DESIGN, CONSTRUCTION AND TESTING OF A CHARCOAL-POWERED CELLOPHANE SEALER

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ABSTRACT

The availability of electricity to power necessary machinery to package and seal goods and products is not readily available to most of the Nigerian populace, since most of the people live in the rural areas. They cannot effectively carry out the technology of packaging their products with the electric heat sealer; hence they continue to use the traditional candle flame method of sealing. This design considers the socio-economic realities of the rural sector by providing sealing equipment that utilizes charcoal as an energy source. The design has been made simple, economical and easy to operate and maintain. The materials for its construction were sourced locally. It was tested and found to seal adequately and has an efficiency of 45% energy utilization.

INTRODUCTION

Even small businesses now package their goods in plastic so that the customer can see clearly what he or she is paying for- and to keep the products clean. But what if there is no electricity to power the necessary machinery?

Packaging is an integral part of food processing; it performs two main functions: to advertise at the point of sale, and to protect food against bacterial infection and contamination through dirt and flies. Packaging is usually done using different packaging materials like: cans (tins), sacks, cartons and nylons.
To seal the packaged goods, electricity usually serves as a source of power to the machinery that does the sealing. However, in the rural areas, traditional means of sealing goods are with the use of candle flame, this method is time consuming. Where electricity is available, the electric sealing machine may not easily be affordable because of its expensiveness. Similarly the non-stability of power supply may force producers of consumables to look for alternative means of sealing or be out of production.

In order to find solution to the above problems, the need to design and construct a heat sealer that would use wood charcoal as a power source was initiated and is presented in this paper. The need for such technology arose during a UNIDO food processing training course in Tanzania. Working with nothing but one of the organizer's memories of heat-sealer prototype developed at India's Central Food Technological Research Institute in Mysore, a local workshop made up a charcoal heat-sealer (Gonelimali, 1995).

Charcoal is readily available in every rural area and very cheap to obtain. The design of this sealing machine will go a long way in encouraging people to package water and locally made drinks since the construction is simple and the cost is within the reach of a local artisan and affordable to any rural business in whatever capacity. It will also serve as a good substitute to the urban dwellers during periods of power outages.

The construction of the charcoal heat sealer is based on the principle of heat transfer by conduction. The charcoal is ignited to burn and transfer heat produced during combustion to the sealing jaw. The complete combustion of charcoal is enhanced by provision of vents and ash collection plate (Ayuba, 1998): the vent provides free air passage. The ash collection plate provides means of ash collection whose presence may retard combustion. The design has been done to ensure complete combustion of charcoal to give the maximum energy needed for the sealing.

Wood charcoal is a black, porous form of carbon produced by the incomplete burning of wood, when wood is burn in limited supply of air (Idris, 1990). When used as fuel, wood charcoal burns without smoke and produces heat more than an equal amount of ordinary wood. It is produced commercially by heating hard wood in large retort with less air. Charcoal is used to a great extent, as domestic fuel both for heating and cooking and it is readily available in all parts of Nigeria.

The basic principle of this design is heat transfer: i.e. heat is generated and transferred to the appropriate medium where it is required by conduction. Conduction is the transfer of heat energy from a part of a body at higher temperature to another part of the same body at lower temperature in physical contact with it (Rohsenow, et al. 1985).

DESIGN CONSIDERATIONS

The analysis is based on heat utilization in sealing cellophane. The following relation gives the theoretical heat needed to melt cellophane:

$$Q_{th} = M_L \times T \times C_L$$

Where Q_{th} = theoretical heat for melting: (J)

M_L = mass of cellophane (0.00173kg):

T = temperature of sealing (170°C):

C_L = specific heat capacity of cellophane (2300J/kg °C).

The heat utilized in raising strip or heating jaw temperature is given by:

$$Q_{st} = M_{st} \times C_{st} \times T_{st}$$

Where Q_{st} = heat of strip (J):

C_{st} = thermal conductivity of strip (0.795 w/m °C):

M_{st} = mass of strip (0.31615kg):

T_{st} = temperature of strip (170°C).

Heat loses through the walls by conduction exist through the four walls of the combustion box (Frank and David, 1990). The following relation gives heat loss through the insulated walls:

$$Q_{wls} = \frac{T_{in} - T_{out}}{\frac{X_{in}}{k_{in} A_{in}} + \frac{X_{gf}}{k_{gf} A_{gf}} + \frac{X_{out}}{k_{out} A_{out}}}$$

Where Q_{wls} = rate of heat loss through each wall lagged (J/sec):

X_{in} = thickness of the inner wall (m):

X_{out} = thickness of the outer wall (m):

X_{gf} = thickness of the glass fibre (insulating material) (m):

k_{in} = thermal conductivity of the inner wall (w/m°C):

k_{out} = thermal conductivity of outer wall (w/m°C):

k_{gf} = thermal conductivity of glass fibre (w/m°C):

A_{in} = area of the inner wall (m^2):

A_{out} = area of the outer wall (m^2):

A_{gf} = area of glass fibre (m^2):

T_{in} = average combustion chamber temperature (°C):

T_{out} = temperature of surrounding (°C).

