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3.4 Process optimization of resources for packaged water factories in Nigeria

S. C. Nwanya, P. O. Onah, I. E. Onyia

Department of Mechanical Engineering, University of Nigeria, Nsukka , Nigeria

Abstract

Inaccessibility to drinking water is an intractable growing problem in developing countries such as Nigeria. This paper, presents the energy and manpower input resources needed to increase water accessibility and guarantee sustainable profitable operations. The work relied on detailed questionnaire administration for data collection from water packaging factories within Nsukka and Enugu Cities. The data were collated and Project Evaluation Review Technique (PERT) was used to determine the amount of energy needed. A profit profile was determined for both sachet and bottle water products. The gross energy sequestered by the packaging process is 87.8J for sachet water and 0.52 MJ for bottle water with average of 10 workforces. Also, optimal production rates of 1658 and 1551 were determined for sachet and bottle water, respectively at a profit of ₦ 291,428.29 per day. The results have significant implications for Nigeria's millennium development goals target for water in 2015.

Keywords:

Energy, optimization, packaged water, process resources

1.0 INTRODUCTION

People need access to a clean water supply for varied uses. Paradoxically, there is shortage of clean water as demand for it continues to grow across the globe at an alarming rate. With almost two – thirds of earth covered by water, it is difficult to understand how a shortage of clean water supply could exist. However, it does exist as only one percent of the water in the world is consumable without treatment [1]. Presently, 1.1 billion people in developing countries have inadequate access to water. The water crisis has also affected health matters of human beings and the cost associated with health spending, productivity losses and labour are greatest in poorest countries with sub-sahara Africa loss about 5 % of its GDP [2]. Since the aforementioned one percent cannot meet the world demand, people have decided on a set of potential interventions for increasing access to water supply.

Generally, two kinds of interventions exist, namely improved water supply technologies (household connections, public standpipe, borehole, and protected spring and rain water collections) and unimproved water supply technologies (unprotected well and spring, vendor provided water and tanker truck provision of water) [3].

Inaccessibility to improved drinking water supply technologies is more acute in rural areas than urban cities. The worsen water shortages in developing world if allowed to continue, the fall-out can reverse significantly progress towards achieving the MDG targets in 2015. As a result, there is need to optimize process factors that will encourage privately owned water enterprises (POWE) to embark on profitable packaging of borehole water through efficient input resource management. Although, government-owned public water utilities (GPWU) schemes used in the past could serve more people than borehole, the former is more expensive to build, maintain and its services are limited by bureaucracy and difficult terrain. Conversely, energy, material and labour are input process factors required for both schemes to function. This work is motivated to investigate the energy and manpower required in borehole method of making water readily available, starting from sumo pump to the packaging point, since it is beneficial to remote off-grid scattered settlement pattern in Nigeria.

Packaging of water is a means of providing the correct environmental condition for water during the length of time it is discharged from borehole, stored or distributed to the consumer. The packaged drinking water comes in many shapes and sizes such as bottle and sachet applications. There are three most common plastic materials used in packaging of water namely, polycarbonate, high density polyethylene and polyethylene terephthalate. For bottle or sachet usage, each material has its own quality issues.

The polycarbonate bottle has blemishes on its wall because of variations in production processes. It also requires a careful sanitizing procedure at the bottling plant in order to be fit for reuse; while for a high density polyethylene bottle, the spout may not always fit the cap, causing leakage in storage. The polyethylene terephthalate bottle requires its storage away from heat; an empty bottle could be deformed when stored at a temperature near 71°C, the filled bottle could consign a fruit taste to its water content if kept in an elevated temperature.

Besides the characteristic nature of the container, there are aesthetic conditions to be met [4], as well as sanitary inspection requirements [5] for example, washing solution application at 49 ^{0}C to 60 ^{0}C for five minutes, taste problems [6], and cap fitting issues encountered during packaging. Therefore, the bottle condition before the filling and after packaging of finished product is a critical success factor. To optimize the bottle appearance, polycarbonate PC redesign and regrind should be kept dry and processed within 20 minutes after drying and then keep all plastic regrind stocks free from contaminants [7].

