison with traditional coal pot. This technology is minimizing the rate of deforestation and carbon emissions (Osei, 2010). A wood charcoal gasifier was developed by PT Minang Jor Danindo Approtech in 2008. The gasifier stove consists of the following major units: Gasifier reactor assembly, Fan assembly and Burner assembly (Belonto, 2008). The reactor assembly is where the fuel is gasified by supplying limited amount of air during the combustion of fuel. Rice husk ash and cement mixture is used to insulate the reactor. A stainless steel perforated sheet is used to hold the fuel. The stove is provided with a sliding-type door for ease of removal of ashes after each operation. The air needed to gasify the fuel is supplied by a 6 cm diameter, 12 volt electric blower. The aim of this paper is to develop and evaluate the performance of a back-up stove for solar "Kilishi" dryer and the objective is to be able to dry "Kilishi" in the night, during rainy season and Hammatan, or when there is low solar radiation.

2.0 DESIGN, CONSTRUCTION AND TESTING

2.1 Design of system components

2.1.1 Design of Burner and ash-tray: The burner is where the combustion of the charcoal takes place. The size of the burner was designed to carry the amount of charcoal required for drying process. A door at the top of the burner is used for charging charcoal as required (Pesambili *et al.*, 2003). The amount of heat supplied by the charcoal is given by:

$$Q_{in} = M_c C.V_c \quad \ldots \quad (1)$$

The quantity of heat loss to the surrounding is:

$$Q_{loss} = UA\Delta T \quad \ldots \quad (2)$$

Then amount of heat transferred to the air moving into the heat-exchanger is:

$$Q_s = Q_{in} - Q_{loss} \quad \ldots\ldots \quad (3)$$

The quantity of heat required for drying is (Brennan, 1981):

$$Q = M_w h_{fg} \quad \ldots \quad .(4)$$

A DC fan located at the ash-tray door blows air into the burner. The switching and speed control of the DC fan is done by an electric temperature controller.

2.1.2 Design of Heat-exchanger: A shell and tube heat-exchanger was designed with hot air from burner passing through the shell and ambient air passing through the tube to the drying chamber. Heat gain by ambient air is given by (Ozisik, 1985):

$$Q_c = M_h cp_c (T_{c1} - T_{c2}) \quad \ldots \quad (5)$$

Mass flow rate of hot air from the burner through the shell side of the heat exchanger was obtained from (Rajput, 2006):

$$Q_h = M_h cp_h (T_{h1} - T_{h2}) \quad \ldots \quad (6)$$

The required length of the heat-exchanger pipe was obtained from (Rajput, 2006)

$$Q_c = U_o A \theta_m \quad \ldots \quad (7)$$

Where $A = \pi d_i l$ … (7b)

Total heat transferred from hot air in the shell side to the ambient air in the tube side is given by:

$$Q_T = \varepsilon C_{min} (T_{h-in} - T_{c-in}) \quad \ldots. \quad (8)$$

The actual air exit temperature through the chimney is;

$$T_{h-out} = T_{h-in} - \frac{Q_T}{C_h} \quad \ldots \quad .(9)$$

The actual air temperature blown into the drying chamber is;

$$T_{c-out} = T_{c-in} + \frac{Q_T}{C_c} \quad \ldots \quad (10)$$

The insulation material used for the heat-exchanger is fiber-glass.

2.1.3 Design of Chimney: The purpose of the chimney here is to provide draught. Due to height difference, pressure at the bottom of the chimney p_1 is greater than pressure at the top of the chimney P_2
(P_1 = atmospheric pressure + pressure due to hot column, while P_2 = atmospheric pressure + pressure due to cold column (Ballaney, 2003). The draught h and actual height H are respectively given by the expressions:

$$h = 353gH\left(\frac{1}{T} - \left(\frac{m+1}{m}\right)\frac{1}{T}\right)\ldots \quad (11)$$

$$H' = H\left(\frac{m}{m+1} \times \frac{T}{T_1} - 1\right) \quad \ldots \quad (12)$$

