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DEVELOPMENT AND MODIFICATION OF A COAL-POWERED CELLOPHANE SEALER FOR PACKAGING

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ABSTRACT

This design work provides an alternative to the use of electric heat sealer as well as an improvement on a previously fabricated charcoal powered one. In this present work, coal is use as energy source as well as addressing the phenomena of heat loss and temperature regulation, which were the major constraints of the previous design. A thermostat has been incorporated at the sealing jaw as well as the use of high insulating material to reduce the heat loss to a minimum. This has greatly increase the efficiency of the heat utilization from 45% to 86%.

Key words: Coal, Cellophane, Design, Energy, Heat transfer, packaging, Sealer, Conduction, Bimetallic strip

INTRODUCTION

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 coal 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. 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 the best materials, which are natural and can be recycled. Different packaging materials like: cans (tins), sacks, cartons and nylons can be use, where these cannot be used, plastic bag may be the best choice (Gonelimali, 1995). 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, (Bala and Ayuba, 2002) constructed a charcoal heat sealer which had 45% energy utilization. The design did not adequately address the phenomena of heat loss, and temperature control was done by reading a thermometer. Those who could not read could not use this. These two problems have been taken care in this design by lagging all surfaces through which heat could be loss. The use of bimetallic strip thermostat with a lighting indicator has been adopted in this work to make its operation easier for all manners of users. Considering the present campaign on the conservation and protection of our natural vegetation the use of charcoal is highly discouraged since it is obtained from wood. Switching from charcoal to coal will conserve the forest, serve as a sink for carbon dioxide (CO_2), a green house gas (Okegbile, 2003), as well as produce more heat than equal volume of charcoal (Dunn et al, 1982). The ultimate analysis, theoretical air required for complete combustion and calorific value of common coal used around Minna (Enugu coal) is as presented by (Akinbode, 1995). 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 coal heat sealer is based on the principle of heat transfer by conduction. The coal is ignited to burn and transfer heat produced during combustion to the sealing jaw. The complete combustion of coal is enhanced by provision of vents and ash collection plate 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 coal to give the maximum energy needed for the sealing. 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 seal cellophane:

$$Q_s = M_L \times T \times C_L \qquad 1$$

Where Q_s = theoretical heat for sealing; (J)
M_L = mass of cellophane (0.00173kg);
T = maximum temperature of sealing (170°C);
C_L = specific heat capacity of cellophane (2300J/kg °C).

The heat required to raise strip or heating jaw temperature is given by:

$$Q_{st} = M_{st} \times C_{st} \times T_{st} \qquad 2$$

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

$$Q_{in} = \frac{T_{in} - T_{out}}{\frac{X_{in}}{k_{in}A_{in}} + \frac{X_{gf}}{k_{gf}A_{gf}} + \frac{X_{out}}{k_{out}A_{out}}} \qquad 3$$

Where Q_{in} = rate of heat loss through insulated walls (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,

$$Q_T = Q_{th} + Q_{st} + Q_{in} \qquad 4$$

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

$$W_c = \frac{Q_T}{C_c} \qquad 5$$

Where W_c = weight of coal (N);
C_c = calorific value of coal, 33,750kJ/kg; (Akinbode, 1995).

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

$$V_{ch} = \frac{M_c}{\rho_c} \qquad 6$$

Where M_c = mass of coal (kg);
ρ_c = density of coal, 1950kg/m^3.

Similarly, the mass of coal is obtained from

$$M_c = \frac{W_c}{g} \qquad 7$$

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

Therefore the volume of the combustion chamber is given by:

$$V_c = \frac{W_c}{g\rho_c} = L \times b \times h \qquad 8$$

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

And

$$h = 3\sqrt{\frac{W_c}{4.5g\rho_c}} \qquad 9$$

The useful heat in sealing operation is

$$Q_{us} = Q_T - Q_{in} \qquad 10$$

Therefore the efficiency of the heat utilization is given by:

$$\eta = \frac{Q_{us}}{Q_T} \times 100\% \qquad 11$$

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

$$\Delta x = \frac{kA(T_2 - T_1)}{Q_T} \qquad 12$$

Where Δx = optimum thickness of wall (m);
k = thermal conductivity of galvanised sheet metal (45.4 w/m °C); Ejup & 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:

$$\Delta x_{gf} = \frac{k_{gf} A_{gf} (T_2 - T_1)}{Q_{th}} \qquad 13$$

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);

$$\dot{m} = \frac{V}{V_m} \qquad 14$$

Where $\dot{m}$ = coal 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 (8.3864 m^3/kg). (Akinbode, 1995).
Therefore,

$$\dot{m} = \frac{23.6A_a\sqrt{h}}{V_m} \qquad 15$$

Where A_a = the required air opening area (m^2):
h = height from datum horizontal level (m).
Hence,

$$A_a = \frac{\dot{m}V_m}{23.6\sqrt{h}} \qquad 16$$

The coal 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 (coal box), while the square pipe was used for the construction of the sealer frame. The coal box has the fo ving 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 welded together, while some were assembled using screws and nuts. Temperature regulation and control is achieved with a thermostat in conjunction with a bimetallic strip shown in figure1, this is fixed to the sealing jaw with a bolt to a plate which is welded to a horizontal bar supporting the coal box. It receives the heat directly from the combustion box. The isometric view of the heat sealer is shown in figure 1.

