Design and Fabrication of a Cost Effective Four Cavity Plastic Injection Mould for Bottled Water Handle

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Authors’ contributions

This work was carried out in collaboration between all authors. Author HEC designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed literature searches. Authors HCG and MCN scrutinized and managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Design and fabrication of a cost effective four cavity plastic injection mould for production of bottled water handle with locally available materials has been achieved. This research is appropriate considering the impact on sales of a sampled company that used handles for their bottled water before the scarcity of handles as a result of monopoly in importation. The clamping force which is a function of cavity pressure, cavity force and projected area was obtained as 243.2239N. The maximum deflection and the maximum bending stress were calculated to be $2.3282 \times 10^{-3}$ mm and $4.4677 \times 10^5$ N/m² respectively. The impact of the handle on the rate of return of the sampled company was tested. It was observed that before the introduction of handle, the Return on Investment (ROI) was approaching 30% and when handle was introduced, the ROI increased to 46.34% and 46.05% for the locally and foreign made handles respectively. However, the ROI declined to 34.41% when the handle was removed in both cases. This clearly shows that the handle has a great impact on the bottled water sales and that the market share for bottled water
industries is expected to increase due to public acceptability. Also, the introduction of handle allowed for better convenience in carrying bottled water especially the 1.5 litre sizes.

Keywords: ROI; bottled water handle; regime.

NOMENCLATURES

- \( F_i \) – Cavity Force
- \( F \) – Clamp Force
- \( W \) – Uniformly Distributed Load (UDL) as a result of the Clamping Force
- \( w \) – Load per Unit length across the face of the mould, Uniform load on the beam
- \( l \) – Length of the beam, Length of the mould face
- \( E \) – Modulus of elasticity
- \( I \) – Area moment of Inertia
- \( M \) – Maximum Bending Moment
- \( b \) – Length of horizontal side of the cross-section
- \( h \) – Length of vertical side of the cross-section
- \( Q \) – Volume flow of the intended resin to be used
- \( L \) – Length of Part being considered
- \( D \) – Runner diameter
- \( S_{\text{max}} \) – Maximum wall thickness of the molded part
- \( R \) – Hydraulic depth of Runner
- \( S \) – Cross-Sectional Area of Runner
- \( \Delta P \) – Pressure loss at the Gate
- \( \mu \) – Viscosity of resin
- \( F_E \) = Ejection Force
- \( F_W \) = Ejection Load
- \( \text{ROI} \) – Return on Investment

1. INTRODUCTION

Nowadays, Injection moulding represents a large portion of the entire plastics processing industry and plastic is now one of the most widely used material in the world, according to Pattnaik et al. [1]. Among various plastic production technologies, injection moulding counts for a significant proportion of all plastic products from micro to macro components stated by Garvey [2].

Today, medical experts are encouraging people to drink water always for vitality. Because of this, demand for bottled water has increased as people tend to carry water about.

According to Weissmann [3], the introduction of handle on bottled water started with the introduction of handles on large size extrusion blow moulded containers which made them more user-friendly, especially where the total weight of the package reached several kilos in household product containers, and where larger weights of 5 to 20-litre containers were involved. Therefore, it is no wonder that handles can be found on most large bottles today, including household chemicals, garden chemicals, automotive fluids, beverage containers (non-carbonated), edible oil bottles, and even the 1.75-litre liquor bottles.

In Nigeria today, the standard sizes for bottles of bottled water are 20 liter, 1.5 liter, 0.75 liter and the 0.5 liter Polyethylene Terephthalate (PET). The 20 liter bottles are for water dispensers which cannot be carried about while the 1.5 liters, 0.7 liters and the 0.5 liters are used to package other things, including bottle water, and they can easily be carried about. The bottles are usually blow moulded.

Introduction of injection moulded polyethylene handles to be attached on the neck of the bottled water of smaller sizes of 1.5 liters and the 0.75 liter sizes has become necessary to enhance better convenience in carrying bottled water and increased acceptance by consumers.

This paper presents the design and fabrication of a four cavity Bottled Water Handle Mould. Also the impact of the handle on a sampled company was ascertained to show the level of public acceptability.
2. DESCRIPTION OF THE MOULD

Just like most moulds, the “four cavity bottled water handle mould” is separated into two sides at a parting line, the “A” side, and the “B” side, to permit the part to be extracted. Plastic resin enters the mould through a sprue in the “A” plate, which branches out between the two sides through channels called runners, and enters each part cavity through a gate. Inside each cavity, the resin flows around cores and conforms to the cavity geometry to form the handles. The amount of resin required to fill the sprue, runner and cavities of a mould is a shot. When a core shuts off against an opposing mould cavity or core, a hole results in the part. Air in the cavities when the mould closes escapes through very slight gaps between the plates and pins, into shallow vents created along the ejection pin.

To permit removal of the part, none of its features was allowed to overhang one another in the direction that the mould opens. Sides of the handles that appear parallel with the direction of draw are typically angled slightly with draft to ease release of the handles from the mould. Because areas in the cavities with bucket-like features tend to shrink onto the cores that form them while cooling, and cling to those cores when the cavity is pulled away; the mould is designed so that the moulded handle reliably remains on the ejector “B” side of the mould when it opens by making the bucket-like features remain on the “B” side, and draws the runner and the sprue out of the “A” side along with the handles. The handles then fall freely when ejected from the “B” side. The resin for the handle is thermoplastic, therefore, coolant, usually water with corrosion inhibitors, will circulates through passageways bored through the main plates on both sides of the mould to enable temperature control and rapid part solidification.

To ease maintenance and venting, cavities and cores are divided into pieces, called inserts, and subassemblies, also called inserts, blocks, or chase blocks. Fig. 2.1 depicts moulds and its component parts.

![Fig. 2.1. Moulds and its component parts](image-url)
2.1 Design Considerations

During the mould design, these important considerations and precautions were taken to ensure that the mould meets the required international standard in mould design as in the works of Bayer Corporation [4] and Gupta and Khurmi [5]:

1. Material that will be most suitable for the design.
2. The clamping force for the mould.
3. Availability of material locally.
4. Maintainability.
5. Cost of manufacture.
6. Suitability to local consumers.
7. The cavity features was design to easy separation of the two sides of the mould.

