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ORIGINAL RESEARCH ARTICLE

MODIFICATION, FABRICATION AND PERFORMANCE EVALUATION OF INSULATED BOX FOR POST-HARVEST HANDLING OF FISH

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ABSTRACT

In order to address the challenges associated with postharvest handling of fresh fish, Nigerian Stored Products Research Institute (NSPRI) developed an insulated transportation mechanism named Ice Fish Box™ which has a capacity of 18 kg of fish and ice. However, capacity and ease of movement was encountered in the developed box leading to modification using a smaller box (inner box) of dimension 495 mm×340 mm× 340 mm fitted into a bigger box of dimension 540 mm×360 mm× 360 mm and a trolley on wheels using human muscle power for ease of movement. The construction was carried out using standard procedures and all materials used were sourced locally. Results of its performance tests indicated that the modified box can carry approximately 60 kg of fish and ice at full load and the trolley can carry load of up to 120 kg of stacked boxes and swerves easily at angle 45°. It is expected that these modifications would allow for more storage of fish and ease movement on all terrains as handlers mostly women find it almost difficult in moving the earlier designed insulated box around.

1.0 Introduction

In fish industries, the high perishability of products makes them spoil almost immediately once harvested, if not properly handled, transported and stored (Akinete *et al*., 2007; Agbon *et al*., 2002). Nigerians are large consumers of fish and it has remained one of the main products consumed in terms of animal protein (Pessu *et al.,* 2016). A major concern is the waste occurring in most distribution chain that not only bring loss of income to fishermen and fish traders, but also contribute to food insecurity (Tsado *et al*., 2012; Towers, 2011). In order to reduce these losses, fresh fish storage time is extended by avoiding damage and bruises by chilling with ice as soon as possible both on board and at the shore (Obodai *et al*., 2009).

Transportation of the harvested fish to the market or processing centers with the fish and ice in the same container becomes necessary because ice is used as chilling substance to keep the temperature of fish lower than ambient temperature. In order to reduce the melting of ice, an insulated box was desired (Sormin *et al.,* 2016). Insulated boxes are made of an insulating material that is best packed between two layers of durable, waterproof, non-absorbent plastics. A good insulator will maintain the inner temperature of the insulated box for a long time.

Nigerian Stored Products Research Institute (NSPRI) developed a technology for transportation, storage and distribution of fresh fish in 2014. It was a portable, semi-air-tight lagged-coolant system with an effective cooling capacity due to uniform coldness distribution within the box. The developed box was insulated/lagged with polyurethane material placed in between two boxes of different dimensions with 490 mm x 290 mm x 200mm and 470 mm x 280 mm x 190 mm respectively and has a capacity of 18 kg when fully loaded. Additionally, the developed box has hole drilled at the center of it and a flexible pipe was connected to it which serves as drainage for melted ice and slime.

A study by Pessu *et al.* (2016) showed that the 18 kg capacity box preserved *Clarias gariepinus L* and *Oreochromis niloticus L.* for 36 hours and 42 hours respectively. The key parameter assessments were found to be within the acceptable limit.

However, it was found that the hole in the insulated box was not effective enough and this directly aid speedy defrosting of ice as well as soaking of fish in the box. In addition, the capacity of the box compared to quantity of fish that was available for transportation was low. In the year 2018, feedbacks received from most users of the developed box and recommendation by Ishola *et al*. (2015), necessitated the idea of modifying the design. Therefore, the aim of this study was to modify the insulated box by increasing its holding capacity, rechanneling the drainage hole to increase outflow of melted ice and also to design and fabricate a trolley for easy carriage of the developed box with suitable materials.

2.0 Materials and Methods

2.1 Design and fabrication protocol

The design and fabrication was based on the need for increased capacity, ease of movement and better drainage over the previous design. This modification was carried out in 2019 at NSPRI Lagos Zonal office. All materials used were sourced from Mushin, Oyingbo and Lagos Island Lagos State. These includes plastic boxes, isocyanate, resin, mild steel angle rods (0.5mm), steel flat bars (0.5mm), round galvanized steel pipe (0.5 mm), swivel and static caster solid tires (10 cm Dia), plastic board (3mm thick), glue, rivets. The modified box comprised of smaller plastic box (495 mm ×340 mm ×340 mm) fitted within a bigger plastic box (540 mm×360 mm ×360 mm) with a holding volume of 60 L and the space between the boxes was filled with polyurethane. Equal volume of liquid resin and isocyanate (1 L) was mixed and was transferred within 20 seconds of mixing into space between the boxes. Mechanical agitation was ensured for even spread of the mixture resulting in a solid mass of polyurethane as the insulating material in such a way that insulator was 22 mm wall to wall. Extruded polyurethane was scrapped followed by riveting a plastic board to serve as cover for the space left by the inner box to the outer box. The lid of the box was insulated with polyurethane of 10 mm thickness and covered using plastic board. Subsequently, a hole was drilled at one side of the box with an affixed flexible pipe (2 mm in diameter) at an angle of 5° to promote faster flow of wastewater. Figures 1 and 2 illustrated the earlier design and the new design respectively while Figure 3 shows the flow chart of the process involved in producing an insulated box.

