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Research Paper

Glass Recycling: Achieving a Compromise between Economics of Production and Environmental Benefit

Beneth C. Chukwudi, Martins B. Ogunedo

Department of Mechanical Engineering, Imo State University, Owerri, Nigeria.

Corresponding Author: Beneth C. Chukwudi

ABSTRACT

Indiscriminate human activities impact negatively on the ecosystem. One of such is the pollution of the environment with non-biodegradable materials. In a bid to remedy this, recycling of such materials become a solution. However, for glass wastes, there seem to be reluctance by glass manufacturers in recycling glass despite the environmental benefits due to the high production cost. To this end, the study aimed at establishing a balance between the cost of production and environmental benefits. Data was obtained from one of the Glass manufacturing companies in Aba, Abia state. This data collected covered a span of six days each for 10%, 25%, 50%, 75% and 100% by mass composition of cullet during the glass production. The study concludes that although recycling of glass has positive effects on the environment, energy cost and furnace running cost, it is not economically viable to recycle glass 100%. This is mainly due to the cost of cullet as against cheap and readily sourced silica sand. However, it suggests that a material mix of 25% cullet composition is optimal for production of glass.

Keywords: Recycling, Glass, Cullet, Production, Economic.

INTRODUCTION

According to, [1] the earth surface is covered by 70% water. Invariably, dry land makes up the remaining 30%. The dry land harbors most of humans activities, and as a result has been subjected to various degrees of pollution. Land pollution is the contamination of the soil either through the introduction of pollutants, or misuse by man which leads to a reduction in the value of land. Indiscriminate disposal of non-biodegradable wastes such as glass, plastics, and aluminium cans contribute immensely to land pollution. Since these non-biodegradable wastes are continually produced, recycling becomes the only way to ensure that presence of such wastes is minimal in our environment. Hence, the need to recycle glass becomes paramount for the purpose of achieving a sustainable eco-friendly environment. Recycling of glass entails processing used or discarded glass materials into new/raw materials suitable for reuse. Benefits associated with recycling glass are similar with those of aluminium as opined by. [2] These benefits include helping save energy needed in production, conserve natural resources, mitigate greenhouse gas emissions, prevent pollution; reduce land fill and incinerator wastes amongst many others. However, regardless of the benefits associated with recycling glass, there are limitations/disadvantages to recycling glass. For instance, [3] opines that recycling glass has been linked with high costs, and due to the ease of forming new glass, it becomes imperative to question the idea of recycling used glass when new ones can be formed with ease from readily available sand using quick and cheap process. Hence, it is to this end the study critically examines the economic implication of recycling glass. This would go a long way to establish whether it is economically viable to recycle glass and how to achieve a harmony between cost of production and glass reuse.

METHODOLOGY

Data Collection

Data was obtained by two means viz: administration of questionnaire as well as through personal interview; this is to ensure that sufficient information about the process of glass manufacture is obtained and to ensure reliability of the data obtained. The data were obtained from one of the Glass manufacturing companies in Aba, Abia state. This data collected covered a span of six days each for 10%, 25%, 50%, 75% and 100% by mass composition of cullet during the glass production. This was done to ascertain the economic implication of recycling glass and determine the mix ratio that would favour cost of production and increase in use of cullets which will eventually reduce the quantity of glass waste in the environment.

Tables 1 to 5 are data collected from the company showing the various variables that affect the cost of production.

Table 1: Data of variables for cost of producing glass with 10% cullet.

Variables	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Diesel Cost (₦)	250	250	250	250	250	250
Diesel Consumption (Litres)	26	25	28	25	27	28
Mass of bottle produced (kg)	243.25	243.25	243.25	243.25	243.25	243.25
Water Rates (₦)	98	98	98	98	98	98
Telephone Bills (₦)	150	200	160	210	190	185
Wage bill (₦)	22000	22000	22000	22000	22000	22000
Marketing Cost (₦)	500	500	500	500	500	500
Furnace Running Expenses (₦)	1500	1200	1400	1400	1300	1300
Transportation Cost (₦)	1500	1500	1500	1500	1500	1500
Warehousing Cost (₦)	500	500	500	500	500	500
Material Cost (₦)	4147.41	4147.41	4147.41	4147.41	4147.41	4147.41

Table 2: Data of variables for cost of producing glass with 25% cullet.

