PRESIDENTS OF THE ASSOCIATION OF PROFESSIONAL ENGINEERS OF TRINIDAD AND TOBAGO

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<td>Myron Wing-Sang Chin</td>
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FOUNDATION MEMBERS OF THE ASSOCIATION OF PROFESSIONAL ENGINEERS OF TRINIDAD AND TOBAGO IN 1959

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<th>Founding President</th>
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Note: APETT's logo was designed by Derek Aleong.
2 Editorial

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I. Notes from the Editors
The APETT Journal aims to provide a broad coverage of subjects relating to engineering. Preference will be given to papers describing original engineering work, or material of specific interest to engineers and those working in related fields, in Trinidad and Tobago (T&T) and the Caribbean Region.

II. About This Issue
This Issue (Volume 45 Number 2) of the Journal includes eight (8) articles. The relevance and usefulness of these articles are summarised below.

**C.A. Fapohunda**, “Societal and Environmental Factors as Inputs in the Development of Sustainable Engineering Curriculum in a Developing Nation: A Case Study”, investigates the effects of peculiar social and environmental issues for a sustainable engineering curriculum in Nigeria. It was found that: (i) consideration given to the nation’s peculiar material and physical environment, (ii) including cross disciplinary engineering issues in multi-cultural circumstance, (iii) the working knowledge should be incorporated into the curriculum, (iv) core of policy making curriculum to enable engineers to realise that public policy affects which technologies are funded and chosen for development and adoption and (v) study of past inventions and promotion of original research works should be promoted for sustainability of engineering. These factors should be taken into consideration in the development of sustainable engineering curriculum.

Based on their work, “Structural Characteristic and Mechanical Behaviour of Polypropylene Composites Reinforced with Entada Mannii Fibre”, O.P. Balogun, J.A. Omotoyinbo, and K.K. Alanem, investigate whether polypropylene composites are suitable for lightweight panel in automobile part. The results show that a remarkable improvement in impact strength was observed for the alkaline-treated composites than the unreinforced and untreated fibre reinforced composites. However, flexural strength and flexural modulus of the alkaline-treated composites improved significantly than that of the untreated and unreinforced composites. The fracture surface morphology of the untreated composites revealed fibre pullout, fibre debonding, and deposition of pores/holes indicated a weak adhesion between the fibre and the matrix. Finally, alkaline-treated fibre reinforced composites revealed significant improvement in the bonding of the fibre to the matrix.

**M.O. Sunmonu, et al.**, “Development of Battery Operated Evaporative Cooling System for Storing Perishables”, develop the evaporative cooling structure for storing perishable fruits (pears). The structure consists of a cooling chamber made of aluminium which is inserted inside the galvanized steel interspaced with river bed sand. The fan consists of a stator (stationary part) and the rotor (rotary part). The fan blades are attached to the rotor which results in blowing of air due to electromagnetic induction. The results showed that the constructed evaporative cooling structure (ECS) was able to maintain store produce at the temperature close to room temperature. From the result obtained, the average temperature of ECS is 24.93°C and relative humidity is 89.50%, while the ambient temperature is 31.14°C and relative humidity is 63.14%. It is however recommended that different size of fan blades of the ECS should be designed and the effect of cooling rate should be considered in further research.

In their paper, “Assessment of Termite Mound Additive on Soil Physical Characteristic”, O.E. Omofunmi and I.O. Oladipo assess termite mound inherent property as additive for improvement of soil strength. It was found that termite mound was classified as sandy clay loam soil and laterite soil was sandy loam. The termite mound has obtained the highest maximum dry density and compressive strength than other two soil samples. Increases in termite mound ratio have significant increase in maximum dry density and little effect on optimum moisture content for both soil samples. Besides, termite mound as an additive is more effective in laterite soil than clay soil in term of compressive strength. The compressive strength of the laterite almost doubled that of the clay soil at the same termite ratio. It is recommended that termite could be used as an additive for laterite soil for building construction.

**A.M. Olaniyan O.R. Karim, and E.O. Eromosele**, “Design and Development a Small-scale Peanut Roaster”, explore a small-scale solution for roasting peanut (Arachid hypogaea L) kernels. Design considerations included high roasting capacity and efficiency, quality of roasted kernels and local availability of construction materials. The essential components of the machine are feed hopper, roasting chamber, discharge outlet, prime mover, speed reduction mechanism and main support and an electric motor. In operation, peanut kernel is fed through the hopper into the roasting chamber; the screw conveyor stirs the kernels in the chamber and then conveys them to the discharge outlet where they are collected after being roasted. The machine performed satisfactorily, and sensory evaluation results also indicate an acceptability of the roasted kernels while an estimate of USD105 was used to develop the machine.

**L. Edwards, S. Maji and D.P. Chakrabarti**, “Stable Geometry for Oil, Water and Gas Phases in Horizontal Pipeline”, investigate the interface configuration for stratified or static three-phase systems in a horizontal circular conduit. The minimum energy principle for two-fluid system adopted has been employed to predict the stable interface. The total energy has been considered as the summation of the potential energies of the three (3)
phases and their surface energies which arise due to the fluid wall interaction, as well as the interfacial shear forces at the common interfaces. Few sample graphs have been plotted to establish the total energy as a function of interface curvature. Additionally, work is done to predict the stable curvature as a function of known input parameters, namely pipe diameter and fluid properties.