There are previous studies on packaged water business and its importance to the human health. A recent work [3] described the concept of packaged water. It refers to water that is packaged generally for consumption in a range of vessels including cans, laminated boxes, glass, plastic sachets and pouches, and as ice prepared for consumption. The short-comings in quality of packaged water have been reported [8] and [9]. Igboekwe et el [10], identified quality parameters of concern in the use of borehole technology. The feasibility of this type of water supply system has been treated

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[11], using willingness to pay method in estimating the benefits and costs. There is no doubt, from these reports that packaged water as a local initiative has led to improved accessibility to drinking water, but we are not out of the woods yet. Although the case for quality, aesthetics, inspection and feasibility have been clearly articulated elsewhere, the resource management and process optimization of packaged water operations are largely absent from the literature.

Better management of resources is a key in sustainable borehole water production if the MDG targets for water are to be achieved in 2015. For this purpose, this study investigated the processes that are involved in water packaging, starting with its extraction from the borehole to the sealing machine, determining of energy and manpower that are needed for packaging of water.

The specific objectives of the study include: to determine the gross energy requirement sequestered by the process, determine the man-power needed and finally optimize the process for most efficient packaged water management.

It explored possible ways of minimizing the cost of production and maximizing the profit through rational management of basic input resources involved, thus helping to provide solutions to the challenges that are facing them. All these course of actions will contribute to long term sustainability of energy and related resource input utilization. This evaluation is limited to energy and manpower resources required for packaged water factories within Nsukka and Enugu cities in Nigeria.

2.0 BACKGROUND INFORMATION

An investigation [12] showed that packaging of treated water started years back in Nigeria when people were using leaves, treated skin, vegetable fibers, coconut palm, earthen wares and later, nylon pouches as materials for packaging of water and it was manually operated[3]. In the old traditional Ibo setting, pre-heated banana and plantain leaves were the most common and widespread leaves used for wrapping food items. They were excellent materials for packaging products that are quickly consumed, as they are cheap and readily available. With the advent of improved water supply technologies and because of the importance of water packaging to the human population at large, packaging drew the attentions of the scholars, engineers and scientist which led to designing, producing and prescribing the most effective ways of treating and packaging water. In 1991 the facility for processing / packaging water was brought to Nigeria [7]. The facility has some challenges facing it in water packaging, among which was the need to determine the amount of energy needed and manpower requirements suitable for operating the factory as well as optimal utilization of available resources. The borehole technology is well suited to scattered rural settlement that is prevalent in Nigeria.

In addition to management of resources, the choice of Nsukka and Enugu cities is important, because they are hosting six campuses of tertiary institutions with estimated population of 100,000 students and increasing mobility of other persons. Therefore, water scarcity portends wide range of human health implications. Since energy is critical in discharging and packaging of the water, we therefore try to know the type and amount of energy that can be used in packaging of water and evaluate the energy, and manpower needed. The relevance of the topic to circumstance of our energy situation in Nigeria cannot be overemphasized.

2.1 Challenges packaged water factories face in Nigeria

The major challenges facing the water packaging factory in Nigeria includes: high cost of production, unreliable grid supply, high level of ineptitude, distribution problem and multiple taxation from the three-tiers of government. The issues of multiple taxation and distribution problems are beyond the scope of this study. The unreliable power supply is the cause of reliance on self-generating sets for production. As a result of the foregoing, cost of packaging operation is high.

High cost of production**:** The problem of high cost of production is there because of inability to quantitatively predict energy and pool of trained manpower required for a continuous operation. The inability to determine required number of trained hands on the job results in poor management of resources. Therefore the problem can be solved, if the optimal amount of energy, number of workforce and raw material are determined, accurately. As reported elsewhere, this type of system, also, cannot be sustainable if reliable energy and competent human capacity inputs are inadequate [13]. This affirmation therefore has necessitated the determination of the amount of energy needed to ensure its sustainable utilization.

Distribution of the produced water is a problem due to bad roads. For example a distance that will take a vehicle one hour, may last for three hours because of bad roads and this results in consumption of more fuels and damaging of vehicles used for distribution. On multiple taxation concern, the water factories should unionize, impliedly, the solidarity canvassed for here is meant to guarantee protection to major variables that drive cost of production- energy, labour and material if the entrepreneurship must be successful. As a possible solution to the high cost of production, this study decides to conduct a process evaluation and optimization of the production line. From this study prospective investor would have been better informed about the success factors for packaged water business.