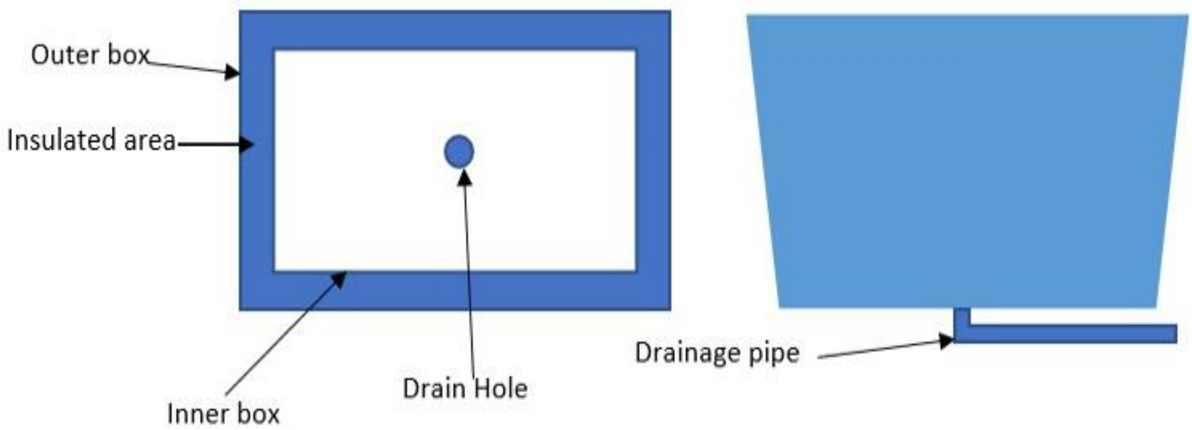

Figure 1. Illustration of the earlier design showing the drainage at the center of the box.

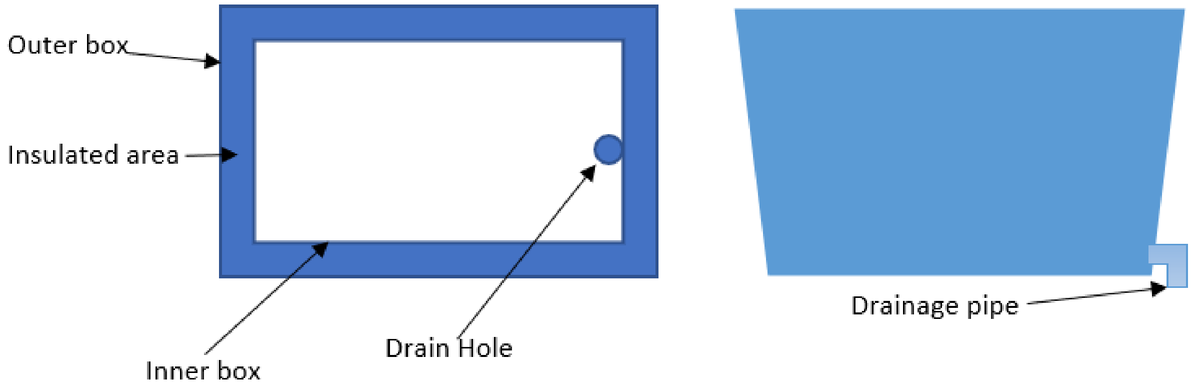

Figure 2. Illustration of the modified design showing the drainage at the center of the box.