N.D. Naraina and K.F. Pun, “Managing Wastewater Discharge of Dairy Processing Plants in Compliance with the Environmental Regulations: A Case Study in Guyana”, assess the status of effluent/wastewater discharged by three dairy processing plants. Samples of effluent/wastewater discharge were collected and analysed with respect to the pollutants parameters stipulated in the GYS 207: 2002 Standard. Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Oil and Grease (O&G) were found as the parameters of significant importance. This study provides information on the level of pollutants and what needs to be done to bring these plants in compliance with the Environmental Regulation of 2000. An effluent/wastewater treatment system (ETS) with accompanied implementation guide was proposed for use at the dairy processing plants. Standard Operating Procedures (SOPs) and guideline were derived to monitor the ETS practices. Future research could validate the key ETS elements identified and examine their ETS processes.

In their article, “Process Optimisation of Spiced African Locust Bean (P. biglobosa) in Different Packaging Materials”, M.O. Sunmonu, M.M. Odewole and A.A. Adeyemi, exploit the process optimisation of spiced African Locust Bean in different packaging materials. It was established that useful information on the optimum values of output parameters with respect to process conditions of African Locust Beans was provided from optimisation analysis. The High Density Polythene and 6% perforation best improved the nutritional qualities of the stored locust beans at the end of the storage period. The results would help in selecting the optimum nutritional value of processed beans under various packaging and storage conditions.

III. Acknowledgements
On behalf of the Association, we gratefully acknowledge all authors who have made this issue possible with their research work. We greatly appreciate the voluntary contributions and unfailing support that our reviewers give to the Journal. Our reviewer panel is composed of academia, scientists, and practising engineers and professionals from industry as listed below:

- Dr. Albert H.C. Tsang; The Polytechnic University of Hong Kong
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Finally, the views expressed in articles are those of the authors. This does not necessarily reflect the opinions or policy of the Association.

KIT FAI PUN, Editor-in-Chief
Faculty of Engineering,
The University of the West Indies,
St Augustine, Trinidad and Tobago
West Indies
October 2017
Societal and Environmental Factors as Inputs in the Development of Sustainable Engineering Curriculum in a Developing Nation: A Case Study

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(Received 8 December 2016; Revised 31 January 2017; Accepted 9 March 2017)

Abstract: There has been a unanimous call for a home-grown engineering curriculum against the backdrop of seeming inefficiency of the graduates of tertiary institutions in developing nations. This paper presents the results of the study conducted to investigate the effects of peculiar social and environmental issues for a sustainable engineering curriculum in Nigeria as a case study. The factors considered were the environment of the mind, the physical environment, relevance of non-engineering courses, the need for studies in classical languages and human administration, as well as the study of past inventions. A well-structured questionnaire was prepared and administered to respondents who are mostly engineers. From the results, the respondents agreed that: (i) consideration to be given to the study of the Nation’s peculiar material and physical environment, (ii) including technological and non-technological ones to help graduates work with cross disciplinary engineering issues in multi-cultural circumstance, (iii) the working knowledge of either Latin or Greek should be incorporated into the curriculum, (iv) core of policy making curriculum to enable engineers to realise that public policy affects which technologies are funded and chosen for development and adoption and (v) study of past inventions and promotion of original research works should be promoted for sustainability of engineering. It can be concluded that these factors should be taken into consideration in the development of sustainable engineering curriculum.

Keywords: Curriculum, Engineering, Environment, Language, Society, Sustainable, Nigeria

1. Introduction

According to Holliday (2016), engineers run toward problems and solve problems. Since the dawn of civilisation, the problems that engineers have been called upon to solve, ranging from the mundane to the sublime. Engineering principles are not only global in applications, but have also played an indispensable role by interfacing with other disciplines like computer, science, law, social sciences, etc. in shaping humans’ social and economic development. For engineer to be able to solve problems, he must be trained to acquire necessary skills, techniques and equipment. Although there are innumerable problems presently confronting the nations of world (Monte et al., 2016), the engineers in developing nations of the world, in relation to their counterparts in the developed nations, seem to be ill-equipped and incompetent to confront the challenges of their various localities.

The International Bank for Reconstruction and Development (IBRD) classified about 81% of the nations of the world - including Nigeria where this investigation was conducted - as developing nations (Todaro, 2016). Classified as developing, because of following societal structural features: (i) lower per-capita income, (ii) low levels of human capital, (iii) high levels of poverty and under-nutrition, (iv) higher population growth rates, (v) predominance of agriculture and low levels of industrialization, (vi) low level of urbanization but rapid rural-to-urban migration, (vii) dominance of informal sector, (viii) underdeveloped labor, financial, and other markets (Kumara, 2016). The inability of engineers in developing nations to wipe out the characteristics displayed by the developing nations has been attributed to inadequate and ill-equipped training (Akintola et al., 2010).

