A MODULE FOR THERMAL PEST CONTROL IN STORED RAW MATERIALS USED IN FEED MILLS / FOOD MANUFACTURING INDUSTRIES

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ABSTRACT

Pests have continued to be problematic in warehouses of most feed mills and food manufacturing industries. Pests are heterogeneous both in space and time, creating gradients and patterns depending on the prevailing environmental variables. Pest control efforts have utilized manipulations of these variables. This project is on a module for thermal control of pests using the hitherto waste steam from the industries. The module is an engineering contraption, which uses steam to raise temperature within it to insecticidal levels (above 45˚C). This causes halt in development and protein denaturing (leading to mortality) of the pests (eggs, larvae and adults). This applied heat also toasts the material inside the module thereby improving its quality. The module consists of a rotary drum with steam passing through convoluted tube (without coming in contact with the handled material), with a capacity of 2 tons/hr of commodities. It accepts steam at 130˚C and discharges it at 110˚C. The steam pressure (permissible) is 2.7 bars. Steam velocity is 8m/s. The volume of the drum is 4 m³. A two- screw- 90 degrees-lead –counter screw-rotation type baffle is installed to achieve even distribution of heat on the material within the drum. The module is efficient, effective and useful in any integrated pest management effort.

Keywords: Module, Thermal Pest Control, Stored Raw Materials, Feed Mills, Food Manufacturing Industries

INTRODUCTION

Stored products in the tropics suffer serious damages due to pest attacks. According to Ogunlana (1976) up to 27.7% losses have resulted from insect damage to maize stored in Nigeria without pest control. Even at 4% level such losses translate to an annual loss of ₦300, 000,000 or 2 million tons. Such Figure for cowpea is 4.5% loss; for fish it is £10 million sterling (Toye, 1976). The most common pests encountered are: *Tribolium castaneum, Tribolium confusum, Sitophilus oryzae* and *Callosobruchus maculatus* (Osuji, 1985). The study of pest control has grown vastly since the introduction of the first synthetic insecticide (DDT) in 1940 (Kumar, 1986). Most advances in our knowledge in this field have taken place in the last sixty years. The literature on the subject is expanding rapidly.

In order to consider using economically feasible control measures against pests reliable information is needed on losses as a result of pest attacks. Stem et al; (1959) used two terms in discussing control measures against pests namely: economic injury level and economic damage. According to Talpaz and Fristic (1975) another term "economic threshold" is a dynamic measure which may vary with infestation level, cost of control, and time of assessment. In practice, all these boil down to the fact that we need to know the accurate estimates of pests population levels that affect production and yield. Stern (1973) concludes that it is important to know the yield per pest density ratio so as to ascertain when control is inevitable. In most of our warehouses where raw materials are stored the pest density ratio is so high that instituting control must be instituted one way or the other. Control is often by chemical and by physical means. Physical control is divided into physical methods and environmental manipulation.

Physical control or physical elimination of the pests often involves the alteration of the environment to make it inimical to the pest. Physical barriers are effective in the control of flour beetles that affect most raw materials like Soya been cakes, palm kernel cake and cassava flours used in feed mills (Dayakar and Ray, 1998). As pests are part of the major production bottlenecks in the feed and food related industries, practitioners always take the easy way out by using insecticides but because of the side effects of these insecticides, physical methods would always serve as suitable control alternatives.

Hand picking of pests is hardly practical in any large-scale control effort but removal of foci of infestations in storehouses is known to greatly affect, reduce and sometimes eliminate the insect population from the stored commodities. This removal of foci of infestations may be possible using various devices. In his studies, Ebeling (1971) listed such devices as jarring, destruction of egg masses and removal by a strong stream of water in considering field pests. For stored products and with a through knowledge of the ecology of the pests, it is possible to develop novel physical control measures. It is against this background that this study was initiated to use thermal control as a means of control in industries. As many industries have steam that is mostly wasted, this would be harnessed as the source heat. In doing this, a module is designed and fabricated that use the

known biological information on raw materials and pests to effect a cost-effective control of pests in stored raw materials.