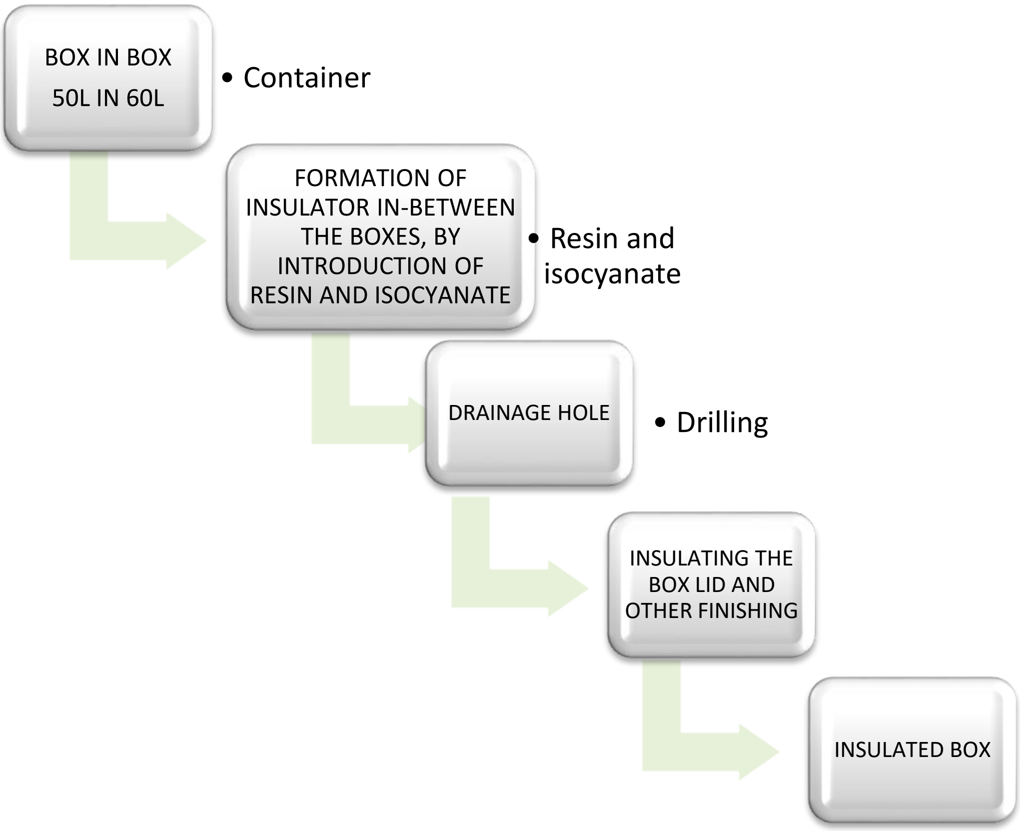

Figure 3. Flow chart showing process followed to producing an insulated box.

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2.2 Trolley Design

2.2.1 Design Principles-Human Factor

Push forces and other human capacities and limitations were put into consideration and assumptions are made as a design guide. These included weight of the trolley (trolley should be 15% of the gross weight of the expected load), frame supporting the caster wheel must not bend to allow the wheel to swivel easily and the handle of the trolley to be held by a mover for easy of movement of the trolley. (ISO - 11228, 2003,2005)

In a stepwise manner, the length and width of the box the trolley is to carry was measured to have the required dimensions and clearance for calculating other parameters for the frame. Designing of frame main goal is to minimize its weight, maximize its strength and rigidity while maintaining a high-level comfort. Having got the required dimension, the thickness of the angle bar is required. Also, caster wheel of diameter 200 mm was chosen which is as described in trolley design guide to accommodate larger weight.

2.2.2 Design Criteria

Fundamentally, factor of safety of the trolley must be defined and must be respected always for the frame. The Maximum Allowed Stress, s_{adm}, was calculated considering the material's Yield Stress,s_e, and the trolley safety factor (Carlos, 2018).

$$s_{adm} = \frac{s_e}{n}\text{, where } n = factor\ of\ safety \qquad (1)$$

However, assumed good factor of safety ranges between 2 and 4 and the framing material which is ASTM A36 mild steel has Yield stress of 36300 psi.

$$\sigma_{adm} = \frac{36300}{3} = 9075psi \sim 62.57\frac{N}{mm^2} \qquad (2)$$

2.2.3 Design Calculations

The design calculations are based on Kaustubh *et al.* (2015) and Shubham *et al.* (2018) work. The frame length as measured was 520 mm and width 365 mm which is to directly carry a box when fully loaded with fish and ice of total weight W = $80Kg \sim$ 784.5N which is radially a downward force that causes the frame to bend, hence we find the thickness of the angle bar used for the frame.

Figures 4, 5 and 6 show the load diagram, shearing force diagram and bending moment calculation respectively used for the design.

Figure 4. Load Diagram

$$\text{Load (F)} = 80kg \sim 784.5N \qquad (3)$$

$R_A$and R_B = vertical reaction at And B respectively.