According to Parashar and Parashar (2012), engineers ought to have the ability to tailor engineering solutions to the local social, economic, political, cultural and environmental context and to understand the impact of local action on the wider world. In Africa generally and particularly in Nigeria, Botha (2015) attributed this to:
deficient education training that is incapable of imparting skills and producing scientific and technological expertise, an environment that is plague with social and political instability that weakened the collective resolution and capacity to confront common problems, and global marginalization due to seeming bondage to policies that are driven from outside the continent resulting in exploitation of her resources and raw materials. Others include inability to abstain from aids that indigenous capacity cannot afford and sustain, absence of wholly indigenous infrastructure to use as platform for further development, and the seeming tendency for African countries to negotiate with other countries from a weak position. Contiuus reliance in the illusion of technology transfer instead of developing a home-grown technology, amongst others, is the reason why Africans engineers are ill-equipped to face challenges (Botha, 2015).

In Nigeria, this inadequacy in training is reflected by the fact that engineers now take up appointment with banks, accounting outfits and other non-engineering outfits (Onwuka, 2009). They ought to have used their engineering skills to create and develop companies, products, processes and services; as well as improve the engineering technologies to enhance the capacity of local manufacturing industries, power supply and other aspects of infrastructure in the society (Buhari, 2016). It is the failure to do these that necessitates the urgent need to domesticate the curriculum in the engineering institutions in order to ensure that the students can adapt what they learn to the vagaries of the Nigerian diverse environment (Ugochukwu et al., 2013; Akinsanya and Omotayo, 2013 and Adamu, 2015). This will be in agreement with stand of Grudzinski-Hall et al. (2007) that the curriculum for engineering studies ought to be developed to address this problem, so that consideration would be given to the cultural, political, and economic climate in which they would be implemented.

2. Deficiencies in Engineering Curriculum in Nigeria
Prior to the development of a new curriculum, careful assessment of the existing one ought to be carried out to identify deficiencies and shortcomings (Carew and Cooper, 2003). As reported by researchers (Rao, 1998); Landis, 2006; Griggs, 2013; Chandler, 2015; Driscoll, 2015 and Vanasupa and Splitt, 2015), there are several deficiencies in the current curriculum that need to be taken into consideration and their effectiveness assessed.

2.1 Environment of the Mind
That is, behavior and attitude in relation to the end of engineering as a career. In developing a sustainable curriculum, the issue of the environment of the mind of typical Nigerian engineering students has to be considered. In Nigeria, gravitation towards engineering is primarily because of perceived economic gains, obviously because of relative poverty. The weighty issue of one’s contribution to the growth and development of the society is rarely the primary reason as their motivation for choosing engineering as career. This is a veiled inference that people with wrong career goals are in the engineering profession in Nigeria.

2.2 Knowledge of Material Constitution of the Physical Environment.
That Nigeria curriculum lacks appreciation of the engineering knowledge and understanding of the material from environment (land, minerals and other raw materials), and thus is unable to impact the skills and develop processes and techniques as well as engineering equipment necessary to tame and harness this environment for developmental purpose. The curriculum, being a colonial heritage (Falade, 2006), was developed for a different environment.

2.3 Recognition of Nigeria Peculiar Society
That Nigerian engineering curriculum used the template that is foreign by ignoring domestic peculiarities and local pattern of growth of the Nigeria society. It does not train engineers to function and operate within the context of the Nigeria society – to create opportunities by solving local problems – but to function by looking out for foreign jobs or model of. It was further stated that in Nigeria, the engineering curriculum, obviously inherited from Britain (Falade, 2006), when compared with the curriculum of Universities in America – a leading engineering nation of the present civilization, did not recognize the place of her own peculiar heterogeneous societal needs in the structure of her engineering curriculum.

2.4 Lack of Appreciation of the Relevance of the Studies in the Classical Languages to Development and Growth of Engineering
The formulator of the curriculum of engineering education failed to recognize the importance of studies in the classical languages of Greek and Latin as necessary condition to unlock some of the secrets of Engineering that are preserved in these languages (Steinmetz, 1910). According to (Driscoll, 2015) that what has been preserved is meant to serve as guide in charting the direction for the future. He further averred that learning Latin, in particular, is not only to have access to the mind and spirit of the Romans and the Greeks, but also improve the ability to communicate in English, in order to participate in engineering on a global scale. This will remove their vulnerability in international relations (Todaro, 2016). In addition, learning the classical languages will help to capture the thought patterns and thought forms of the original thinkers to learn principles of, for example, the Roman machines, engines, bridges, building, and civil/structural engineering of Caesar years. These thought pattern and forms can then be stretched further, or used in a new or novel way, or modify to
accommodate some factors that were not taken into considerations in their time, in an attempt to solve local problem(s). These fundamental subjects for engineering are: mathematics, Physics, Chemistry and English language (Olafuyi and Adewale, 2005), and their terminologies are entirely based on Latin and Greek words and roots (Steinmetz, 1910).

2.5 Human Resources and Management issues of Engineering

Engineers have little or no input in policy formulation that would improve engineering practices. The curriculum did not contain adequate (i) quantitative and qualitative studies of human resources (different skills level and natural diversities) which could have given an insight into how leadership skill and actions are learned to inspire and motivate a diverse group to bond together to achieve a desirable result, and (ii) elemental principles in the art and science of human administration, that would have made engineers worthy of consultation of capable of assumption of leadership position at any level in future. This is a natural consequence of ability to bond with others.