OPERATIONAL METHOD

To operate the heat sealer, the box filled with coal 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 is started by putting the cellophane between the heated jaw and applying pressure with a foot pedal located at the underneath of the sealer. Heat generated in the sealing jaw is conducted to the bimetallic strip, which has been preset to the desired temperature ranges of 90°C minimum and 170°C maximum. When the temperature rises to about 170°C the bimetallic strip connected to the sealing jaw expands and lifts up thereby compressing a copper wire within the bimetallic strip until the circuit is closed. Current then flows from a dry cell into a bulb indicator on the strip which glows indicating the maximum temperature has been attained. The handle of the lifting mechanism is then turned through 90° to lift the coal box thereby breaking contact between the box and the sealing jaw. As soon as the contact is broken, the heat decreases and the bimetallic strip returns to its initial position. The box is held in this position until the temperature decrease to the minimum. The circuit is again opened and the indicator bulb switches off signifying the minimum temperature has been reached. The handle of the lifting mechanism is then restored to its initial position to enhance continued transfer of heat to the sealing jaw. 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. However, it was realised that the temperature regulating mechanism still requires manual means to disengage the coal box thereby delaying sealing operation. This however can be improved upon by additional self-acting mechanism.

CONCLUSION

This paper has presented the design and construction of locally made sealing machine that uses coal to supplement the electrical type with good sealing features and high output. This has also provided an improvement for higher efficiency through the use of coal, heat control and temperature regulation mechanism.

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CONSTRUCTION

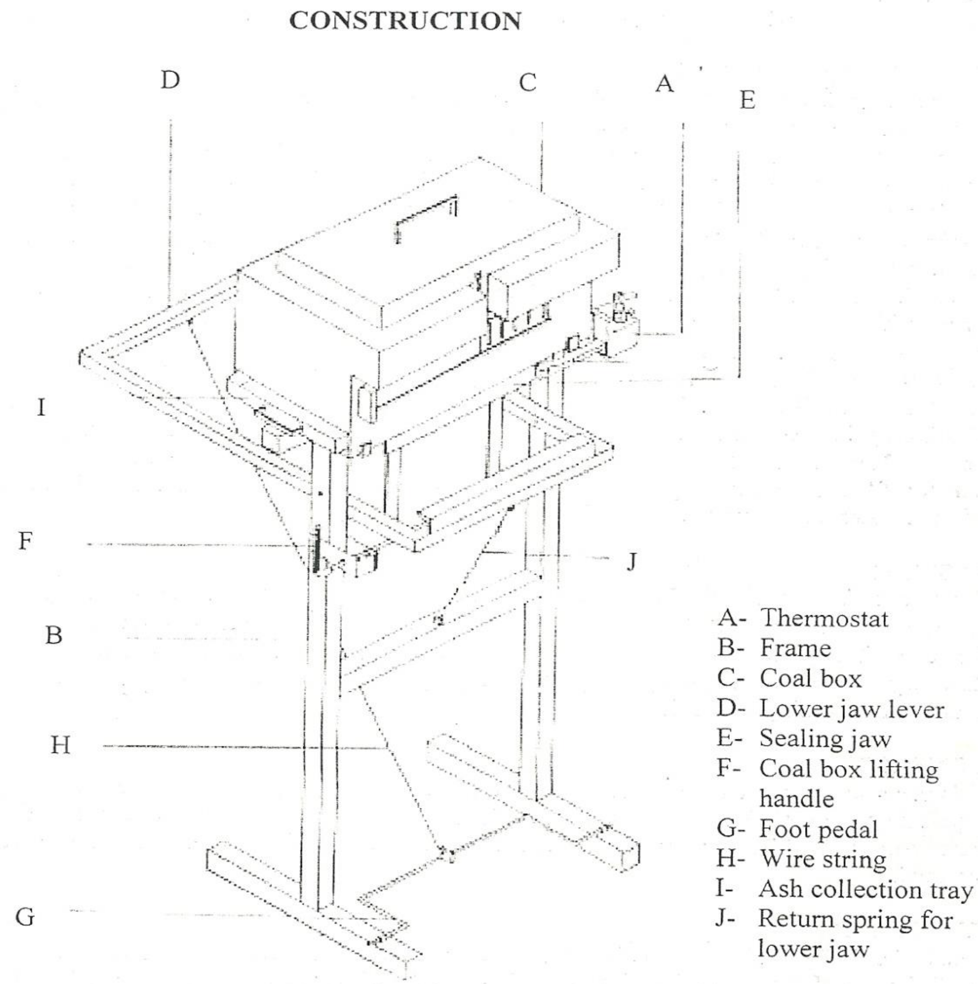

Figure 1: Coal-powered Cellophane Sealer