The Role of Environmental Manipulation in Pest Control: Banks (1976) summarized the use of ecological factors against insects, even though the use of this is not very widespread. The use of physical control methods is growing in importance in stored commodities in view of the problems posed by the increasing use of insecticides. Busvine (1968) says that time is ripe for biologists to use engineers to develop modern technology for pest control that will reduce cost, be environmentally friendly and effective. This presentation is our modest effort in this direction.

Most industries that store commodities that are attacked by pests produce steam as waste products of their boilers. The steam can be channeled to two processes both of which will help in pest control. These are: 1. Dehydration. 2. Raising the temperature;

Dehydration: Most set ups use dust desiccants which kill insects by destroying the water proofing properties of the insect cuticles. This permits a lethal rate of water loss from the insect body. The use of relative humidity also is very efficient in stored products. The death of insects is largely due to excessive water loss from insect bodies caused by prolonged opening of their spiracles. Howe (1965) noted that many storage pests cannot reproduce at ambient relative humidity of 50% and Banks (1976) noted that the possibility of producing an atmosphere dry enough to be insecticidal but which is only out of equilibrium with the commodity merits further research.

Temperature: Temperatures as high as 45°C normally used in artificially drying grains for storage, for feed and food processing facilities are lethal to insects. Efficient portable grain drying equipment has been used for the purpose of elevating temperatures to control pests to stored commodities. This project has designed a module capable of generating high temperature over a short period to effect insecticidal action in stored commodities prior to use in product processing.

MATERIALS AND METHODS

Engineering Theory and Design

Type: Rotary drum steam-through-tube module.

Working Fluid: Wet saturated steam.

Material Handled: Grains, Cakes, Flours.

Capacity: 2 tons of grain/other commodities. The module was designed as a rotary shell and tube heat exchanger with the working fluids as wet saturated steam making the tube pass and air making the shell passes.

From an existing boiler, wet saturated steam at 130°C and 2.7 bars is channeled into the drum. The steam is expected to heat the air in the drum to 100°C before exiting at 110°C. The choice of steam at 130°C is to avoid condensation within the tube. Again, the exit temperature was set at 110°C for the same reason. In event of condensation, the tilt of the drum will force the condensate to drain out (Figure 1).Through the grain inlet; the grains are introduced into the drum. The drum, which has baffles inside, rotates at 4 rpm. The baffles mix the commodities inside the drum and ensure that each commodity comes into contact with the 100°C air. The enclosed raw materials will stay for 30 minutes in the drum before being discharged.
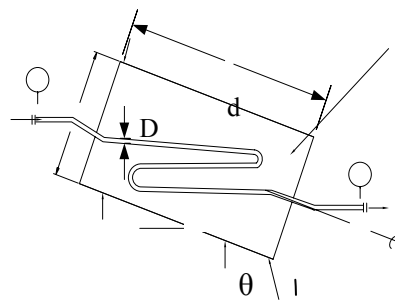
**Figure 1: The schematic diagram of the module**

Definition of Parameters
C_p = Specific heat of fluid (kJ/kg. K)
μ = Dynamic viscosity (kg/m.s)
k = Thermal conductivity (kW/m.K)
p = Pressure (bar, Pa)
Q = Quantity of heat transferred (W)
ρ = Density (kg/m^3)
Pr = Prandtl number
Re = Reynolds number
Nu = Nusselt number
m = Mass flow rate (kg/s)
h = Heat transfer coefficient (kW/m^2 K)
θ = Drum tilt angle (°)
L = Length of drum (m)
D = Diameter of drum (m)
d = Pipe diameter (m)
d_i = Inside pipe diameter (m)
N = Drum rotation (rev/min)
T_1 = Steam inlet temperature (°C)
T_2 = Steam outlet temperature (°C)
R_1, R_2 = Support reactions (N)
T_{air} = Temperature of air inside drum (°C)
v = Velocity (m/s)
σ_c = Circumferential stress (MPa)
t = Sheet thickness (m)
r = Radius (m)

Design Determinants: D, d, L, steam flow rate, inlet and outlet temperatures of steam, heat transfer from steam, drum rotation speed, duration of grain in the drum, size of motor, entry and discharge of grain, gear parameters, number of pipe turns, baffle design, drum tilt, load borne by the drum, materials to be used, fabrication and cost.