Variables	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Diesel Cost (₦)	250	250	250	250	250	250
Diesel Consumption (Litres)	20	18	16	18	21	15
Mass of bottle produced (kg)	243.25	243.25	243.25	243.25	243.25	243.25
Water Rates (₦)	98	98	98	98	98	98
Telephone Bills (₦)	150	200	160	210	190	185
Wage bill (₦)	22000	22000	22000	22000	22000	22000
Marketing Cost (₦)	500	500	500	500	500	500
Furnace Running Expenses (₦)	1200	1100	1100	1200	1100	1100
Transportation Cost (₦)	1500	1500	1500	1500	1500	1500
Warehousing Cost (₦)	500	500	500	500	500	500
Material Cost (₦)	5885.29	5885.29	5885.29	5885.29	5885.29	5885.29

Table 3: Data of variables for cost of producing glass with 50% cullet.

Variables	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Diesel Cost (₦)	250	250	250	250	250	250
Diesel Consumption (Litres)	15	15	17	14	13	12
Mass of bottle produced (kg)	243.25	243.25	243.25	243.25	243.25	243.25
Water Rates (₦)	98	98	98	98	98	98
Telephone Bills (₦)	150	200	160	210	190	185
Wage bill (₦)	22000	22000	22000	22000	22000	22000
Marketing Cost (₦)	500	500	500	500	500	500
Furnace Running Expenses (₦)	1000	1000	1000	900	1100	1000
Transportation Cost (₦)	1500	1500	1500	1500	1500	1500
Warehousing Cost (₦)	500	500	500	500	500	500
Material Cost (₦)	9513.75	9513.75	9513.75	9513.75	9513.75	9513.75

Table 4: Data of variables for cost of producing glass with 75% cullet.

Variables	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Diesel Cost (₦)	250	250	250	250	250	250
Diesel Consumption (Litres)	13	13	15	14	12	13
Mass of bottle produced (kg)	243.25	243.25	243.25	243.25	243.25	243.25
Water Rates (₦)	98	98	98	98	98	98
Telephone Bills (₦)	150	200	160	210	190	185
Wage bill (₦)	22000	22000	22000	22000	22000	22000
Marketing Cost (₦)	500	500	500	500	500	500
Furnace Running Expenses (₦)	900	950	900	800	950	900
Transportation Cost (₦)	1500	1500	1500	1500	1500	1500
Warehousing Cost (₦)	500	500	500	500	500	500
Material Cost (₦)	14242.71	14242.71	14242.71	14242.71	14242.71	14242.71

Table 5: Data of variables for cost of producing glass with 100% cullet.

Variables	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Diesel Cost (₦)	250	250	250	250	250	250
Diesel Consumption (Litres)	10	11	9	10	10	10
Mass of bottle produced (kg)	243.25	243.25	243.25	243.25	243.25	243.25
Water Rates (₦)	98	98	98	98	98	98
Telephone Bills (₦)	150	200	160	210	190	185
Wage bill (₦)	22000	22000	22000	22000	22000	22000
Marketing Cost (₦)	500	500	500	500	500	500
Furnace Running Expenses (₦)	800	750	800	940	600	750
Transportation Cost (₦)	1500	1500	1500	1500	1500	1500
Warehousing Cost (₦)	500	500	500	500	500	500
Material Cost (₦)	19947	19947	19947	19947	19947	19947

Economic Model Development

An economic model was developed in order to determine the cost of manufacturing glass from the various compositions of cullet. Figure 1 shows a flow chart of the model development.