2.1.4 Stove Efficiency: The back-up stove efficiency,

$$\eta_b = \frac{WL}{m_b CV + P_f} \quad \ldots \quad (13)$$

Percentage of moisture removed from the "Kilishi" is given by;

$$PMR = \frac{g_1 - g_2}{g1} \times 100 \quad \ldots \quad (14)$$

2.2 Construction and Assembly

2.2.1 Construction of Burner and ash-tray: The material used for the construction of the burner and ash-tray (Figure 1) is 2 mm thick galvanized steel sheet. For the burner, four trapezoidal sheets were cut. The height of each sheet is 156 mm. The lengths of the parallel sides are 200 mm and 100 mm. The slanted sides of the sheet were joined to form a truncated pyramid. The inner sides and the top of the pyramid were lined with 5 mm thick layer of an insulator made from a mixture of clay and cement. Grates were drilled on the bottom plate for ventilation and ashes collection.
Ash-tray was constructed by cutting three pieces of 0.104 m x 0.3129 m and one piece 0.21 m x 0.1 m the three pieces were joined to form an open box and the 0.21 m x 0.1 m sheet was joined to the bottom of the box and the top was joined to the bottom of the burner.

2.2.2 Construction of the Heat-exchanger: The material used for the construction of the heat-exchanger (Figure 2) is 2 mm thick galvanized steel sheet. The shell and tubes were constructed separately, and then assembled together. The shell was made up of internal part and external part. The internal part was made by folding 400 mm x 320 mm sheet along 320 mm side and joint to form open cylinder. The ends of the cylinder were covered with 100 mm diameter sheet having 40 mm diameter hole at its center.
The external part was made by folding and joining 600 mm x 942 mm sheet along 942 mm side to form an open cylinder. The internal part was centrally fixed inside the external part and the space between them was filled with fiber glass. The ends of the external part were covered with 300 mm diameter sheet having 40 mm diameter hole on its center.
The tubes were made from copper pipe of 12.7 mm external diameter. Three copper pipes each 0.3 m long were fixed axially on a 40 mm diameter plates from both ends. The plates were fixed in the central hole of the internal part.