2.6 Lack of Knowledge of Previous Indigenous Engineering Technology as Important to Sustainable Engineering

The inability of Nigerians to keep and control their own original inventions weakens her quest for sustainable engineering. It is said that a person can only consume another man’s invention but unable to grow, improve, or sustain it. The present curriculum lacks necessary modules that showcase the study and appreciation of past invention. The study of past indigenous inventions will help to bring to fore what we had, and a need to improve and sustain them will be birthed. Sustainable engineering is possible on the platform of what Nigeria has had her own, and not on what she does not have. A curious look at the benchmark minimum academic standard (BMAC) for accreditation of engineering programs in Nigeria Universities as set by the accreditation body - the Council for the regulation of Engineering in Nigeria (COREN, 2014) – showed that the above were not considered as important for accreditation purposes. Previous studies on engineering curriculum for developing nations by (Jha, 2007) and (Akindotola, et al., 2010) also failed to address the issues above. Thus, the extents to which the recognition or non-recognition of these, are factors in the development of sustainable engineering curriculum in Nigeria is the subject of this study.

3. Methodology

3.1 Population and Sample Size

The target population for this survey consisted of all the practicing engineers in Nigeria, irrespective of the disciplines, working in both private and public sectors, in the academia and in the industry, without consideration of gender and age. The sample size to represent this population was obtained from Equations 1 and 2 (Cangelosi, et al., 1976; Kish, 1995; Ali, et al., 2013).

\[
n = \frac{n'}{(1 + \frac{n'}{N})} \quad \text{Eq.1}
\]

and

\[
n' = \frac{p \times q}{\frac{V^2}{n}} \quad \text{Eq.2}
\]

Where \( n \) = the required sample size, \( n' \) = the first estimate of sample size, \( N \) = the population size, \( P \) = the proportion of the characteristic being measured in the target population, \( q = 1 - p \), and \( V \) = standard error of sampling population.

In order to get the maximum sample size for this work, the values of \( p \) and \( q \) were taken as 0.5. The standard error was also set equal to 10% to determine the sample size. This value represents the maximum standard error allowed (AlSalman, 2004). The Nigerian Society of Engineers (NSE) has a gross membership of 53,776 (NSE, 2015). On the other hand, the Council for the Regulation of Engineering in Nigeria (COREN) has about 45000 members on their register. The NSE and COREN are the two bodies that regulate engineering practice in Nigeria. To obtain a reasonably large sample size for this work, the value of 53,776 was used. On the basis of this, the minimum sample size of 25, using Equations 1 and 2 was obtained.

3.2 Statistical and Data Analysis

A set of questionnaire was designed for data collection. It was structured into eight sections. Out of 186 questionnaires distributed, a total number of 97 questionnaires, representing about 52% of the total, and more than the required minimum of 25 as computed earlier, were returned. The data collected from the returned questionnaire were statistically analysed qualitatively and quantitatively. In order to estimate the internal consistency of the defined Likert scale, Cronbach’s alpha method of estimating internal consistency, reliability expressions of equation 3, as used by Ekolu (2016) was used.

\[
\alpha = \frac{N}{N-1} \left(1 - \frac{\sum_{i=1}^{N} \sigma_i^2}{\sigma_T^2}\right) \quad \text{Eq.3}
\]

Where, \( N \) is the number of test items or questions, \( \sigma_i^2 \) is the variance for each test item, and \( \sigma_T^2 \) is the total variance. Cronbach’s alpha reliability coefficient normally ranges between 0 and 1, and the closer Cronbach’s alpha coefficient is to 1.0 the greater the internal consistency of the items in the scale. The statistical tools employed for questions in section 3 – 7 were mode, median and inter quota range (IQR) for the descriptive analysis while Mann-Whitney U test was used for quantitative analysis. These are statistical tools that are considered as suitable for ordinal scale (Archilleias, 2013 and Archilleias, 2014).
Questions in Sections 3-7 were structured in ordinal form of a 5-point Likert scale consisting of five responses, each with a different weighting for statistical analysis purposes: Strongly agree (SA) = 5, Agree (A) = 4, Undecided (U) = 3, Disagree (D) = 2, Strongly disagree (SD) = 1. Although the questionnaire was designed in such a way as to capture the probability of branch of engineering, academic qualification, and years of experience as factors that influenced the responses of the respondents, these are discussed only where they failed to agree with the general pattern of responses. All the analysis was carried out with the SPSS and MS-Excel software packages.

4. Results and Discussions
4.1 The Profile of the Respondents
The characteristics and background information of the respondents were presented in Table 1. From Table 1, it can be observed that the combined percentage of respondents who were Civil, Computer, Electrical and Mechanical Engineers is 81%. When this figure is compared with the annual output of engineering graduates from Universities and Colleges in which the four disciplines usually account for at least 67% of all engineering graduates (DE, 2007; Abdullahi, 2013), then the sample can be considered to be representative of practising engineers in Nigeria. Also the fact that Nigeria is still a developing country requiring massive construction of basic developmental infrastructure requiring the services of the four disciplines Civil, Computer, Electrical and Mechanical Engineers (Poothia, 2010), the high combined percentage of engineers in the four disciplines among the respondents is to be expected.