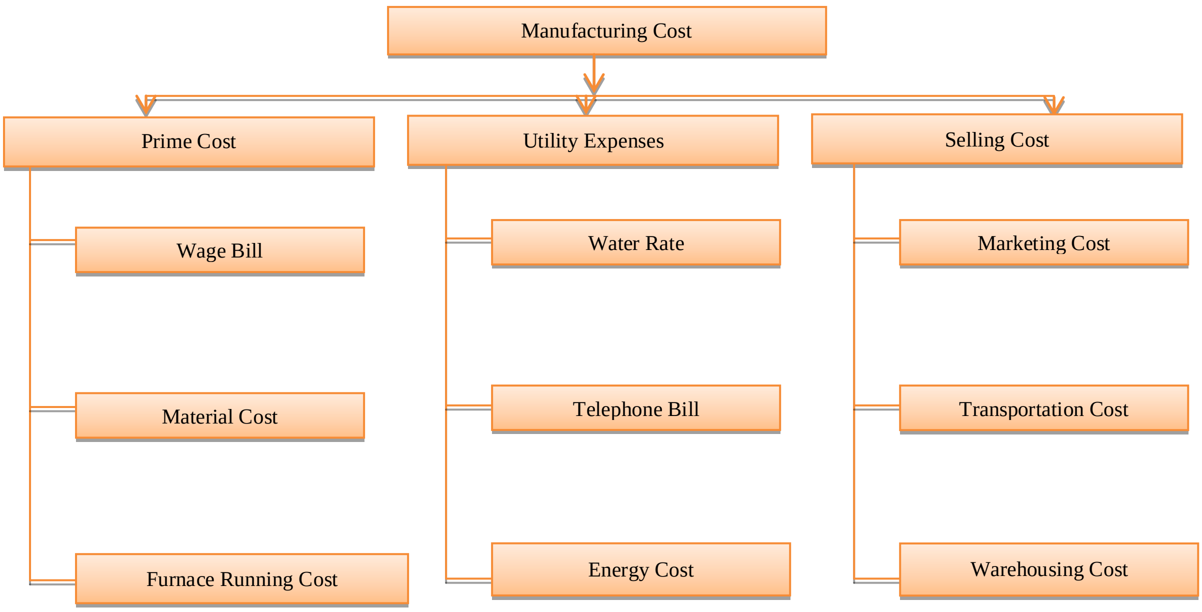

Figure 1: Economic model development flow chart.

The response variables of the model are prime cost, utility expenses and selling cost, while the primary variables of the responses are wage bill, material cost, furnace running cost, water rate, telephone bill, energy cost, marketing cost, transportation cost, and warehousing cost.

Model Presentation

Prime Cost: Equation 1 gives the model for determining the prime cost per unit kg of producing glass at the various composition of cullet.

$$Prime\ Cost = W_b + M_c + F_{rc} \quad (1)$$

Where: W_b = Wage bill, M_c = Material cost, F_{rc} = Furnace running cost.

Data on the wage bill and furnace running cost was gotten from the factory, and are shown in Tables 1- 5. While the value for the material cost was developed using data gotten from the factory for the mix ratio, unit cost per kg of material, and mass of bottles produced daily. The model equation used to determine the material cost per unit kg is shown in equation 2.

$$M_c = \frac{\sum U_c M_b M_r}{\sum M_m} \quad (2)$$

Tables 6 – 10 show the material cost for the production of a unit kg of glass using 10%, 25%, 50%, 75%, and 100% compositions of cullet.

Table 6: Material cost for glass production using 10% cullet.

Material	Mix ratio (% wt) (M_r)	Unit cost (U_c)	Mass of bottles (M_b)	Mass of material (M_m)	Material cost (M_c)
Silica sand	60	3.5	243.25	145.95	510.825
lime Stone	10	25	243.25	24.325	608.125
Lime	7	20	243.25	17.0275	340.55
Soda Ash	5	35	243.25	12.1625	425.6875
Soda	8	15	243.25	19.46	291.9
Cullet	10	60	243.25	24.325	1459.5
Total	100				4147.413
Material unit cost (₦/kg) = 17.05					

Table 7: Material cost for glass production using 25% cullet.

Material	Mix ratio (% wt) (M_r)	Unit cost (U_c)	Mass of bottles (M_b)	Mass of material (M_m)	Material cost (M_c)
Silica sand	45	3.5	243.25	113.058	395.703
lime Stone	10	25	243.25	25.124	628.1
Lime	7	20	243.25	17.5868	351.736
Soda Ash	5	35	243.25	12.562	439.67
Soda	8	15	243.25	20.0992	301.488
Cullet	25	60	243.25	62.81	3768.6
Total	100				5698.131
Material unit cost (₦/kg) = 23.425					

Table 8: Material cost for glass production using 50% cullet.