2.2 Design Specifications

The following design specifications were taken into consideration:

a. Mould should be able to withstand loading of 5 tons.

b. Density of material used must be less than that of lead.

c. The clamping position of the mould must be inculcated during design to prevent it from slipping.

d. Material used must withstand the melting temperature of resin (about 200°C).

e. The mould is designed to have a proper resting base on the machine platens.

f. Tough and stiff materials were selected to withstand maximum loading of 5 tons and ensured material does not wear easily.

g. The cavity must have uniform wall thickness.

h. Avoided sharp corners in the design. Sharp inside corners concentrate stresses from mechanical loading, substantially reducing mechanical performance.

i. Provided minimum draft angles or tapers of 0.5° on all product features such as walls, ribs, posts, and bosses that lie parallel to the direction of release from the mould to ease part ejection.

j. The mould is designed so that the cores can separate from the part in the mould-opening direction.

2.3 Design Calculations

The method used for determining the required clamp force was to obtain the product of the projected area of the part to be moulded and a factor of 2 to 8 tons per square inch which is the maximum machine capacity (tonnage) the mould is being designed for. According to Hieber and Isayev, [6], the lower tonnage can be used for high flow materials and the higher tonnage for low flow (stiff) materials. High Density Polyethylene (HDPE) is used and it is a high flow material. Therefore, being on a safe side, an average of 5 tons/in$^2$ was used.

$$F = 5 \times 6.89 \times 10^{-3} \text{ MPa or N/mm}^2$$  \[\text{conversion factor from lb/in}^2 \text{ (psi) to MPa (N/mm}^2\text{)}\]

Cavity Pressure = $3.45 \times 10^{-2} \text{ MPa}$.

2.3.1 Projected area determination

Fig. 2.2 shows the diagram of the designed Bottled Water Handle showing labels which indicate the different cross-sections that are present on the handle. These sections are labeled according to the similarity of the figures they represent to aid in the projected area calculation. Each of the labeled areas is demarcated with a yellow line; for instance, label “A” represent a semicircular cross-section while label “B” represents a rectangular cross-section and so on.

The average thickness of the product is estimated to be 2 mm, hence estimated shot volume = 6409.06*2 = 12818.12 mm$^3$.

Therefore, the projected area is $6409.06 \text{ mm}^2$; it substitute in equation (1) to obtain;

$$F_i = P \times A$$ \hspace{1cm} (1)

$F_i$ – Cavity Force

P – Cavity pressure

A – Projected Area

$\therefore$ Cavity Force, $F_i = 221.11 \text{ N}$

Therefore, Clamping Force, $F = 221.11 + 10\% F_i$

= 221.11 + 22.11

$\therefore F = 243.22 \text{ N}$

The force on the face of the mould which is equal to the clamping force is a Uniformly Distributed Load (UDL).
Fig. 2.2. Cross-section of handle showing the dimensions and labels

| S/N | Portion label | Number per cavity | Number on mould | Formula used for the section | Unit area (mm$^2$) | Area on cavity (mm$^2$) | Total area on mould (mm$^2$) |
|-----|--------------|------------------|-----------------|-------------------------------|-------------------|-------------------------|-----------------------------|
| 1   | A            | 2                | 8               | $\frac{\pi r^2}{2}$         | 39.30             | 78.60                   | 314.40                      |
| 2   | B            | 2                | 8               | Lb                           | 185.00            | 370.00                  | 1480.00                     |
| 3   | C            | 2                | 8               | $\frac{1}{4}(\pi R^2 - \pi r^2)$ | 90.32            | 180.64                  | 722.56                      |
| 4   | D            | 1                | 4               | Lb                           | 110.00            | 110.00                  | 440.00                      |
| 5   | E            | 2                | 8               | $\frac{1}{2}bh$             | 19.25             | 38.50                   | 154.00                      |
| 6   | F            | 2                | 8               | $lb - \frac{\pi r^2}{2}$    | 32.87             | 65.73                   | 262.92                      |
| 7   | G            | 1                | 4               | $\frac{1}{4}(\pi R^2 - \pi r^2)$ | 358.14          | 358.14                  | 1432.56                     |
| 8   | H            | 4                | 16              | $\frac{1}{2}(\pi R^2 - \pi r^2)$-lb | 69.09           | 276.36                  | 1105.44                     |
| 9   | K            | 1                | 4               | Lb                           | 3.00              | 3.00                    | 12.00                       |
| 10  | L            | 1                | 4               | Lb                           | 85.50             | 85.50                   | 342.00                      |
| 11  | M            | 1                | 1               | $\pi r^2$                    | 143.14            | 143.14                  | 143.14                      |

Total projected area 6409.06

2.3.2 Determination of the reactions $R_A$ and $R_B$ at supports “A” and “B”

For Equilibrium,

$$R_A + R_B = W$$  \hspace{1cm} (2)

$$\sum M = 0$$  \hspace{1cm} (3)

Taking moment about ‘A’, we have

$$R_A = 121.61 \text{ N and } R_B = 121.61 \text{ N}$$

Fig. 2.3. The Free Body Diagram (FBD) of the force acting on the face of the mould at maximum clamping force
2.3.3 Determination of Shear Force (SF) equation at any given point on the face plate

\[ V_x = R_x - wx \]

\[ V_x = 121.61 - 1.26x \]

2.3.4 Determination of Bending Moments (BM) on the mould

\[ M = \frac{wx}{2} (l - x) \]

\[ \text{Note:} \quad \frac{dM}{dx} = \frac{wl}{2} - wx = V_x \]

However, \( @ x = \frac{l}{2}, M \) has its maximum value
\[ \therefore M_{\text{max}} = 5.87 \text{Nm} \]

2.3.5 Determination of maximum deflection on the mould

According to Bayer Corporation [4], Maximum elastic deflection (at the mid-point along \( l \)) of a beam under a uniform load is given as follows:

\[ \Delta = \frac{5wl^4}{384EI} \]

Where,
\( w \) – Uniform load on the beam (force per unit length)
\( l \) – length of the beam
\( E \) – Modulus of elasticity
\( I \) – Area moment of Inertia

For tool steel, \( E \) is at the range of 190 – 212. For the sake of this work, it adopt 190 GPa = \( 190 \times 10^9 \text{N/m}^2 = 190 \times 10^5 \text{N/mm}^2 \).