In addition, 10 of the respondents, representing 10.3% had doctoral degrees in their respective discipline, reflected a fair representation of both the industry and academia in the survey.

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**Table 1.** The Characteristics of the Respondents

Keys: AGR = agricultural engineers, CVL = civil engineers, CPE = computer engineers, EEE = electrical engineers, IDE = industrial engineers, MEC = mechanical engineers, MME = metallurgical engineers, MTR = mechatronic engineers, AQ = academic qualifications, HQ = highest academic qualifications, PQ = professional qualifications, S = Nigerian Society of Engineers, R = Council for the Regulation of Engineering in Nigeria, N = NONE.
Only 22 respondents (representing 22.6%) are yet to be certified by any of the engineering regulation bodies in Nigeria. Thus the fact that the majority of the respondents – 77.4% of the respondents – are certified by the engineering regulations bodies that is indicative of ability to give reliable response to the survey questions. Also significant is the fact that 79.38% of the respondents have working experience of more than five years, and thus in a position to give reliable response, confirming the adequacy or otherwise of the curriculum that underpinned their training and certificates. When viewing the background data of the respondents collectively, it can be inferred that the data obtained for this research work can be relied upon. This is because all the respondents are highly educated, with recognisable academic and professional qualification, as well as substantial years of working experience.

4.2 Reasons for Choosing Engineering as a Career

The responses of the respondents as to their choice of engineering as career are presented in Figure 1. It can be seen that the most common reason cited for choice of engineering as career was to solve the problems of the society. This choice is consistent across branches of engineering, educational and working experience groupings. This result, with particular reference to Nigeria, conflicted with the earlier held notion that engineers in developing nations are in engineering, solely for the economic reasons. Moreover, only about 4% gave economic reasons as the reason for their choice of engineering. Thus, the reason for the seemingly relative incompetence of Nigerian engineers is to be sought in domain apart from pursuits of economic interests, because awareness of engineers’ professional responsibility to their society (Vanasupa and Splitt, 2015) is shown by the majority of the respondents.

![Figure 1. Reasons for the choice of Engineering as a Career](image)

4.3 Issues in Development of Sustainable Engineering Curriculum

The summary of the responses to questions on five broad issues of: (i) knowledge of the environment, (ii) problems of the society, (iii) necessity of the classical languages, (iv) human management skills for engineers and (v) sustainability issues of engineering; are presented in Table 2. The reliability tests measured through Cronbach’s alpha reliability coefficient gave a value of 0.969. The 0.969 suggested an excellent internal consistency of the items in the scale and that items in the test are highly correlated (Gliem and Gliem, 2003).

4.3.1 Environmental Awareness

With over 98%, mode and median each of 5 and IQR of 1, the respondents were unanimous that the knowledge of the materials and physical environment was relevant to engineering (see Table 2). There was also consensus that the curriculum in Nigerian engineering schools did not make adequate provision for the acquisition of Nigeria’s material and physical environment. This is represented by IQR value of 1. Thus there is need for the curriculum to address this deficiency. The Universities in the developed countries recognised this that are evidenced in the work of (Hack, 2012; Ethics Tamu., 2016).

4.3.2 Problems in Nigeria Society

While about 87% of the respondents, with IQR 1 agreed that the curriculum gave adequate exposure to peculiar Nigeria problems (about 23 was itemised), there was also consensus that the same curriculum was deficient in depth theoretical principles and requisite skills as necessary to solve these problems. It is now being acknowledged that the principles and skills required to solve society problems are to be founded on engineering education that is built on the base of multi disciplines, including technological and non-technological ones, in order to help its graduates work with cross disciplinary engineering issues in multi-cultural circumstance (Ye, 2010; Iqbal-Khan et al., 2014; Holliday, 2016; Monte Jr, et al., 2016). Engineers must not be ignorant of his society and the way that society works. This can be seen from the fact the United States of America (USA) – the leader in this technological age – consider it more desirable to dedicate more than 20% of the time in teaching the subjects in humanities and social sciences (Rao, 1998). In Nigeria, the figure is 7% (Falade, 2006). Engineering curriculum in Nigeria, then, should be, broadened to include both theoretical and working knowledge of non-technical content. Some topics suggested by (Falade, 2006) included: Communications Skills; Management Skills; Economics, Business Practices; International Cultures and Languages; Community Sensitivities; as well as Environmental and Sustainable Development Issues. These nontechnical topics are seen as desirable by most sections of the engineering profession. They are usually identified by industrial employers of engineers as attributes, which they perceived were lacking in traditional engineering graduates.
Table 2. Summary of Issues in the Development of Sustainable Engineering Curriculum