To determine the support reaction taking moment at A, $M_A = 0$

Therefore, $(784.5 * 50.8) + (784.5 * 314.2) - (R_B * 365) = 0$ (4)

$$\frac{286342.5}{365} = R_B = 784.5$$

Summation of all vertical forces was 0. i.e $Y = 0$

$R_A + R_B = 1569$ (5)

$$R_A = 784.5$$

Load on the wheels, $R_{A1} = R_{A2} = \frac{R_A}{2} = \frac{784.5}{2} = 392.25N$ (6)

For the fixed tires.

$$R_B = 784.5N$$

Figure 5. Shear Force Diagram

Shearing Force Calculation

Shear force (SF) at A = 784.5

SF at $C = 784.5 - 784.5 = 0$

SF at $D = 784.5 - 784.5 - 784.5 = -784.5$

SF at $B = 0$

Bending Moment Calculation

$$M_A = 0$$

$$M_C = 784.5 * 50.8 = 39852.6Nmm$$

$$M_D = (784.5 * 314.2) - 784.5 * 263.4 = 39852.6Nmm$$

$$M_B = 0$$

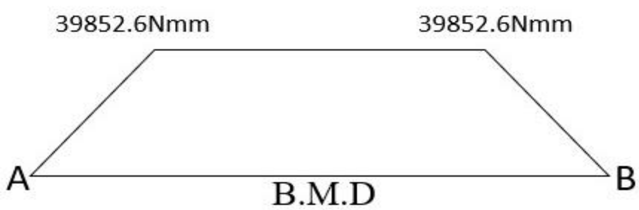

Figure 6. Bending Moment Diagram

Maximum bending moment, M = $39852.6Nmm$
Sectional Modulus for square pipe or tube was assumed

$$Z = \frac{b^4 - h^4}{6b} \quad (7)$$

$$= \frac{50.8^4 - h^4}{304.8}$$

And $Z = \frac{M}{s_{adm}} = 637.64mm^3$ (8)

Therefore, $194352.67 = 50.8^4 - h^4$

Now, $h^4 = 50.8^4 - 194352.67 = 6465350.1396$

Then, $h = \sqrt[4]{6465350.1396} = 50.42mm$

Wall thickness of angle,

$$t = \frac{b - h}{2} \quad (9)$$

$$= \frac{50.8 - 50.42}{2} = 0.2mm$$

Standard value for angle thickness of 0.5 mm gauge was used for this work.

2.2.4 Design Layout

The layout is a three-wheeled which can be used as suited for in the two configurations of three wheeled vehicle (Delta and Tadpole configurations). The design outline of trolley is shown in Figure 7.

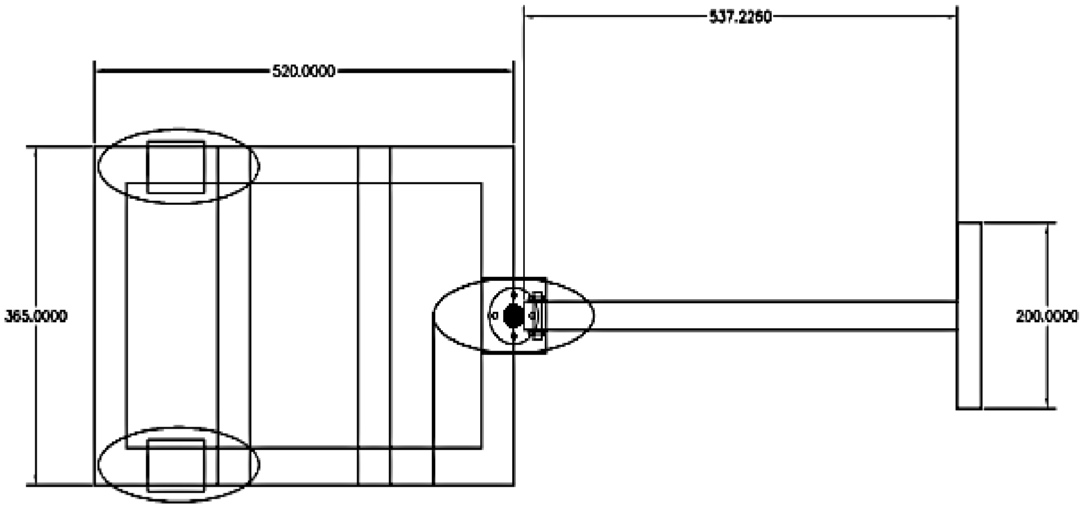

Figure 7. Design outline of the trolley

2.3 Performance Test

2.3.1 Drainage Testing

The drainage of the modified insulated box was tested with known amount of water poured in the box and the time taken for complete draining of the water was noted and compared to the earlier design.