But,
\[ I = \frac{bh^3}{12} \]
\[ b = 197 \text{mm}, \text{and} \ h = 20 \text{mm} \]
\[ I = \frac{193 \times 20^3}{12} = 128666.67 \text{mm}^4 \]
\[ \therefore \Delta_{\text{max}} = 2.328\times10^{-3} \text{mm} \]

2.3.6 Determination of maximum bending stress on the mould

The maximum bending stress for a rectangular cross section could be given as stated below according to Bayer Corporation [4].

Maximum Bending Stress,
\[ \sigma_{\text{max}} = \frac{Mc}{I} = \frac{M}{Z} = \frac{6M}{bh^2} \]

\[ \sigma_{\text{max}} = \frac{6M}{bh^2} \quad (8) \]

\( M \) – Maximum Bending Moment
\( b \) – Length of horizontal side of the cross-section
\( h \) – Length of vertical side of the cross-section
\( c = \frac{h}{2} \)

\[ Z = \text{Sectional Modulus}, \frac{l}{c} \]
\[ \sigma_{\text{max}} = 4.4677 \times 10^5 \text{ N/m}^2 \]

\[ b = 197 \]
\[ c = h/2 = 20 \]

\[ h = 20 \]

\[ \text{All Dimensions are mm} \]

Fig. 2.4. Rectangular face plate showing details of deflection

Fig. 2.5. Rectangular cross-section of the face plate
2.4 The Material Selection

The choice of material to build a mould is primarily one of economics. To select the adequate material for the design, the first step was to translate the design requirements, which was done in section 2.1, into a material specification. Making reference to the Ashby’s Chart according to Ashby [7], materials that fail constraints in the specification were screened out to obtain the go/no-go criteria. Then the next was ranking (an ordering of the materials that fall within the “go” criteria) by ability to meet objectives in other words called Material Indices. The promising candidates (materials) were sought for. The next step is to seek, from the subset of materials which satisfy the primary constraints, those which maximize the performance of the component. For instance, for the design of stiff components; the modulus E is plotted against density $\rho$, on log scales of the Ashby chart. The performance index (tension on stiff beam) is given as shown:

$$ C = \frac{E}{\rho} $$

(10)

Taking logs of equation (1),

$$ \log E = \log \rho + \log C $$

(11)

This is an equation of the form $y = mx + b$ which is a family of straight parallel lines; one line for each value of the constant C. The slope is always 1 and log C is the y intercept. The index for bending on beam is:

$$ C = \frac{E}{\rho} $$

(12)

Equation (3) will gives another family of lines, this time with a slope of 2.

The index for bending on light-stiff plate is:

$$ C = \frac{E}{\rho} $$

(13)

Equation (4) will gives another family of lines, this time with a slope of 3.

All materials which lie on ISO-line of $E^{\frac{1}{3}}/\rho$ will perform equally well.

To obtain the optimum material, other Ashby material selection charts that highlight other material qualities were considered. They as stated below:

- Strength – Density chart: $\frac{g}{\rho^2}$ and $\frac{g}{\rho}$
- Fracture Toughness – Density chart: $\frac{k}{\rho^2}$, $\frac{k}{\rho}$, $\frac{k}{\rho^2}$, $\frac{k}{\rho}$ and $\frac{k}{\rho^2}$
- Modulus – Relative Cost chart. $C_R = \frac{c}{kg \text{ of material}}$ $c/\text{kg of mild steel rod}$

Finally steel was most favoured because it satisfies the criteria:

- Economic machinability
- Smallest change in size upon heat treatment
- Good polishability
- Great compressive strength
- High wear resistance
- Sufficient corrosion-resisting quality

2.5 Manufacturing Processes

Once the design is completed manufacturing begins. Mould making involves many steps which include:

- Marking-Out
- Milling and turning
- Heat-treating
- Grinding and honing
- Electrical discharge machining
- Polishing and texturing

To save cost, common mould components are purchased from suppliers e.g. bolts.

When all of the parts are completed the next step is to fit, assemble and test the mould. The mould must have venting features added to allow the air to escape as earlier stated in the vent design. At last, the mould must be tested to insure the products are correct and that the mould is performing properly.

2.6 The Operation Process Chart

The Fig. 2.6 represents the operational process involved in the manufacture of the mould. The mould is made of two major parts, the cavity and the core. Under the cavity, are the female base plate, female face plate, the sprue bush and the locating ring. While on the core are the male base plate, male face plate, face plate support, locating pin, ejector plate and the ejector pin. Under each are circles and rectangular boxes that indicate the operations and the events taken to produce individual parts before finally assembling them to form the cavity and the core respectively.
Fig. 2.6. The operation process charts
2.7 Exploded View of Mould

Below is the exploded view of the manufactured mould showing all the parts arranged for assembly.