Total theoretical heat required for sealing is.

$$Q_t = Q_{th} + Q_{st} + Q_{wls}$$

To determine the weight of charcoal needed to give the above theoretical heat, the following relation is used:

$$W_{ch} = \frac{Q_t}{C_{ch}}$$

Where W_{ch} = weight of charcoal (N);
C_{ch} = calorific value of charcoal, 30 MJ/kg; (Dun et al. 1982).

The size of the combustion chamber is determine by considering the volume of charcoal needed thus:

$$V_{ch} = \frac{M_{ch}}{\rho_{ch}}$$

Where M_{ch} = mass of charcoal (kg);
ρ_{ch} = density of charcoal, 1950kg/m^3; (Dun et al. 1982).

Similarly, the mass of charcoal is obtained from

$$M_{ch} = \frac{W_{ch}}{g}$$

Where g = acceleration due to gravity (m/sec^2).

Therefore the volume of the combustion chamber is given by:

$$V_{ch} = \frac{W_{ch}}{g\rho_{ch}} = L \times b \times h$$

Where L = 3h, length of combustion chamber (m);
b = 1.5h, width of combustion chamber (m);
h = height of combustion chamber (m).

And

$$h = 3\sqrt{\frac{W_{ch}}{4.5 g\rho_{ch}}}$$

The used heat in sealing operation is

$$Q_{us} = Q_t - Q_{wts}$$

Therefore the efficiency of the heat utilization is given by:

$$\eta = \frac{Q_{us}}{Q_t}$$

Determination of optimum thickness of the wall is done using Fourier's law as

$$\Delta x = \frac{kA(T_2 - T_1)}{Q_t}$$

Where Δx = optimum thickness of wall (m);
k = thermal conductivity of galvanised sheet metal (45.4 w/m °C); Ejup and Tyler (1991).
A = total surface area of combustion chamber (m^2);
T_1 and T_2 = temperature of the inner wall and the environment respectively (°C).

The optimum thickness of the insulating material (fibre glass) is obtained thus:

$$\Delta x_{gf} = \frac{k_{gf} A_{gf} (T_2 - T_1)}{Q_{th}}$$

For k_{gf} = 0.8 w/m °C

To determine the area of air opening for supply of air for complete combustion, we use the relation (Dun et al. 1982):

$$m = \frac{V}{V_m}$$

Where m = charcoal burning rate (11.33g/min);

V = volume flux through an opening = $23.6A_a \sqrt{h}$ (m^3/s);

V_m = minimum amount of air for stoichiometric combustion (m^3/kg).

Therefore,

$$m = \frac{23.6A_a\sqrt{h}}{V_m}$$

Where A_a = the required air opening area (m^2);

h = height from datum horizontal level (m).

Hence,

$$A_a = \frac{mV_m}{23.6\sqrt{h}}$$

CONSTRUCTION

The charcoal heat-sealer was constructed using two types of material, the galvanised iron sheet and a hollow square pipe. The galvanised sheet was used for the construction of the combustion chamber (charcoal box), while the square pipe was used for the construction of the sealer frame.

The charcoal box has the following dimensions: height 102 mm, length 292 mm, width 104 mm and the thickness of the wall is 1mm. The frame has the following dimensions: height, 715 mm, width, and 340 mm. Also an 8 mm-iron rod was used for the lifting mechanism for ash collection. Most parts of the sealer were assembled by welding, while some were assembled using screws and nuts. The isometric view of the heat sealer is shown in figure.

OPERATION

To operate the heat sealer the box filled with charcoal is ignited to start combustion. As combustion starts the box gets heated and this heat is transferred to the sealing jaw by conduction. When the temperature reaches 90 °C sealing of cellophane begins by putting the cellophane between the heated jaw and applying pressure with a foot pedal located at the underneath of the sealer. When the temperature rises to about 170 °C the handle of the lifting mechanism is turned through 90° to lift the charcoal box thereby breaking contact between the box and the sealing jaw. The box is held in this position until the temperature decrease to 100 °C, the handle of the lifting mechanism is then restored to its initial position to enhance continued transfer of heat to the sealing jaw.