2.3.2 No load and Capacity Testing

No load test was carried out as described by Ishola *et al.* (2015), ice blocks were purchased at Abule Oja, Lagos State and transported to NSPRI Lagos Zonal Office fish processing center. Measured quantity of crushed ice were introduced into the modified insulated box and immediately transferred outside the fish processing center. Ambient temperature and relative humidity were recorded using digital data logger and the capacity of the modified insulated box was determined.

3. Results and Discussion

3.1 Modified Box

The modified box holds approximately 60 kg of ice as compared to the earlier design that can take approximately 18 kg of ice. Also, it was observed that the draining efficiency of the modified box was better than the earlier design; 5 L of water poured in the modified box took 23 min 42 sec to drain completely compared to 50 min 25 sec observed in the earlier design with retention of 850 mL of water. This was due to change in the position of the drain spot of the modified box and slanting of the box in contrast to the earlier box in which drip hole was located in the middle of the box and elevated.

3.2 No Load Test

In order to test the insulating capacity of the modified box, the box was put through a no-load test experiment using crushed ice. 59 kg of crushed ice was introduced and placed in the open at the fish processing center NSPRI Lagos office at an ambient temperature of 28.8 °C and 74.6 % relative humidity. The ice melted completely at 96 hours in which amount of ice after 24 hours of sampling was carried out. Figure 10 represents no load test parameters including temperature, relative humidity and quantity of ice that remained in a 24hour sampling period while Figure 11 shows the box fully loaded with crushed ice.

Figure 10. No load test parameters.

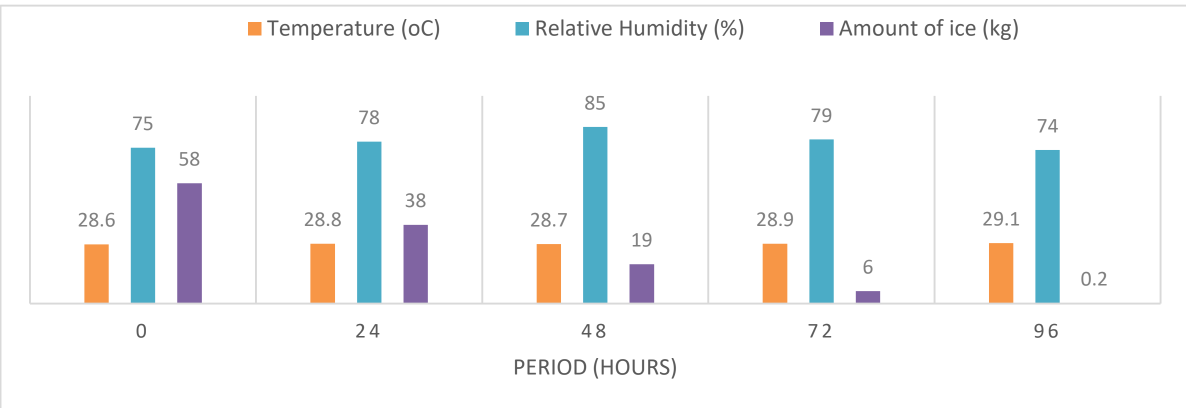

Figure 11. No load test (Fully loaded box with ice)

3.3 Trolley

Total weight of the trolley was found to be approximately 7.4 kg which is in line with trolley design recommendation that states that trolley should be around 15% of the total weight it was meant to carry according to designing trolleys guide. Consideration as to where the trolley will be used was noted which is riverine area as obtained from observations report from responders of the earlier fish box preceding this newly fabricated box. Taking this into consideration, the trolley was painted with an anti-corrosion paint which is to serve as protection for the trolley skeleton. The trolley and loaded stacked boxes are shown in Figure 12.

a. b.

Figure 12. Actual views of the (a) trolley and (b) loaded modified Insulated boxes stacked on the trolley.

4. Conclusion

This study was carried out to modify the insulated fish box by increasing its holding capacity, rechanneling the drainage hole to improve the area of water letting out system and also to design and fabricate a trolley for easy carriage. As shown in the results, the drainage of the modified insulated box performed better compared to the earlier design and the box can take approximately $60\ Kg$ of ice block as compared to the earlier design which takes 18 Kg.

Also, the introduction of trolley and a swivel wheel for easy movement and steering over different terrains will boost productivity (as minimal energy is required). There will be an improvement in post-harvest handling of fresh fish leading to reduction in loss and increase earnings in the value chain.

Conclusively, the study has successfully achieved all its objectives and therefore adoptable for any fish boxes to be produced.

Declaration

There is no conflict of interest and authors agreed to publish the manuscript

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