![Exploded View of Mould](image)

**Fig. 2.7. The exploded views of the mould**
3. COST ANALYSIS

For a 50 kg material, revenue accrued is given as:

\[ R = C + P \]

Cost, \( C = \) Overhead + Transport + Material Cost
Profit, \( P = \) Markup, \( M \) \(*\) Cost, \( C \)

From [online] [8] and Jeremiah and Amos [9], Corporate Tax Rate = 30%
Inflation Rate = 7.9%
Interest Rate, \( i = 13\% \)

3.1 Weighted Average Cost of Capital (WACC)

\[ WACC = \%\text{Debt}\ast i + \%\text{Equity}\ast r \]

\[ WACC = 0\%\ast 13\% + 100\%\ast 18\% \]
\[ = 18\% \]

3.2 Minimum Acceptable Rate of Return (MARR)

\[ \therefore MARR_{\text{Before Tax}} = \frac{\text{MARR}_{\text{After Tax}}}{(1 - \text{Effective Tax Rate})} \]

\[ \therefore MARR_{\text{Before Tax}} = \frac{0.18}{(1 - 0.3)} = \frac{0.18}{0.7} = 25.71\% \]

Therefore, Markup = 25.71%

For a 50 kg material, the costs are attached as below:

Material cost = \( \text{₦} 100000 \)
Transport = \( \text{₦} 500 \)
Overhead = \( \text{₦} 5021.59 \)
Profit, \( P = \text{₦} 3990.60 \)

\[ M_p = 5021.59 + 500 + 10000 + 3990.60 \]
\[ M_p = \text{₦} 19512.20 \]

\[ R = \frac{R_a \ast M}{50000} \]

\[ R_a \] – Revenue accrued from 50 kg material
\[ M \] – Mass of a handle (g)

After weighing the handle, it was observed that the weight is 2.314 g; fraction of the runner, sprue and gate weight is 1.72 g.

Therefore, \( 2.314 + 1.72 = 4.03g \).

\[ \therefore \text{Cost of a Handle} \approx \text{₦} 1.60 \]

3.3 Cost of Introducing Handle in a Company

3.3.1 Work measurement

Table 3.1 shows the “Cycle Study Form” and the time obtained for the element in the work measurement.

To obtain the time taken by a worker to fix one handle on a bottled water, work measurement, which involves motion and time study, was carried out as stated in Table 3.1. Equation (18) shows how the average time was obtained mathematically.

\[ T_{av} = \frac{\sum t_o}{N} \]

\[ T_{av} \] – Average time taken to fix one handle on a bottle
\[ \sum t_o \] – sum of observed time
\[ N \] – number of observations

Average time taken to fix one handle on a bottle = 10.50 sec
Average time taken to fix handles on one dozen = 10.50 \( \times \) 12 = 126 sec
Available working time in a month = 25 days \( \times \) 8 hrs = 200 hrs/month
= 200 \( \times \) 3600 = 720,000 sec/month
Average salary of a factory worker for a month = \( \text{₦} 18000 \)

\[ S = \frac{S_m}{W_t} \]

\[ S \] – salary of a staff per second
\[ S_m \] – Salary for one month
\[ W_t \] – Available working time in a month

Average salary of a staff per second

\[ = \frac{18000}{720000} = \text{₦} 0.03 \text{ per Sec} \]
\[ L = S \times T_d \]  

L = Labour Cost for hanging handles on a dozen of bottled water  
\[ S \] = salary per second  
\[ T_d \] = time to fix handle on one dozen

Therefore, labour cost of hanging handles on a dozen of bottled water = 0.025 x 126 = \₦ 3.15

Other cost incurred as a result of introducing the handle for a dozen:

- Transportation = \₦ 1.00
- Disinfectant = \₦ 3.775
- Total = \₦ 4.78

Recall, cost of one handle = \₦ 1.60

Hence, cost of handle for a dozen = \₦ 1.60 x 12 = \₦ 19.20 /Dozen

Therefore, extra cost incurred as a result of introducing Handle for one dozen = Cost of one Dozen of Handle + Labour + Other Cost Incurred  
\[ = 19.20 + 3.15 + 4.78 = \₦ 27.125 /Dozen \]

### 3.4 Tabulated Costs of Material for Conventional Bottled Water

The tables show the materials and their cost for making conventional bottled water without the consideration of the cost of handle.

**Table 3.1. Cycle study form**

| S/N | Element       | Observed Time, OT (Sec) | Total OT | Ave. OT | R | BT |
|-----|---------------|--------------------------|----------|---------|---|----|
| 1   | Hanging of handle on bottle water | 10.80 10.60 10.50 10.70 10.60 10.40 10.30 10.40 105 | 10.50 | | |

*Note: OT = Observed Time, R = Rating, BT = Basic Time*

**Table 3.2. Cost of one dozen of 50 cl bottle water**

| S/N | Description | Quantity | Unit Cost (₦) | Cost (₦) |
|-----|-------------|----------|---------------|----------|
| 1   | Bottle      | 12       | 15            | 180      |
| 2   | Label       | 12       | 3             | 36       |
| 3   | Water       | 12       | 0.15          | 1.8      |
| 4   | Cover       | 12       | 2.5           | 30       |
| 5   | Shrink wrap | 1        | 5             | 5        |

**Total Cost** 252.8

**Table 3.3. Cost of one dozen of 75 cl bottle water**

| S/N | Description | Quantity | Unit Cost (₦) | Cost (₦) |
|-----|-------------|----------|---------------|----------|
| 1   | Bottle      | 12       | 17            | 204      |
| 2   | Label       | 12       | 5             | 60       |
| 3   | Water       | 12       | 0.225         | 2.7      |
| 4   | Cover       | 12       | 2.5           | 30       |
| 5   | Shrink wrap | 1        | 7             | 7        |

**Total Cost** 303.7

**Table 3.4. Cost of one dozen of 150 cl bottle water**

| S/N | Description | Quantity | Unit Cost (₦) | Cost (₦) |
|-----|-------------|----------|---------------|----------|
| 1   | Bottle      | 12       | 21            | 204      |
| 2   | Label       | 12       | 5.5           | 66       |
| 3   | Water       | 12       | 0.45          | 5.4      |
| 4   | Cover       | 12       | 2.5           | 30       |
| 5   | Shrink wrap | 2        | 7             | 14       |

**Total Cost** 367.4
3.5 Return on Investment (ROI) Analysis

In order to make decision on which of the investment regime to invest in, return on investment (ROI) analysis is used. This enabled us to choose which of the investment regime has a better return.

\[
\text{ROI} = \frac{R - I_c}{I_c} \quad (21)
\]