Material	Mix ratio (% wt) (M_r)	Unit cost (U_c)	Mass of bottles (M_b)	Mass of material (M_m)	Material cost (M_c)
Silica sand	28	3.5	243.25	73.7296	258.0536
lime Stone	8	25	243.25	21.0656	526.64
Lime	5	20	243.25	13.166	263.32
Soda Ash	4	35	243.25	10.5328	368.648
Soda	5	15	243.25	13.166	197.49
Cullet	50	60	243.25	131.66	7899.6
Total	100				8788.623
Material unit cost (₦/kg) = 36.13					

Table 9: Material cost for glass production using 75% cullet.

Material	Mix ratio (% wt) (M_r)	Unit cost (U_c)	Mass of bottles (M_b)	Mass of material (M_m)	Material cost (M_c)
Silica sand	10	3.5	243.25	29.156	102.046
lime Stone	5	25	243.25	14.578	364.45
Lime	3	20	243.25	8.7468	174.936
Soda Ash	3	35	243.25	8.7468	306.138
Soda	4	15	243.25	11.6624	174.936
Cullet	75	60	243.25	218.67	13120.2
Total	100				11882.76
Material unit cost (₦/kg) = 48.85					

Table 10: Material cost for glass production using 100% cullet.

Material	Mix ratio (% wt) (M_r)	Unit cost (U_c)	Mass of bottles (M_b)	Mass of material (M_m)	Material cost (M_c)
Silica sand	0	3.5	243.25	0	0
lime Stone	0	25	243.25	0	0
Lime	0	20	243.25	0	0
Soda Ash	0	35	243.25	0	0
Soda	0	15	243.25	0	0
Cullet	100	60	243.25	332.45	14595
Material unit cost (₦/kg) = 60					

Utility Expenses: The model equation for the utility expenses is shown in equation 3.

$$U_e = \frac{W_r + T_b}{\sum m} + E_c \quad (3)$$

Where: W_r = Water rates, T_b = Telephone bills, E_c = Energy cost.

Values for water rates and telephone bill were obtained from the factory as shown in Tables 1- 5, while the energy bill refers to the cost of running the diesel generator. The equation used to determine the energy bill is given in equation 4.

$$E_c = \frac{\sum C_f p}{\sum m} \quad (4)$$

Table 11 - 15 shows the cost of energy for the production of glass using various composition of cullet.

Table 11: Energy cost for glass production using 10% cullet.

Diesel Cost (p) (₦/Litre)	250	250	250	250	250	250	
Diesel Consumption (C_f)(Litres)	26	25	28	25	27	28	
Mass of bottle produced (m) (kg)	243.25	243.25	243.25	243.25	243.25	243.25	1702.75
Energy cost	6500	6250	7000	6250	6750	7000	46250
Energy costper unit kg (₦/kg) = 27.16194							

Table 12: Energy cost for glass production using 25% cullet.

Diesel Cost (p) (₦/Litre)	250	250	250	250	250	250	
Diesel Consumption (C_f)(Litres)	20	18	16	18	21	15	
Mass of bottle produced (m) (kg)	243.25	243.25	243.25	243.25	243.25	243.25	1702.75
Energy cost	5000	4500	4000	4500	5250	3750	32000
Energy cost per unit kg(₦/kg) = 18.79313							

Table 13: Energy cost for glass production using 50% cullet.

Diesel Cost (p) (₦/Litre)	250	250	250	250	250	250	
Diesel Consumption (C_f)(Litres)	15	15	17	14	13	12	
Mass of bottle produced (m) (kg)	243.25	243.25	243.25	243.25	243.25	243.25	1702.75
Energy cost	3750	3750	4250	3500	3250	3000	25250
Energy costper unit kg (₦/kg) = 14.82895							

Table 14: Energy cost for glass production using 75% cullet.