<table>
<thead>
<tr>
<th>Theme</th>
<th>Propositions</th>
<th>SA (5)</th>
<th>AG (4)</th>
<th>UD (3)</th>
<th>DA (2)</th>
<th>SD (1)</th>
<th>Mode</th>
<th>Median</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of the Environment</td>
<td>Engineering knowledge of the materials and physical environment are necessary for sustainable development in Engineering</td>
<td>60 (61.86)</td>
<td>36 (37.11)</td>
<td>1 (1.03)</td>
<td>0 (0.00)</td>
<td>0 (0.00)</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>The curriculum make adequate provision for acquiring the knowledge of Nigeria’s material and physical environment</td>
<td>6 (6.19)</td>
<td>3 (3.09)</td>
<td>7 (7.22)</td>
<td>47 (48.45)</td>
<td>34 (35.05)</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Problems of the Society</td>
<td>Curriculum gave adequate exposure to the problems in the Nigerian society.</td>
<td>39 (40.21)</td>
<td>48 (49.49)</td>
<td>3 (3.09)</td>
<td>6 (6.19)</td>
<td>1 (1.03)</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>The curriculum equipped engineers to solve the problems in Nigeria</td>
<td>12 (12.37)</td>
<td>16 (16.50)</td>
<td>18 (18.56)</td>
<td>28 (28.87)</td>
<td>23 (23.71)</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Curriculum contains modules that impact skills required in the local society</td>
<td>18 (18.56)</td>
<td>14 (14.43)</td>
<td>5 (5.16)</td>
<td>44 (45.36)</td>
<td>16 (16.49)</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Necessity of the classical Language of either Latin or Greek</td>
<td>Study of either Latin or Greek is necessary for the unlocking of the fundamental principles of engineering</td>
<td>21 (21.65)</td>
<td>11 (11.34)</td>
<td>40 (41.24)</td>
<td>15 (15.46)</td>
<td>10 (10.31)</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>The current curriculum makes adequate provision for acquiring a working knowledge of it</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>97 (100)</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Human Management for Engineers</td>
<td>Engineers should take part actively in Human Administration as a means to drive sustainable engineering</td>
<td>46 (47.42)</td>
<td>35 (36.08)</td>
<td>9 (9.28)</td>
<td>6 (6.19)</td>
<td>1 (1.03)</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>The curriculum exposure one to duties and obligation involved in the human administration</td>
<td>18 (18.56)</td>
<td>20 (20.62)</td>
<td>11 (11.34)</td>
<td>25 (25.77)</td>
<td>23 (23.71)</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>The curriculum contains sufficient elements in the arts and science of human governance in the curriculum</td>
<td>10 (10.31)</td>
<td>12 (12.37)</td>
<td>23 (23.71)</td>
<td>22 (22.68)</td>
<td>30 (30.95)</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>The business of human administration should be left out of the curriculum</td>
<td>5 (5.16)</td>
<td>13 (13.40)</td>
<td>11 (11.34)</td>
<td>47 (48.45)</td>
<td>21 (22.65)</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Sustainability issues in Engineering</td>
<td>Knowledge of past indigenous invention necessary for sustainability in engineering</td>
<td>57 (58.76)</td>
<td>30 (30.93)</td>
<td>5 (5.16)</td>
<td>2 (2.06)</td>
<td>3 (3.09)</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>There are modules, in the curriculum dealing with the study of past indigenous invention as means to ensure sustainability.</td>
<td>63 (64.95)</td>
<td>30 (30.93)</td>
<td>4 (4.12)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Control and ownership of engineering equipment is necessary for sustainability</td>
<td>25 (25.77)</td>
<td>41 (42.27)</td>
<td>2 (2.06)</td>
<td>22 (22.68)</td>
<td>7 (7.22)</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

**Keys:** SA = Strongly Agree, AG = Agree, UD = Undecided, AG = Agree, SD = Strongly Disagree, IQR = inter quartile range.

Figures in the parenthesis represent the percentages in relation to the total.

4.3.3 Classical Languages

Though not presently in the curriculum up to PhD level, respondents seemed to be undecided on the desirability of the study of classical language with the mode and median each of 3. However, with IQR of 2, respondents seemed to be favourably disposed towards it, probably due to the...
contribution of the PhD holders’ engineers among respondents (see Table 3). It can be seen that all the respondents (100%) with PhD degree thought the study of classical languages of Latin or Greek should be introduced into the curriculum. About 67.7% of MSc holders agreed. The undecided was in the lower academic rung – the BSc and HND holders. However, the value of the study of Classics in engineering education has long been recognised by educators, because of its considerable utilitarian value, since the terminology of science is entirely based on Latin and Greek words and roots (Steinmetz, 1910).

<table>
<thead>
<tr>
<th>Qualification</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Undecided</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>PhD</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MSc</td>
<td>21</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>BSc</td>
<td>2</td>
<td>2</td>
<td>15</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>HND</td>
<td>0</td>
<td>3</td>
<td>16</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

### 4.3.4 Engineers as Administrators

From Table 1, the majority of the respondents agreed that engineers should operate actively in the domain of human administration; and that its learning should form part of the curriculum. However, it is the opinion of the respondents that elements of the arts and science of human governance, as well as exposures to the broad issues of duties and obligations in a society that is diverse in composition, and in which they are supposed to function, are not covered in the curriculum.

The curriculum did not equip the students with the technological and public policy skills to make substantive contributions to this public policy discussion. The consequence of this is that engineers are completely ignored, as unworthy of consultations during policy formulations by all the tiers of government (Atume, 2010). It is the realization that public policy affects engineering practice that Universities in advanced countries included “Engineering and Public Policy” as part of the curriculum (Helble, 2016). Students will study the core of the engineering curriculum as well as the core policymaking curriculum so as to realize that public policy affects which technologies are funded and chosen for development and adoption.