It is worth noting that the breaking of contact between box and jaw do not stop the process of sealing. The operation is simple and allows the sealing of 15 cellophane sachet of 'pure water' in one minute, depending on the skill of the operator.

TESTING

The test carried out with the heat sealer produced a very good and strong seal at sealing temperature in the range of 90 °C to 170 °C above this temperature the seal becomes poor due to high temperature. A calibrated thermometer indicating the sealer temperatures monitors the temperature.

CONCLUSION

This paper has presented the design and construction of locally made sealing machine that uses wood charcoal to supplement the electrical type with good sealing features and high output. This will provide a basis for improvement for higher efficiency of charcoal heat-sealing machine in terms of energy utilization and temperature regulation.

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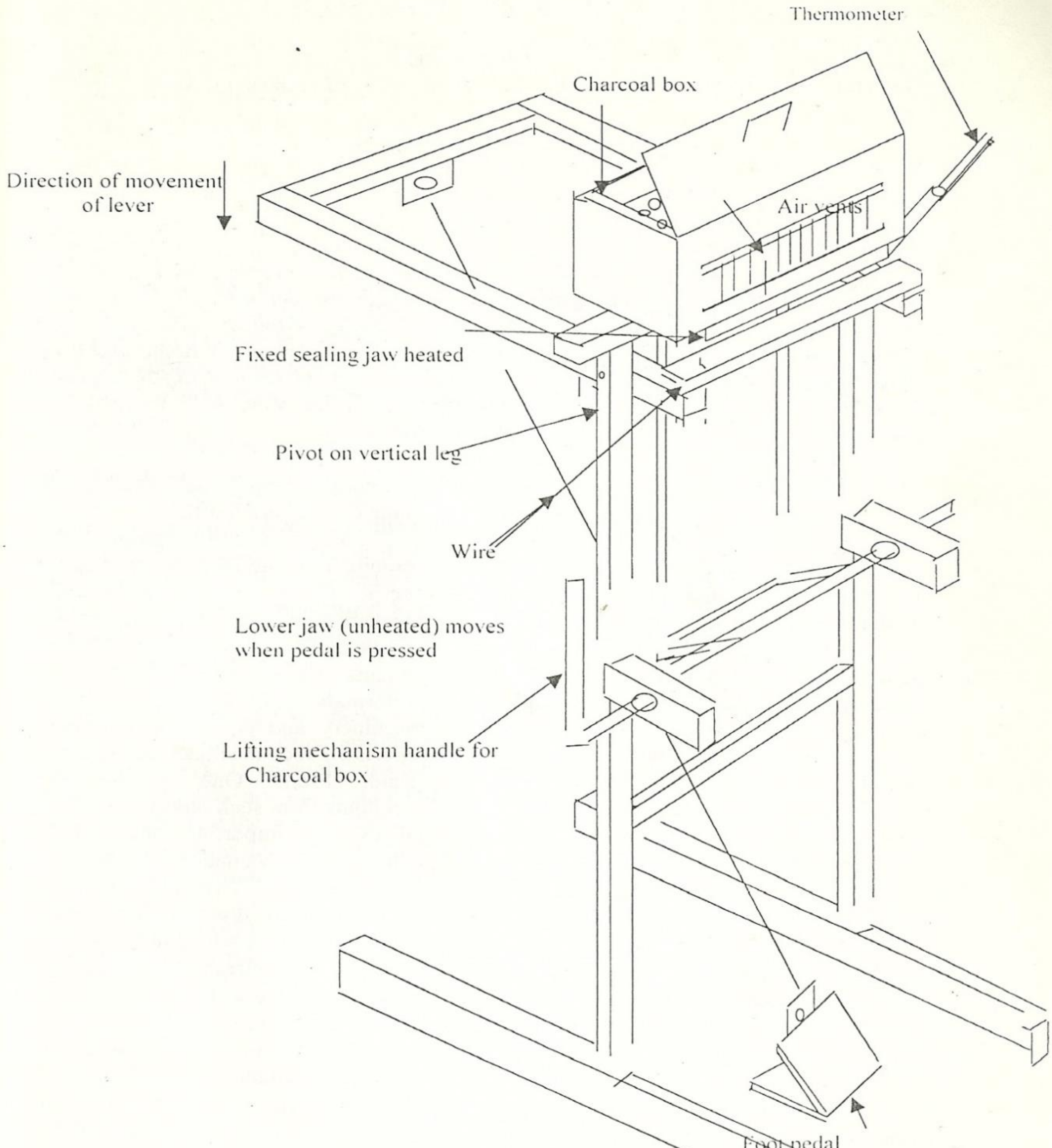

Figure: Isometric view of fabricated Heat Sealer using Charcoal