The Design: The density of sample commodity e.g. – rice was determined to be 865 kg/m³. From this, the volume to contain 2 tons of raw materials was determined (4m³) and the length followed suit as 3 metres. **D** was then determined. **d** was chosen from the table of available pipe diameters. The number of pipe turns was determined to be 9. Therefore, the pipe length used for the design was 27 metres.

Particulars: Temperature of steam at entry = 130°C; Temperature of steam at discharge = 110°C; Steam pressure = 2.7 bars; Steam velocity = 8 m/s; Final temperature of air in drum =100°C; Length of drum =3 m; Volume of drum = 4m³

Thermal Considerations: Having selected the following parameters: d = 0.0779m, ρ_{130} = density of steam at 130°C = 0.5542 kg/m³, v = 8m/s and p = 2.7 bars, the mass flow rate of the steam was calculated as 0.21 kg/s. The heating load was calculated as Q = 3487.6 W for the 27m length of pipe. This means that 3487.6 Joules of heat energy is given out per second from steam for heating of air to 100°C. From energy balance, the mass flow rate of air was 0.0495 kg/s. From this, the velocity of air inside the drum was calculated to be 0.012m/s. This translated to drum rotation of approximately 4.0 rpm considering losses and using a generous factor of safety. For effective heating of the raw materials, the drum should actually rotate at a very slow pace. This will effect good heat transfer from steam to grain. Good mixing of grain was achieved by the use of baffles attached inside the drum shell. A 2-screw-π/2-lead-counterscrew-rotation type baffles were used, (Figure 2 a, b).
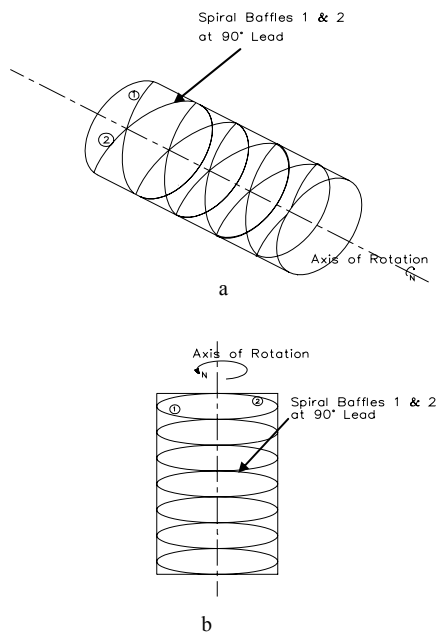
Figure 2 (a) and (b): The baffles

The heating tubes were arranged in a three-layer pattern. This is to achieve even heat distribution within the drum, (Figure 3 a, b).
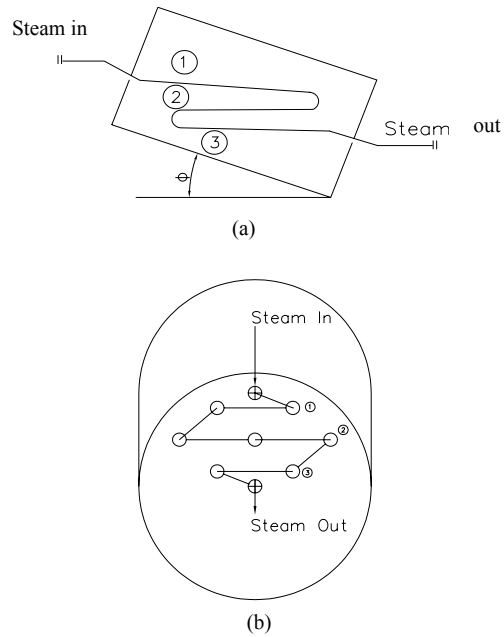

Figure 3 (a) and (b): The heating tube arrangement

RESULTS

Structural Analysis: The weight of the whole structure was approximated to be the weight of the drum and its accessories plus the weight of the grain. The weight of the grain is already known i.e. 2000 kg but the weight of the drum is yet to be known. This can be calculated if the thickness of the end plates of the drum and the thickness of the steel sheet are known.