ROI - Return on Investment

\( R \) - Revenue from Investment
\( I_c \) - Investment Cost

This analysis was done on the three regimes as stated below:

3.5.1 Considering the response of the locally made handle

3.5.1.1 Before handle regime

\[
R_{BHR} = \sum A_{PBHR}
\]

\[
BHR = \sum A_{PBHR}
\]

\( R_{BHR} \) - Average sales of a dozen of the bottled Water sizes before handle regime
\( I_{BHR} \) - Average Cost of producing a dozen of the bottled Water sizes before handle regime

\[
R_{BHR} = \left\{ (A_{50cBHR}) + (A_{75cBHR}) + (A_{150cBHR}) \right\}
\]

\[
I_{BHR} = \left\{ (I_{50cBHR}) + (I_{75cBHR}) + (I_{150cBHR}) \right\}
\]

3.5.1.2 During handle regime

\[
R_{DHR} = \sum A_{PDHR}
\]

\[
DHR = \sum A_{PDHR}
\]

\( R_{DHR} \) - Average sales of a dozen of the bottled Water sizes During handle regime
\( I_{DHR} \) - Average Cost of producing a dozen of the bottled Water sizes During handle regime

\[
R_{DHR} = \left\{ (A_{50cDHR}) + (A_{75cDHR}) + (A_{150cDHR}) \right\}
\]

\[
I_{DHR} = \sum A_{PDHR}
\]
3.5.1.3 After handle regime

\[ I_{eAHR} = \sum A_{PAHR} \]  

\[ I_{eAHR} = \text{Average Cost of producing a dozen of the bottled Water sizes After handle regime} \]

\[ I_{eAHR} = \left[ (I_{c50cAHR}) + (I_{c75cAHR}) + (I_{c150cAHR}) \right] \]  

\[ I_{cAHR} = \text{Average Cost of producing a dozen of the bottled Water sizes After handle regime} \]

\[ I_{cAHR} = \left[ (I_{c50cAHR}) + (I_{c75cAHR}) + (I_{c150cAHR}) \right] \]  

\[ I_{cAHR} = \text{Investment Cost} \]

\[ I_{c50cAHR} = \text{Average Cost of producing a dozen of 50 cl After handle regime} \]

\[ I_{c75cAHR} = \text{Average Cost of producing a dozen of 75 cl After handle regime} \]

\[ I_{c150cAHR} = \text{Average Cost of producing a dozen of 150 cl After handle regime} \]

4. RESULTS

The design was done with the proper engineering design procedure and the following results were obtained.

The cost of introducing handle was determined; also the difference in the Cost/mass was obtained between the foreign and locally made handle and presented in the table.

4.1 Comparison of Locally Made Handle and Foreign Handle

The locally made handle showed a significant reduction in weight to that of the foreign made handle. This reduction also shows that the material usage is reduced from the cost/mass ratio column. This in turn shows a reduction in cost of production.

4.1.1 Financial implication of using bottle water handle

From section 3.2, the cost of handle was obtained as $1.60 per handle. This value was in turn used to obtain the cost of introducing handle into the bottled water company in section 3.3 to be $27.13 per dozen. Furthermore, with reference to the sales data presented in Appendix A1, the rate of return on investment (ROI) as a result of this extra cost.
4.1.2 Considering the response of the locally made handle

The graph above represents the response of the Locally Made Handle. The graph shows that before the introduction of handle, the ROI was approaching 30% and when handle was introduced, the ROI increased to 46.34%. However, the ROI took a nose dive when the handle was removed to the tune of 34.41%.

4.1.3 Considering the response of the foreign made handle

The graph above represents the response of the Foreign Made Handle. The graph shows that before the introduction of handle, the ROI was approaching 30% and when handle was introduced, the ROI increased to 46.05%. However, the ROI took a declined to 34.41% when the handle was removed.

Table 4.1. Results from mechanical design

| S/N | Features                          | Numerical values |
|-----|-----------------------------------|------------------|
| 1   | Cavity Pressure.                  | 0.03 MPa         |
| 2   | Projected Area Determination      | 6409.06 mm²      |
| 3   | Clamping Force                    | 243.22 N         |
| 4   | Reactions at the supports Rₐ and Rₐ | 121.61 N        |
| 5   | Determination of Shear Force (SF) | $V_x = 121.61 - 1.26x$ |
| 6   | Determination of Bending Moments (BM) on the mould | 5.87 Nm |
| 7   | Maximum Deflection                | 2.3282x 10² mm   |
| 8   | Maximum Bending Stress            | 4.4677x10² N/m²  |

Table 4.2. Comparison of locally made handle and foreign handle

| Handle type | Cost ($) | Mass (g) | Cost/Mass ratio ($) |
|-------------|----------|----------|---------------------|
| Foreign     | 2.50     | 2.47     | 1.01                |
| Local       | 1.60     | 2.31     | 0.69                |
| Difference  | 0.90     | 0.16     | 0.32                |

Table 4.3. locally made handle responses

|                                  | Before handle regime (%) | During handle regime (%) | After handle regime (%) |
|----------------------------------|--------------------------|--------------------------|------------------------|
| Response of Locally Made Handle (ROI) | 29.69                    | 46.34                    | 34.41                  |

Fig. 4.1. Response of locally made handle
Table 4.4. Foreign made handle responses

|                     | Before handle regime (%) | During handle regime (%) | After handle regime (%) |
|---------------------|--------------------------|--------------------------|-------------------------|
| Response of foreign made handle | 29.69                    | 46.05                    | 34.41                   |

**Fig. 4.2. Response of foreign made handle**

5. DISCUSSION

The design results as obtained shows that maximum deflection is $2.33 \times 10^{-3}$ mm. Therefore, the deflection obtained is minimal, therefore is negligible. The maximum bending stress is $4.4677 \times 10^5$ N/m$^2$ this indicates that the material can withstand the stress as the yield strength, $S_y$ and ultimate tensile strength, $S_u$ of steels are within the values $5.1\times10^8$ N/m$^2$ and $7.1\times10^8$ N/m$^2$ according to Todd et al. [10].