2.2 Determination of energy and manpower requirements

Energy and Manpower can be determined using energy analysis which means determination of energy required in the process of making a good or service within the framework of an agreed set of conventions or applying the information so obtained. Once the system is defined; the energy requirements of the system can be determined.

3.0 MATERIALS AND METHODS

In this study, the production line was first broken down into basic operational units for logical evaluation. A typical in-situ packaged water factory consists of borehole, filtration, equipment housing/ piping, moulding and sealing / bottling machines units. A second step was to determine a weighting factor or amount of time for each operation. The next was determination of the energy and manpower requirements per unit.

Table 1: Process activity, equipment, time and energy involved in an in-situ water packaging factory

Stages	Power (kW)	Amt.of time (s)	Energy (J)	Machines used
1,2	3.0	3,600	10,800	Sumo pump
1,3	1.5	1800	2,700	Sumo pump
2,4	0	3600	0	Reservoir Tank
3,5	0	180	0	Storage tank
4,6	1.33	5,400	7,182	Electric pumping machine
5,7	1.33	18,000	7,182	Electric pumping machine
7,8	0	18,000	0	Supply tank
8,9	1.33	18,000	23,940	Electric pumping machine
9,10	0	18,000	0	Filtration plant
10,11	0.5	18000	9,000	Ultra-violent ray
11,12	1.5 (23)	18000	27,000 (414000)	sealing machine (bottling)
Total energy needed for one day =87,804J and 501,804J for sachet and bottle, respectively.				

Stages 1,2 and 1,3 involved water discharge from boreholes into storage tanks in 2,4 and 3,5. The meanings of other activities can be inferred from machines used in table 1.

3.1 Borehole

A borehole may be constructed for many different purposes, including the extraction of water or other fluids (such as petroleum) or gases (such as natural gas) as part of a geotechnical investigation, environmental site assessment, mineral exploration, temperature measurement or as a pilot hole for installing piers or underground utilities. In this context, boreholes are made for geothermal installations as well as pumping water from underground well. Typically, a borehole used as water well is completed by installing a vertical pipe and well screen to keep the borehole from caving. This also helps prevent surface contaminants from entering the borehole and protects any installed pump from drawing in sand and sediment.

Its power consumption, measured in terms of electrical rating of sumo pump machine is 4.5kW. The borehole technology is distinct for its low scale of production which suits scattered rural settlement.

3.2 Method of energy analysis

Energy and manpower requirements were determined using energy analysis technique. An energy analysis can be carried out from both a technical perspective and an economic perspective. An energy analysis from a technical prospective is called process analysis. An energy analysis from an economic perspective is called input-output energy analysis. For this study, the focus is on process analysis.

Energy analysis is important because it can be used to determine the energy invested in every step of the production process [15]. A survey conducted has shown that there is growing number of packaged water factories and their anticipated market expansion would require rational practices for profit and loss assessment of the production activity. In this study, linear programming is the optimization methodology proposed for decision making on profitability.

4. 0 RESULTS, ANALYSIS AND PROCESS OPTIMIZATION

In this study, project evaluation and review techniques (PERT) is used in process evaluation of energy and manpower needed in packaging operations. PERT requires three estimates of time for each activity. These times are combined to produce what is known as an expected time for a particular activity. With the estimated time and power consumed at the different stages, the process energy requirement is calculated as product of time and power consumption. Two major products, namely bagged (sachet) water and bottled water are produced from the process. Total energy consumed for each product line is 0.088MJ and 0.502MJ per day, respectively for sachet and bottled water production. The evaluated process activity outcome is presented in table 1.

When the machine makes a bag of water, it creates the bag from a continuous roll of polyethylene plastic material. For manpower involvement, an average of 0.075kW per normal human being is engaged [16]. By applying the human power index, the manpower requirement cost (MRC) index can be estimated as follows:

$$MRC_h = 0.075 N_h T_h C_h \quad [17] \qquad (1)$$

Where N = number of persons involved, T = time taken by persons for a given activity, C = cost/person

From the field survey, the manpower, energy and of quantity of water produced per day by nine out of 25 surveyed factories are shown in table 2. The nine factories use average 10 workforces and produce sachet and bottle water, simultaneously.