### 4.3.5 Sustainability Issues

Sustainability issues of the investigation was anchored on the premise that a person may not legally improve or be intellectually sustained with what belongs to another without first acquiring permanent ownership of it, and also demonstrate the ability to protect it permanently. For the word of (Holliday, 2016), “protection of one’s technology” is the rule in the engineering and technological world. Nigeria presently consumes nearly everything, including knowledge and products of other nation’s intellectual efforts. It is thus not surprising then that the respondents gave overwhelming support for the study of past original local inventions, no matter how modest, is relevant to the sustainability issues of engineering. It is not presently covered in the curriculum. This can be seen from Table 1 with the mode and median each of 5 and IQR of 1. This is similar to the program titled “Inventions and Inventors” been mounted by Yale University in which focus was on American inventors (Chandler, 2015). Modules in the curriculum dealing with this will give the students opportunity to discuss their ideas. Students will know who the inventors were, the inventions and the progress it brought as well as the problems it created. In this way students will be challenged about the need to carry out inventions that do no harm to the environment.

### 4.4 Suggestions for the Development of Sustainable Curriculum

In order to know some of the thoughts not captured by the questionnaire, the respondents were asked to suggest ways to achieve sustainability in engineering education in Nigeria. The suggestions with frequency of five and above were shown in Figure 2. It was found that two suggestions are worth being commented on. The suggestion that some basics of engineering should be taught at the secondary school levels, if considered, will create space for other non-technical courses that may be included at the University level. Also the suggestion of sustained investment and funding of original research by Government, if implemented, will not only turn Nigeria into producer of knowledge (instead of consumer), but will also enhance sustainability in engineering curriculum.

### 5. Conclusions

The results of this investigation showed that Nigeria engineers are aware of their professional responsibility to their society. The inability to functionally perform those responsibilities is traceable to some deficiencies in the curriculum that underpinned their training. These deficiencies are:

1. The curriculum is failed to appreciate the relevance of the engineering study of Nigeria’s physical and material environment;
2. The curriculum is lacking in society-relevant non-engineering contents;
3. The curriculum made no effort to provide; linkage to its engineering root and foundation through the teaching of Latin or Greek;
4. The curriculum failed to equip engineers in the nuances of public policy and decision making processes, and
5. The curriculum ignored the relevance of the study of past inventions as a mean to ensure sustainability of engineering.
Moreover, sustained investment and funding of original research by Government will not only turn Nigeria into producer of knowledge (instead of consumer), but will also enhance sustainability in engineering curriculum. Although this research was conducted in Nigeria, the findings are also applicable to Nations with similar colonial educational system.

References:

Figure 2. Some of respondents’ suggestions towards sustainable engineering curriculum

Table:
<table>
<thead>
<tr>
<th>Suggestion</th>
<th>Percentage</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction of basic engineering principles from secondary schools</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adoption of policy of local content technology by the Government</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher remunerations for engineers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustained Investment in/Funding of Research by Government</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laboratory should be equipped and well staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Courses related to human administration and policy issues should be introduced</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curriculum to be domesticated for social,cultural and environmental challenges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practicals geared toward industrial and sociatal challenges should be introduced</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total

20
December 2016, from: http://engineering.dartmouth.edu/magazine/perspective-engineering-and-politics


Olafuyi, O.A. and Adewale, E.S. (2005), A Review of Petroleum Engineering Education Curriculum in Nigeria, University of Ibadan, Nigeria


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Structural Characteristic and Mechanical Behaviour of Polypropylene Composites Reinforced with Entada Mannii Fibre

Oluwayomi P. Balogun, Joseph A. Omotoyinbo, and Kenneth K. Alaneme

1. Introduction

In recent years, the use of biodegradable plant derived fibres in reinforcements of polymer based composites had raised interest and awareness among researchers and industries. Several plant fibres have been explored in this regards with varied degrees of success. Among natural fibres for composites are the bast fibres, extracted from the stems of plants such as jute, kenaf, flax, ramie and hemp. They are widely used due to their excellent properties such as low cost, weight reduction, good dimensional stability and good mechanical strength (Mohanty et al., 2000). Natural fibres as potential reinforcement of composites are emerging rapidly as substitute to the counterpart synthetic fibres in applications such as automotive, aerospace, marine, sport and electronic equipment (Monteiro et al., 2009). The automobile industries are successfully applying natural fibres in the interiors and exteriors panels (Thakur, 2014; Ashori et al., 2008). The goal of using natural fibres in automobile exterior and interior components is essential to recover eco-efficiency, renewability and also trim down the production cost (Jeyathi and Janci, 2012).

Research works on the use of both long and short fibres in composites production are widely used for automobile applications. The efficiency and performance of the short fibre in reinforcement of composites is less as compared with long fibre due to orientation and distribution (Jeyanthi and Janci, 2012). However, the same short natural fibre can be used in automotive components by considering automotive safety legislations, crashworthiness and safety especially in selection of light weight panels (Feng and Feng, 2002). While fibre reinforced composites have already proven their worth as weight-saving materials, the current challenge is to improve the interfacial adhesion between the fibre and matrix, physical properties and make them cost effective.