Diesel Cost (p) (₦/Litre)	250	250	250	250	250	250	
Diesel Consumption (C_f)(Litres)	13	13	15	14	12	13	
Mass of bottle produced (m) (kg)	243.25	243.25	243.25	243.25	243.25	243.25	1702.75
Energy cost	3250	3250	3750	3500	3000	3250	23250
Energy cost per unit kg (₦/kg) = 13.65438							

Table 15: Energy cost for glass production using 100% cullet.

Diesel Cost (p) (₦/Litre)	250	250	250	250	250	250	
Diesel Consumption (C_f)(Litres)	10	11	9	10	10	10	
Mass of bottle produced (m) (kg)	243.25	243.25	243.25	243.25	243.25	243.25	1702.75
Energy cost (₦)	2500	2750	2250	2500	2500	2500	17500
Energy cost per unit kg (₦/kg) = 10.27749							

Selling Expenses: Data used in developing the model for the selling expenses were as obtained from the factory and shown in Tables 1 – 5. The equation for the selling expenses is shown in equation 5.

$$S_e = \frac{Mt_c + T_c + W_c}{\sum m} \quad (5)$$

Where: Mt_c = Marketing cost, T_c = Transportation cost, W_c = Warehousing cost.

RESULTS

Table 16 shows the cost of manufacturing glass using various percentages of cullet. The table reveals that the prime cost increases as the percentage of cullet increase in the material mix.

Table 16: Manufacturing cost of glass using various percentages of cullet.

% Cullet	Prime Cost (₦/kg)	Utility Expenses (₦/kg)	Selling Cost (₦/kg)	Manufacturing Cost (₦/kg)
10%	114.04	28.32	10.28	152.63
25%	119.52	19.95	10.28	149.75
50%	131.68	15.98	10.28	157.94
75%	143.99	14.81	10.28	169.08
100%	154.62	11.43	10.28	176.33

Figure 2 suggests that the reason for the direct proportionality that exists between the percentage composition of cullet and the prime cost is due to the increase in material cost as the percentage composition of cullet increases. This is so because cullet costs more than silica sand used in glass production as seen in Tables 6 – 10.

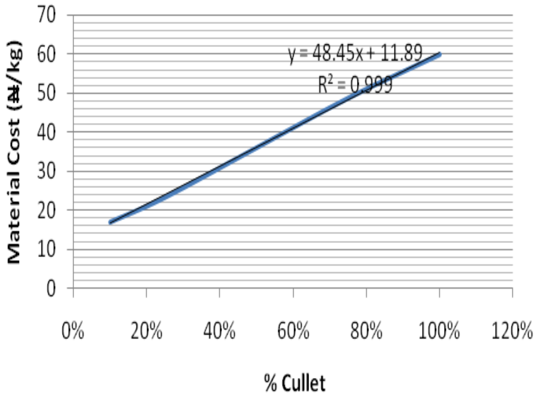

Figure 2: Variation of % cullet against material

However, the utility expense is noted to decrease as the percentage cullet increases. This observation as shown in figure 3 is due to the reduction in the energy cost as the percentage of cullet increases in the material mix.

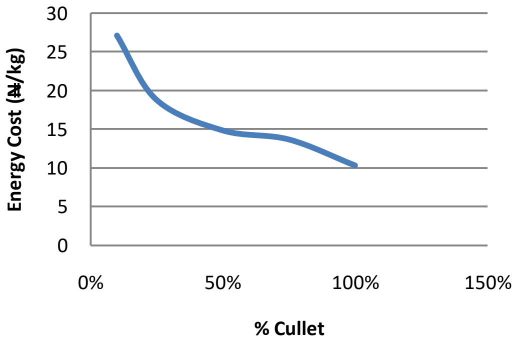

Figure 3: Variation of % cullet against energy cost

From figure 3, it is seen that there is a steep decline in energy cost between 10% and 25% composition of cullet. This decline is likely to be the reason a sharp drop is noticed in the manufacturing cost between the two percentage compositions.

CONCLUSION

Although recycling of glass has positive effects on the environment, energy cost and furnace running cost, it is not economically viable to recycle glass 100%. This is mainly due to the cost of cullet as against cheap and readily sourced silica sand. However, findings from this study suggest that a material mix of 25% cullet composition is optimal for production of glass, thereby achieving a compromise between economic and environmental benefits.

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