Table 2: Quantity of water produced, manpower (workforce) and energy used per day

Water produced in hectoliter per day, Y	Energy used by-the sector X_1 (KJ per day)	Manpower / workforce X_2 (man-day)
3.0	36.936	16
1.2	14.774	8
2.0	24.624	7
2.5	30.78	10
4.0	49.248	18
0.6	7.387	5
0.8	9.850	1
10	121.880	17
9	110.808	16

4.1 Decision analysis

A wide variety of criteria play a part in the viability of packaged water operation. The operation, just like every other business activity, is profit-oriented. It is important to assess all of the cost factors in order to determine how the most cost – effective plan could be obtained. Several methods were used and one of them was the cost analysis approach. We determined five important cost items that needed to be analyzed. These cost issues are:

- Power consumption
- Water production
- Material (packaging)
- Human resources
- Maintenance.

The first two cost issues analyzed cost of water production and energy use. The energy costs for water packing machine were disclosed, based on an electricity rate that was estimated by Power Holding Company of Nigeria (PHCN).

In addition to economic factors, quantitative information on fuel requirements, capacity of machines, number of labour and material that play roles in water packaging decision analysis were determined.

With the knowledge of these cost estimates, we can determine the profit profile of a typical water packaging factory.

4.2 Process optimization of production line

Since sachet and bottle products will compete for materials, energy and human resources, it is not clear which resource mix between the two products would be most profitable. Thus, Optimization is necessary to develop low cost strategies that will enable packaged water firms make decisions on how best to produce their goods at an affordable price. For the aforementioned reason, this study has determined a typical profit profile for both sachet and bottle water products as shown in table 3 for one of the sampled factories.

Table 3: profit profile for package water factory of two product capacity

S/n	Description of item	Product lines Bag (X_1)	 Carton (X_2)	Available Investment Naira (₦)
1.	Selling price / unit	60	400	
2.	Direct raw material cost	2.7	24.20	42000
3.	Direct labour cost (in terms of energy)	2	1	4867
4.	Electricity usage and cost	15	230	5684.8
5.	Profit	40.30	144.80	

To optimize the profit, the constraints on input resources such as direct raw materials, labour and electricity are shown in table 3. These available investments in Naira (₦) values are limiting conditions for formulating linear programming algorithm for a production line.

Assumptions: the costs and incomes are assumed linear with quantity of products produced, thickness of material used is uniform and usage of each resource and its quantity are directly proportional to the level of each activity. The assumptions lead to formation of LP model with objective function, Z f (x_i) in equation (2).

Where f (x_i) = function of x_1 and x_2 variables, x_1 = units of sachet product; x_2 = units of bottled product; Z = objective function (maximization of profit). Mathematically, Maximize:

$$Z = 40.30X_1 + 144.8X_2 \qquad (2)$$

Subject to

$$2.7X_1 + 24.2X_2 \leq 42000 \qquad (3)$$

$$2X_1 + X_2 \leq 4867 \qquad (4)$$

$$1.5X_1 + 23X_2 \leq 568.48 \qquad (5)$$

Where

$$X_1 \geq 0, X_2 \geq 0 \qquad (6)$$

Using Gauss Jordan reduction technique, vectors (X_1 and X_2) that satisfy the set of constraint equations (3) to (5) can be determined. By solving these constraints analytically, X_1 = 1658 and X_2 = 1551. The profit per day based on these vector quantities is ₦291,428.29.

Multiple Regression Analysis

In order to translate the produced packaged (sachet and bottled) water in table 2 into requirement for inputs of manpower and energy a multiple regression technique is used. The quantity of water produced per day in table 2 was regressed with manpower and energy as independent variables using Statistical Package for Social Sciences, SPSS software version 16. The results of the multiple regressions are shown in tables 4, 5 and 6. Based on the regression analysis (coefficients in table 6), only energy significantly affects water production and the estimated regression parameter gives rise to equation 7. The R-square statistic has value of 1.0. This statistic is usually expressed in percentages and this result indicates that a total variability in quantity of water produced is completely accounted for by energy utilized.

Table 4: Summary of R-Square statistic

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	27.67551

a. Predictors: (Constant), Manpower, Energy

Table 5: ANOVA[b] table for multiple regression

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	9.695E7	2	4.848E7	6.329E4	.000[a]
Residual	4595.602	6	765.934		
Total	9.696E7	8			

a. Predictors: (Constant), Manpower, Energy

b. Dependent Variable: Water

Table 6: Test of significance of regression coefficients

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	-2.508	21.527		-.117	.911
Energy	81.870	.295	1.001	277.786	.000
Manpower	-4.682	7.443	-.002	-.629	.552

a. Dependent Variable: Water

$$\hat{Y} = 81.87X_2 \qquad (7)$$

Where $\hat{Y} =$ quantity of water produced.