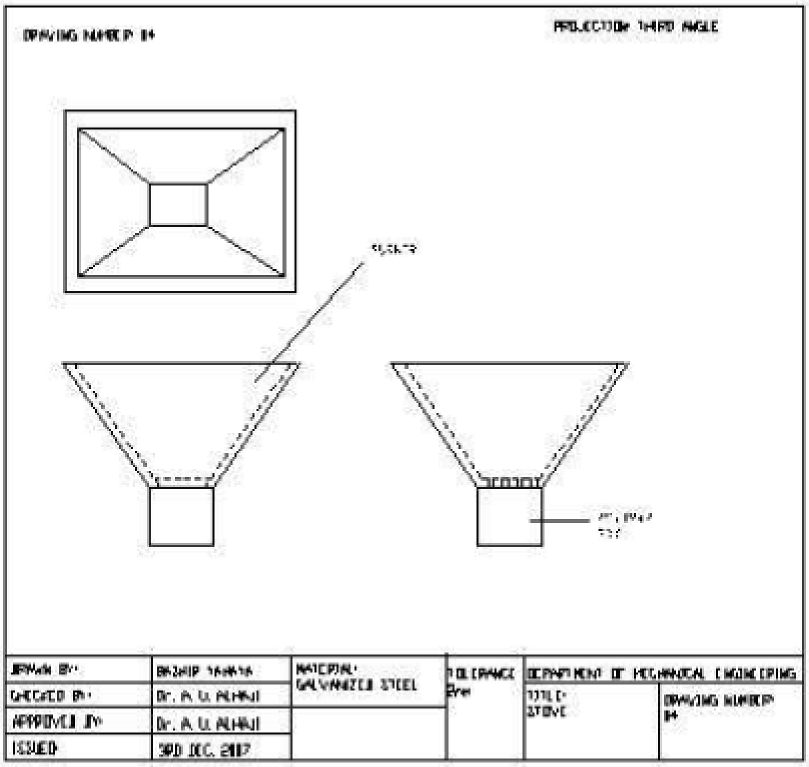

Figure 1: Burner and Ash-tray

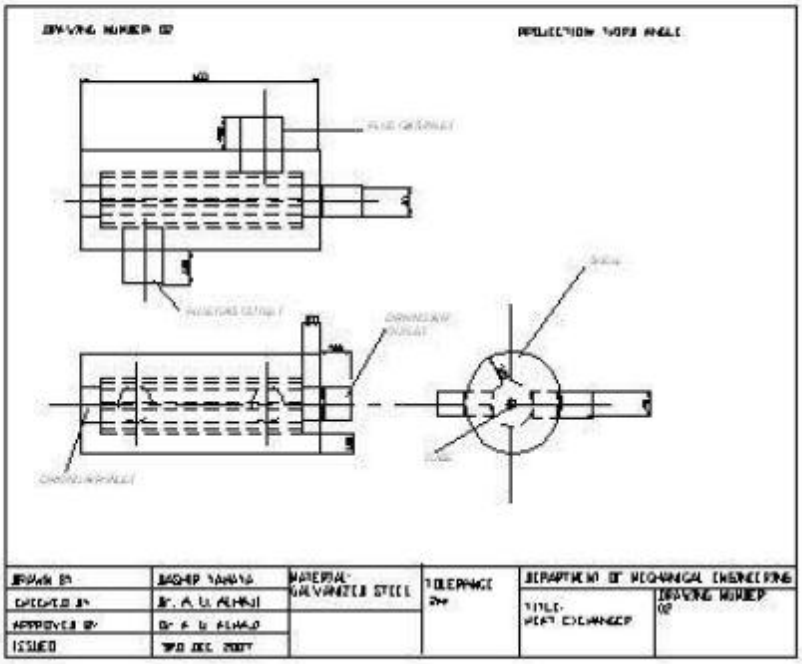

Figure 2: Heat exchanger

2.2.3 Construction of chimney: Galvanized steel sheet (2 mm) was used for the construction of the chimney (Figure 3). A sheet with dimension 600 mm x 400 mm was cut and bent into square cross-section of sides 100 mm. A square hole of 100 mm sides was cut the top of ones side and a circular hole of 40 mm diameter was cut at the bottom of the opposite side.

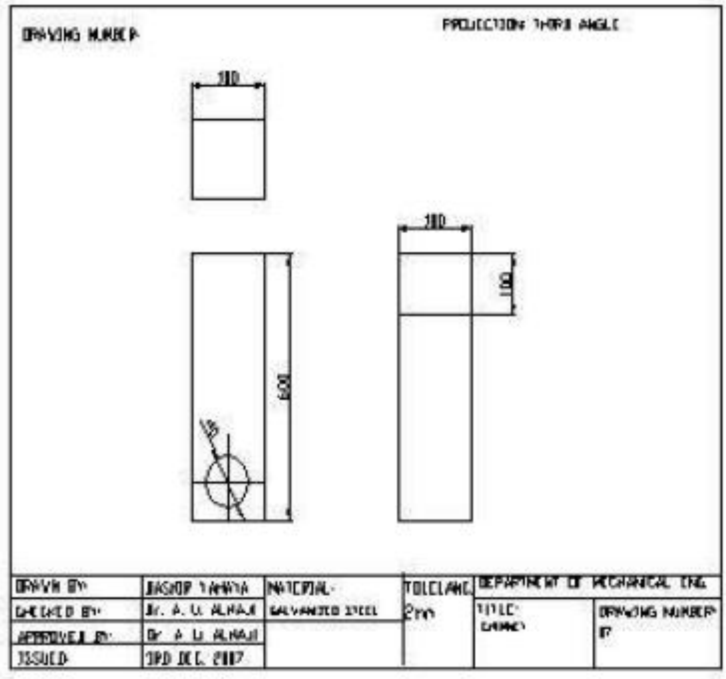

Figure 3: Chimney

2.2.4 Assembly: The components of the back-up stove were assembled as follows: The burner and the ash-tray unit were attached to the heat-exchanger using 40 mm diameter pipe. The connection was made from one of the slanted sides of the burner to the 40 mm diameter hole on the shell side of the heat-exchanger.

The chimney was attached to the 40 mm diameter pipe. The pipe was connected to the 40 mm diameter hole on the shell side of the heat-exchanger opposite to burner. In the 40 mm diameter holes at both ends of the tube side, a fan on one end and the other end is attached to the drying chamber using 40 mm diameter pipe.