The cost of introducing handle was determined; also the difference in the Cost/mass was obtained between the foreign and locally made handle and presented in the table.

It was presented that the difference in cost/mass ration is 0.3199 N/g. This means that in every 50 kg of handle, the bottled water company saves:

$50000 \times 0.32 = \text{₦} 15995$.

This amount of money saved is significant enough to encourage the bottled water companies in Nigeria.

5.1 Comparing the Responses of the Locally and the Foreign Made Handle

The graph above represents the superimposition of the responses of the locally and Foreign Made Handle. The graph curves show that before the introduction of handle, the ROI was approaching 30 % and when handle was introduced, the ROI increased to 46.34 % and 46.05 % for the locally and foreign made handles respectively. This 0.29 % difference during the introduction of handle could be attributed to $\text{₦} 0.90 ($\text{₦} 2.50 - \text{₦} 1.60) in foreign and locally made handle price. However, the ROI took a declined to 34.41 % when the handle was removed in both cases though this is still higher than the response at the initial time before the introduction of handle. This is

Table 4.5. Comparison of foreign and locally made handle responses

|                     | Before handle regime (%) | During handle regime (%) | After handle regime (%) |
|---------------------|--------------------------|--------------------------|-------------------------|
| Response of locally made handle | 29.69                    | 46.34                    | 34.41                   |
| Response of foreign made handle | 29.69                    | 46.05                    | 34.41                   |
attributed to the fact that the company still retains some of the market share gained during the introduction of handle.

6. CONCLUSION

This work has demonstrated the ability to design and manufacture an injection mould for bottled water handle from locally available materials. With the increase in the number of bottled water industries, this project would have a profitable application in bottled water production due to increased demand for bottled water. The simplicity of the design and the availability of materials for the mould design, and the handle from local petrochemical industries make this work practicable. The impact of the handle on the financial returns of the sampled company is enough reason to encourage bottled water companies to venture into the use of handle for their smaller sizes, 1.5 liter and 0.75 liter, of bottled water. Nevertheless, the cost incurred as a result of introduction of handle to the bottled water is small compared to the benefit accrued to the company. Commercializing this will be cheap and economically viable to the mould manufacturing industry, the plastic industry and the bottled water industry.

In the future, it is recommended that more work be done on the optimization of number of cavities for economic use of machines. Also, it is recommended that more research work be done to ascertain the acceptability of the product owning to the effect of the handle noticed on the company as reported in this work.

Therefore, we recommend that local plastic industries should embark on the production of bottled water handle for local consumption. Also, bottled water companies should patronize local manufacturers of bottled water handle at reduced cost.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Appendix I

Data showing the weekly sales and financial details of bottle water before, during and after the use of bottle water handle by Impact Pharmaceuticals Ltd, Opposite Anamco, Emene Industrial Layout, Enugu. November, 2014-January, 2015.

Table App I-1. Data Showing the weekly sales and financial details of bottle water before the use of bottle water handle

| Sales before the use of bottle water handle (₦) |
|-----------------------------------------------|
| 50cl | 75cl | 150cl |
| Quantity (Dozens) | 50cl | 75cl | 150cl |
| Cost (₦) | Cost (₦) | Cost (₦) |
| 300 Each | 400 Each | 600 Each |

| November 2007 week | 50cl | 75cl | 150cl |
|---------------------|------|------|------|
| 1                   | 119  | 35700| 219  | 87600| 14   | 8400 |
| 2                   | 113  | 33900| 221  | 88400| 12   | 7200 |
| 3                   | 117  | 35100| 227  | 90800| 17   | 10200|
| 4                   | 118  | 35400| 225  | 90000| 16   | 9600 |

| December 2007 week | 50cl | 75cl | 150cl |
|--------------------|------|------|------|
| 1                  | 113  | 33900| 221  | 88400| 15   | 9000 |
| 2                  | 121  | 36300| 230  | 92000| 19   | 11400|
| 3                  | 118  | 35400| 227  | 90800| 13   | 7800 |
| 4                  | 116  | 34800| 222  | 88800| 14   | 8400 |

| January 2008 week | 50cl | 75cl | 150cl |
|-------------------|------|------|------|
| 1                 | 114  | 34200| 221  | 88400| 20   | 12000|
| 2                 | 116  | 34800| 231  | 92400| 14   | 8400 |
| 3                 | 120  | 36000| 226  | 90400| 12   | 7200 |
| 4                 | 116  | 34800| 217  | 86800| 16   | 9600 |

| February week | 50cl | 75cl | 150cl |
|---------------|------|------|------|
| 1             | 116  | 34800| 213  | 85200| 13   | 7800 |
| 2             | 113  | 33900| 228  | 91200| 17   | 10200|
| 3             | 121  | 36300| 223  | 89200| 14   | 8400 |
| 4             | 119  | 35700| 233  | 93200| 16   | 9600 |

| March week | 50cl | 75cl | 150cl |
|------------|------|------|------|
| 1          | 113  | 33900| 212  | 84800| 25   | 15000|
| 2          | 118  | 35400| 222  | 88800| 13   | 7800 |
| 3          | 111  | 33300| 231  | 92400| 11   | 6600 |
| 4          | 122  | 36600| 225  | 90000| 14   | 8400 |