4.3 Discussion

4.3.1 Bagged water

In the bagged water system, the machine used is Argenpack 2500 and it produces 2500 sachets of 60 cl size per hour or 125 bags per hour. The Argenpack 2500 machine requires 1.5kW of power to operate and average production rate 42 kg of PET per day. Using this value, the machine produces average of 50 litres/kWh or 83.33 bags/kWh with plastic material consumption of ₦2.7/g and labour rate of ₦1.5/man-hour. From the utility tariff (Power holding company) we found that cost of 1kWh of electricity is ₦10 for industrial consumption.

4.3.2 Bottled water

For the bottling system, blown bottles can be made in-situ from performs or they can be purchased from plastic bottle vendors. In order to make bottle, the mode of operation a polyethylene terephthalate (PET) blow mold machine has been described in section 3.4.

The KBA 2500 consumes 23kW of power per hour. The cost of the whole system including air compressors and air purification and other accessories at local rate is ₦69, 565.3/kWh.

In order to make a 500ml bottle, material for perform is needed at the cost of ₦ 24.2 per perform. Filling, labeling, capping and packaging the bottles are each other issues entirely. To fill the bottles, an additionally piece of equipment called VP–50 from Venus packaging [18] is required. This machine fills approximately 2500 bottles per hour. The overall calculated cost of perform blowing into plastic bottle, water supply, filling, labeling and capping is ₦ 7. 73/ 500ml bottle.

The ANOVA test for the regression model indicates that the model is adequate to describe the relationship between water produced and energy and manpower utilized in an automated production line. In an automated process, machine displacement of labour is prevalent. This feature is significantly vindicated in the result of individual test of coefficients. The test for manpower's coefficient in table 6 revealed that manpower does not significantly affect water production. Therefore, there is direct relationship between water produced and energy utilized in the production such that little change in energy requirements have great influence on water production as shown in figure 1.

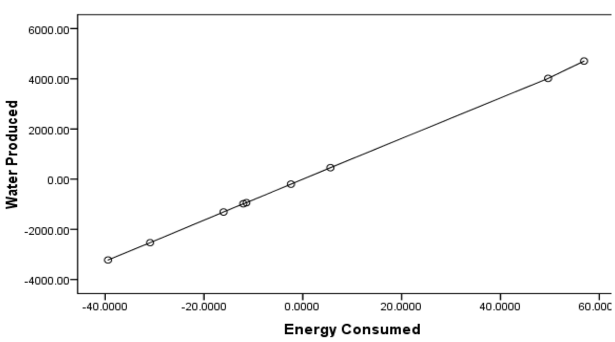

Figure 1: Effect of changes in energy consumed on water produced.

Also, it can be inferred from the foregoing discussion on the optimized production rates the facts that water packaging has a business implications and significance for Nigeria in meeting MDG targets for in 2015. As a business venture, it can add 3600 new jobs in 36 States of our country, thus, cutting down unemployment rate. In the MDG target, it increases access to portable water and also helps to avoid water borne-diseases.

5.0 CONCLUSION

This study presents a process evaluation as well as optimization of resources for a representative in-situ water packaging factory. It also, discuses the challenges faced by packaged water factories and the possibility of running them profitably. For profitability, the study determined a typical profit profile for a firm that produces both sachet and bottle water products. The study also shows the importance of using PERT when evaluating a production line.

Based on results of the study, the gross energy requirement sequestered by the process is 87.8J for sachet water and 0.52 MJ for bottle water packaging with average of 10 workforces. Also, the optimal production rates of 1658 and 1551 were determined for sachet and bottle water, respectively at a profit of ₦ 291,428.29 per day. The analysis of variance (ANOVA) test for the regression model indicates that the model is adequate to describe the relationship between water produced and energy and manpower utilized in an automated production line. Thus, we can advice someone to do the business as well as determine the amount of profit the business can generate per day. In conclusion, the study presents water packaging as a profitable business opportunity after evaluation of the required resources for its operation.

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