The end plates were made of 12 mm thick steel plates. The thickness of the steel sheet was determined by analyzing the drum as a thin walled pressure vessel see Figure 4.
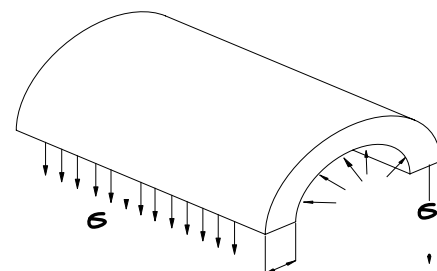
Figure 4: Thin walled pressure vessel

In stress analysis, σ_c must not exceed the permissible working stress σ_{max}. For this steel, σ_{max} is 241 MPa. Using a factor of safety of 4.0 and $\sigma_c = \sigma_{max} / 4$, thickness of sheet was determined to be 3mm.

Finally, the working load was found to be approximately 30 kN. From the analysis, we have the following specifications:

(a) **Prime mover:** 3.5 hp, 715 rpm, 220/400 V induction motor.

(b) **Gear train:** Worm set/spur set.
    (i) φ50 mm driver motor worm.
    (ii) φ130 mm driven gear on the same shaft with
    (iii) φ136 mm pinion driving
    (iv) φ1430 mm spur (Drum).
(c) **Support:** Simple support type.
(d) **Bearings:** (i) Specialized tapered roller bearings on the supports.
    (ii) Pipe bearing: Single-row 02-series deep-groove angular-contact ball bearings.
    Bore – φ90 mm.

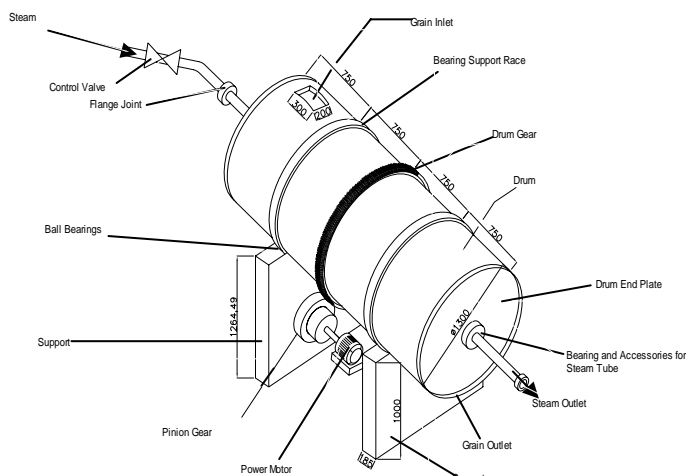Figure 5 is a diagram of a fully assembled module.

Figure 5: A fully assembled module

The Benefits of Control Using the Module

1. The steam to be used is from boiler operations for other production processes.
2. Highly skilled engineers and scientists are not really needed to operate the module.
3. Investment cost is high on acquiring the equipment but will be used for several years with minimal repairs.
4. The high temperature highly and adversely affects the biology and behaviour of the insects and dehydration reduced relative humidity of the operations.
5. The biological integrity of the commodities is retained and is intact.
6. Yield and profitability of production is increased.

DISCUSSION

The module presented has succeeded in greatly harnessing the heat energy from the otherwise waste steam while leaving behind some sensible heat, which could be used for other operations. Thus, beyond the role as a veritable pest control contraption it is also an energy saving device.

Temperature is the single most important factor regulating life processes in nature. Other regulatory processes such as predation, disease and competition act on the residual populations, which have survived the effects of temperature. Survival and abundance can be ecologically predicted by relating known levels of temperature tolerance to the severity of either the very low temperatures of refrigeration or the high temperature such as the one generated by this module or the other such heat generating systems to periods of exposure

Scientists are well aware of the problem of invertebrate survival at sub zero temperatures and this subject has attracted the most attention. From such studies we now know that insects exhibit one of two seemingly immutable strategies to survive such temperature variations but not high temperatures. Insects switch between tolerance and intolerance. The degree to which they do this, gives the indication of the ecological relevance of the spectrum of the adaptations of which the operations of this module deals a death blow.

Chemical engineers developed theories, which describe and predict how temperature changes cause hygroscopic compounds and lipids with some porous solid in insects, to dry and these theories also are used to explain drying behaviour of insects subjected to the operations of this equipment. It also explains drying found to occur within the raw materials, thus extending their shelf life.

Any interested parties are free to access the designers of this module for its construction for their use. It is cost effective, efficient and easy to operate. It provides a useful tool in an integrated pest management in the industries.

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