Before handle regime

| 50cl | 75cl | 150cl |
|------|------|------|
| Mean Quantity | 116.7 | 223.5 | 15.25 |
| Mean Sales    | 35010 | 89400 | 9150  |
Table App I-2. Data showing the weekly sales and financial details of bottle water during the use of bottle water handle

| Sales during the use of bottle water handle (₦) |   |   |   |   |   |
|-----------------------------------------------|---|---|---|---|---|
|                                               | 50cl | 75cl | 150cl |
|                                               | Quantity | Cost (₦) | Quantity | Cost (₦) | Quantity | Cost (₦) |
|                                               | (Dozens) | N320 Each | (Dozens) | N500 Each | (Dozens) | N650 Each |
| April week                                     |   |   |   |   |   |
| 1                                              | 125 | 40000 | 229 | 114500 | 19 | 12350 |
| 2                                              | 124 | 39680 | 245 | 122500 | 20 | 13000 |
| 3                                              | 131 | 41920 | 263 | 131500 | 21 | 13650 |
| 4                                              | 130 | 41600 | 267 | 133500 | 27 | 17550 |
| May week                                       |   |   |   |   |   |
| 1                                              | 133 | 42560 | 273 | 136500 | 25 | 16250 |
| 2                                              | 130 | 41600 | 292 | 146000 | 23 | 14950 |
| 3                                              | 125 | 40000 | 330 | 165000 | 31 | 20150 |
| 4                                              | 129 | 41280 | 263 | 131500 | 32 | 20800 |
| June week                                      |   |   |   |   |   |
| 1                                              | 127 | 40640 | 260 | 130000 | 22 | 14300 |
| 2                                              | 135 | 43200 | 306 | 153000 | 27 | 17550 |
| 3                                              | 136 | 43520 | 296 | 148000 | 31 | 20150 |
| 4                                              | 132 | 42240 | 299 | 149500 | 33 | 21450 |
| July week                                      |   |   |   |   |   |
| 1                                              | 128 | 40960 | 300 | 150000 | 23 | 14950 |
| 2                                              | 127 | 40640 | 288 | 144000 | 28 | 18200 |
| 3                                              | 131 | 41920 | 292 | 146000 | 29 | 18850 |
| 4                                              | 135 | 43200 | 283 | 141500 | 34 | 22100 |
| August week                                    |   |   |   |   |   |
| 1                                              | 126 | 40320 | 294 | 147000 | 26 | 16900 |
| 2                                              | 134 | 42880 | 309 | 154500 | 30 | 19500 |
| 3                                              | 133 | 42560 | 317 | 158500 | 31 | 20150 |
| 4                                              | 137 | 43840 | 305 | 152500 | 35 | 22750 |
| During handle regime                           |   |   |   |   |   |
| Mean Quantity                                  | 130.4 | 285.55 | 27.35 |
| Mean Sales                                     | 41728 | 142775 | 17777.5 |
Table App I-3. Data showing the weekly sales and financial details of bottle water after the use of bottle water handle

| Sales after the use of bottle water handle (₦) |
|-----------------------------------------------|
| 50cl  | 75cl  | 150cl |
| Quantity (Dozens) | Cost (₦) | Quantity (Dozens) | Cost (₦) | Quantity (Dozens) | Cost (₦) |
|---|---|---|---|---|---|
| September week |
| 1 | 118 | 35400 | 221 | 92820 | 13 | 7800 |
| 2 | 113 | 33900 | 228 | 95760 | 19 | 11400 |
| 3 | 119 | 35700 | 233 | 97860 | 21 | 12600 |
| 4 | 120 | 36000 | 231 | 97020 | 25 | 15000 |
| October week |
| 1 | 122 | 36600 | 230 | 96600 | 13 | 7800 |
| 2 | 114 | 34200 | 233 | 97860 | 20 | 12000 |
| 3 | 124 | 37200 | 235 | 98700 | 22 | 13200 |
| 4 | 121 | 36300 | 234 | 98280 | 21 | 12600 |
| November week |
| 1 | 111 | 33300 | 232 | 97440 | 12 | 7200 |
| 2 | 129 | 38700 | 235 | 98700 | 23 | 13800 |
| 3 | 121 | 36300 | 229 | 96180 | 18 | 10800 |
| 4 | 111 | 33300 | 231 | 97020 | 19 | 11400 |
| December 2008 week |
| 1 | 131 | 39300 | 227 | 95340 | 15 | 9000 |
| 2 | 119 | 35700 | 232 | 97440 | 18 | 10800 |
| 3 | 103 | 30900 | 237 | 99540 | 19 | 11400 |
| 4 | 115 | 34500 | 233 | 97860 | 21 | 12600 |
| January 2009 week |
| 1 | 101 | 30300 | 231 | 97020 | 13 | 7800 |
| 2 | 113 | 33900 | 233 | 97860 | 18 | 10800 |
| 3 | 135 | 40500 | 234 | 98280 | 22 | 13200 |
| 4 | 120 | 36000 | 230 | 96600 | 17 | 10200 |
| After handle regime |
| 50cl | 75cl | 150cl |
| Mean Quantity | 117.8 | 231.45 | 18.45 |
| Mean Sales | 35340 | 97209 | 11070 |
Appendix II

MATLAB Programme for Plots

Programme for 50cl Response

\begin{verbatim}
%Quantity of 50cl sold before the use of handle
a1=[119 113 117 118 113 121 118 116 114 116 120 116 116 113 121 119 113 118 111 122];
mean(a1)%Mean Quantity of 50cl sold before the use of handle
b1=[125 124 131 130 133 125 129 127 135 136 132 128 127 131 135 126 134 133 137];
mean(b1)%Mean Quantity of 50cl sold during the use of handle (but without handle)
c1=[118 113 119 120 122 114 124 121 111 129 121 111 129 111 131 119 103 115 101 113 131 120];
mean(c1)%Mean Quantity of 50cl sold after the use of handle

%Price of corresponding quantity sold before the use of handle
x1=a1.*300;
mean(x1)%Mean Sales of 50cl sold before the use of handle

%Price of corresponding quantity sold during the use of handle
y1=b1.*300;
mean(y1)%Mean Sales of 50cl sold during the use of handle

%Price of corresponding quantity sold after the use of handle
z1=c1.*300;
mean(z1)%Mean Sales of 50cl sold after the use of handle

plot(a1,x1,'k-*',b1,y1,'k-o',c1,z1,'k-s')
grid on
xlabel('Quantity Sold Per Week(Dozens)')
ylabel('Sales(Naira)')
title('Response of 50cl During the three Regime')
legend('S1=300Q1','S2=300Q2','S3=300Q3',0); %Creates Legend and position it @ best fit
\end{verbatim}