2.3 Testing Procedure

One kilogram (1 kg) of charcoal was added into the burner and fire was set. After 15 minutes the burner was closed and stove fan was switched on. 3.02 kg of meat was arranged on the drying trays in the drying chamber. The heat-exchanger fan was switched on.

Wet and dry bulb thermometers were attached at the drying chamber air inlet and air outlet. The drying chamber door was closed, and the following parameters were measured and recorded; wet and dry bulb thermometer readings at 1 hour interval and meat weight at 2 hours interval. The moisture content of the meat was calculated for each meat weight.

When the moisture content of the meat is around 14%, it was removed from the drying chamber and soaked in a prepared mix-powder solution for about 30 minutes. The mixture is returned to the drying chamber and the drying process continues. The wet and dry bulb temperature of the inlet and outlet of the drying chamber were recorded. The sample weight was measured and recorded at 1hours interval. Moisture content of the sample was calculated for each meat weight. When the moisture content of the sample is around 7% the sample is removed from the drying chamber and is ready for packaging. Measured and recorded parameters are: Relative humidity, sample mass and temperature.

3.0 RESULTS AND DISCUSSIONS

3.1 Results

The components of the stove were designed using the equations presented in section 2.1 and the parameters shown in Table 1. The data recorded during testing are, also, presented in Table 2.

Table 1: Design Parameters

S/N	PARAMETERS	VALUES
1	Heat required for drying, Q	10,155.46 kJ
2	Mass of charcoal required, M	0.68 kg
3	Surface area of the heat-exchanger pipe, A	0.0101 m^2
4	Length of the heat-exchanger pipe, l	0.25 m
5	Heat-transfer in the heat-exchanger	115.05 W
6	Heat-exchanger exit temperature through the chimney, T_{h-out}	99.74 ^{o}C
7	Temperature of air into the drying chamber, T_{c-out}	65^{o}C
8	Draught, h	2.99 Nm^2
9	Actual chimney height, H$^'$	0.295 m
10	Efficiency, η	8.8%

Table 2: Test Results

Time	T_a(°C)	Chamber inlet air		Chamber exit air		M_s(kg)
		Temp. (^{o}C)	RH_1(%)	Temp. (^{o}C)	RH_2(%)	
Stage 1 Drying Process (Before soaking in a mix-powder solution)						
9:00am	33	48	33	40	54	3.02
10:00am	33	51	29	39	56	
11:00am	34	54	23	43	44	1.87
12:00noon	34	56	22	48	33	
1:00pm	35	56	22	52	27	1.09
Stage 2 Drying Process (After soaking in a mix-powder solution)						
1:30pm	35	62	14	56	22	2.2
2:00pm	35	60	18	48	33	
3:00pm	35	62	14	49	32	1.9
4:00pm	34	62	14	55	25	1.73

3.2 Discussion

Heat losses through the walls of the burner, connecting pipes and the heat-exchanger contribute to the temperature pattern of the drying chamber inlet temperature. This can be reduced by sealing all leakages in the different components of the stove. Drying was achieved in seven hours which is good when compared with the traditional methods which last for three to seven days depending on weather condition. The low efficiency of the stove is due to heat losses during the fans off period (i.e. when the fans are switched off). This is necessary, because the temperature range required in the drying chamber should be controlled (between 65^{o}C – 70^{o}C) to avoid case hardening of the "Kilishi" which cause contamination of the product.

4.0 CONCLUSION

The charcoal stove was developed for use as a back-up to solar "Kilishi" dryer. The drying time was considerably reduced from three to seven days in the traditional methods to seven hours. Contamination from the environment has been eliminated by enclosing the meat in the drying chamber. The amount of charcoal used (2.13 kg) to produce 1.73 kg of "Kilishi" is economical considering the price of each (as of the time of the experiments, 1 kg of charcoal was around ₦50, 1kg of fresh beef was ₦800 and 1kg of "Kilishi" was around ₦ 2,600). The hot air that enters the drying chamber doesn't mix with the flue gases from the burner. Smoke emissions from the stove were very low; this reduces pollution to the environment. The stove can be used in rural areas where there is no electricity, since the fans can operate using dry cells.

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