Programme for 75cl Response

\begin{verbatim}
%Quantity of 75cl sold Before the use of Handle
a2=[219 221 227 225 217 230 227 222 221 231 226 217 213 228 223 233 212 222 231 225];
mean(a2)%Mean Quantity of 75cl sold before the use of handle
b2=[229 245 263 267 273 292 320 263 260 306 296 299 300 288 292 283 294 309 317 305];
mean(b2)%Mean Quantity of 75cl sold during the use of Handle

c2=[221 228 233 231 230 233 235 234 232 235 229 231 227 232 237 233 231 233 234 230];
mean(c2)%Mean Quantity of 75cl sold after the use of Handle

%Price of corresponding quantity sold before the use of handle
x2=a2.*400;
mean(x2)%Mean Sales of 75cl sold before the use of handle

%Price of corresponding quantity sold during the use of handle
y2=b2.*(475-20.4);
mean(y2)%Mean Sales of 75cl sold during the use of handle

%Price of corresponding quantity sold after the use of handle
z2=c2.*420;
mean(z2)%Mean Sales of 75cl sold after the use of handle

plot(a2,x2,'k-*',b2,y2,'k-o',c2,z2,'k-s')
grid on
xlabel('Quantity Sold Per Week(Dozens)')
ylabel('Sales(Naira)')
title('Response of 75cl During the three Regime')
legend('S1=400Q1','S2=(475-20.4)Q2','S3=420Q3',0); %Creates Legend and position it @ best fit
\end{verbatim}

Programme for 150cl Response

\begin{verbatim}
%Quantity of 150cl sold Before the use of Handle
a3=[14 12 17 16 15 19 13 14 20 14 12 16 13 17 14 16 25 13 11 14];
mean(a3)%Mean Quantity of 150cl sold before the use of handle
b3=[19 20 21 27 25 23 31 32 22 27 31 33 23 28 29 34 26 30 31 35];
mean(b3)%Quantity of 150 cl sold During the use of Handle

%Price of corresponding quantity sold before the use of handle
x3=a3.*450;
mean(x3)%Mean Sales of 150cl sold before the use of handle

%Price of corresponding quantity sold during the use of handle
y3=b3.*(450-20.4);
mean(y3)%Mean Sales of 150cl sold during the use of handle

%Price of corresponding quantity sold after the use of handle
z3=c3.*500;
mean(z3)%Mean Sales of 150cl sold after the use of handle

plot(a3,x3,'k-*',b3,y3,'k-o',c3,z3,'k-s')
grid on
xlabel('Quantity Sold Per Week(Dozens)')
ylabel('Sales(Naira)')
title('Response of 150cl During the three Regime')
legend('S1=450Q1','S2=(450-20.4)Q2','S3=500Q3',0); %Creates Legend and position it @ best fit
\end{verbatim}
Mean Quantity of 50cl sold before the use of handle = 116.7000 Dozens
Mean Quantity of 50cl sold during the use of handle = 130.4000 Dozens
Mean Quantity of 50cl sold after the use of handle = 117.8000 Dozens

Mean Sales of 50cl sold before the use of handle = N35010
Mean Sales of 50cl sold during the use of handle = N39120
Mean Sales of 50cl sold after the use of handle = N35340

Mean Quantity of 75cl sold before the use of handle = 223.5000 Dozens
Mean Quantity of 75cl sold during the use of handle = 285.5500 Dozens
Mean Quantity of 75cl sold after the use of handle = 231.4500 Dozens

Mean Sales of 75cl sold before the use of handle = N89400
Mean Sales of 75cl sold during the use of handle = N129810
Mean Sales of 75cl sold after the use of handle = N97209

Mean Quantity of 150cl sold before the use of handle = 15.2500 Dozens
Mean Quantity of 150cl sold during the use of handle = 27.3500 Dozens
Mean Quantity of 150cl sold after the use of handle = 18.4500 Dozens

Mean Sales of 150cl sold before the use of handle = N9150
Mean Sales of 150cl sold during the use of handle = N19145
Mean Sales of 150cl sold after the use of handle = N11070
Average quantity sold during the use of handle = 285.55 + 27.35 = 312.9
Average Cost of using handle = 312.9 x 20.4 = N6383.16
Appendix III

Engineering Drawing

Fig. AIII-1. Back plate for male

Fig. AIII-2. Back plate for female
Fig. AIII-3. Sprue bush

Fig. AIII-4. Locating pin
Fig. AllI-5. Ejection plate with ejection pins and guide pins

Fig. AllI-6. Face plate projections (male)
Fig. AIII-7. Face plate projections (female)

Fig. AIII-8. Face plate support (wire frame)
Fig. AII-9. Locating ring

Fig. AII-10. Explosion projections of mould assembly
Fig. AIII-11. Pictorial projection of mould assembly with explosion

Fig. AIII-12. Projections of assembled mould (wire frame)
Fig. AllI-13. Projections of assembled mould (solid)

Fig. AllI-14. Pictorial projection of mould assembly (wire frame)
Fig. AllI-15. Pictorial projection of mould assembly (glass)

Fig. AllI-16. Pictorial projection of mould assembly with part numbers
Fig. AIII-17. Pictorial representation of handle

Table AIII-18. Bill of materials/quantity

| Item no. | Description/name     | Quantity |
|----------|----------------------|----------|
| 1        | Base Plate Female    | 1        |
| 2        | Face Plate Female    | 1        |
| 3        | Sprue Bush           | 1        |
| 4        | Locating Ring        | 1        |
| 5        | Locating Pin         | 4        |
| 6        | Ejection Pin         | 12       |
| 7        | Face Plate Support   | 2        |
| 8        | Ejection Plate       | 1        |
| 9        | Base Plate Male      | 1        |
| 10       | Face Plate Male      | 1        |
| 11       | M-14 Allen Bolts     | 4        |
| 12       | M-8 Nipples          | 4        |
| 13       | M-8 Bolts            | 4        |