Interfacial adhesion between fibre and matrix plays an important role in the production of fibre reinforced composites (Kabir et al., 2013). A good interfacial adhesion between fibre and the matrix enhanced stiffness and strength but brittle in nature (Beckermann and Pickering, 2008). On the other hand, a weak interfacial adhesion between the fibre and matrix leads to a lower strength and stiffness with increase toughness (Aruan and Pickering, 2014). On this account, poor fibre-matrix...
adhesion which impoverishes mechanical properties of the composite has been a major concern of natural fibres as reinforcements in polymer composites (Arrakhiz et al., 2013). Many attempts have been made by researchers towards improving the mechanical properties with the aim of improving the interfacial adhesion between the fibre and matrix.

Ahmed et al. (2006) adopted the use of chemical modification to improve the fibre–matrix interfacial adhesion. This improved the mechanical properties of the treated composites such as tensile strength and flexural properties of the composites, respectively.

Arun and Pickering (2014) worked on Comparison of harakeke with hemp fibre as a potential reinforcement in composites. The result revealed that tensile strength of treated Harakeke and hemp fibre was improved after the chemical treatment using 5 wt% NaOH/ 2 wt% Na₂SO₃ and 5 wt% NaOH removing surface constituents from the fibre. This shows a potential use of the fibres in reinforcement of polymer composites. Incompatibility of the natural fibre exists due to the hydrophilic nature and the hydrophobic nature of polymer matrix which creates a weak interface between the fibre and the matrix.

Fatai et al. (2009) worked on evaluation of the effect of fibre volume fraction on mechanical properties of a polymer matrix composite. Bagass fibre of various formulations of 0%, 2%, 4%, 6%, 8%, 10%, 15% and 20% were prepared as the reinforcement of composites. Investigation revealed that, there is possibility of using the bagass fibre as reinforcement with improvements in the UTS, modulus of elasticity and extension at break of the composites attaining a maximum reinforcement at 10%.

Al Maadeed et al. (2012) investigated the mechanical and thermal properties of use of date palm wood/glass fibre reinforced composites of recycled polypropylene. Addition of 5% glass fibre to the wood flour would increase the tensile strength by 18% relative to the wood flour alone. The hardness properties of the glass fibre composites was improved and then other composites.

Ayrilmis et al. (2011) evaluated the physical, mechanical and flammability properties of coconut fibre-reinforced polypropylene (PP) composite panels. Fibre volume of (40, 50, 60 and 70%) weight were selected and compounded with polypropylene matrix. The results show that, addition of coconut fibre into the matrix would increase the flexural strength, tensile strength and hardness of the composites with increasing fibre loading up to 60%wt.

Islam and Haque (2013) investigated the influence of fibre surface treatments on the mechanical properties of coir fibre-reinforced polypropylene composites. Sodium hydroxide (NaOH) was used for the chemical treatment of the fibre to remove fibre constituents and wax from the fibre surface and enhanced fibre-matrix interfacial. The result revealed that the mechanical properties of the composites were improved than untreated fibre reinforced composites owing to the chemical treatment which helped to remove fibre constituents that could be detrimental to the fibre-matrix bonding.

Recently, there has been interest in investigating the potentials of Entada mannii plant stem fibre as reinforcement in PMCs (Balogun et al., 2015). Entada mannii belongs to the family (Oliv.) Tisser - Leguminous mermosaesae, and liana plant. The plant is about 5 to 10m high semi-climber which grows in the tropical forest of Nigeria, Gabon and Madagascar. The Entada mannii plant which is traditionally acclaimed for its competence as binding and rope making material in several indigenous communities in Africa is yet to receive attention as a potential source of fibres for reinforcing polymers. This natural fibre can be easily modified by chemicals to improve their mechanical and physical properties (Balogun et al., 2016). In spite of lots of research done on the use of natural fibre in reinforcement of polypropylene composites for automobile applications, no research work has been reported on the use of randomly distributed Entada mannii fibre of lower weights for light components in automobile applications. The aim of this study investigates the mechanical behaviour of thermoplastic composites reinforced with short Entada mannii fibre suitable for light weights in automobile applications.

2. Materials and Methods

2.1 Materials

Entada mannii bast was obtained from Ikare-Akoko, Ondo State, Nigeria; Polypropylene-Homopolymer was supplied by Safripol, South Africa; Teflon sheet was used as the releasing agent; while a 5% of Maleic anhydride polypropylene (MAPP) served as the coupling agent to improve the fibre-matrix interfacial bonding.

2.2 Methods

2.2.1 Extraction of fibre

The Entada mannii fibre was obtained from the bark stem plant (see Figure 1) by hand stripping method. The extracted fibres were dried in an oven at 65 °C for two (2) days to remove moistures and other fibre constituents that could be detrimental to the fibre matrix bonding.

![Figure 1. Distribution of Entada mannii plant containing the fibre](image-url)

(a) (b)
2.2.2 Fibre surface treatment
A 5% NaOH solution was used for the fibre surface treatment of the *Entada mannii* fibre. The fibres were immersed in the NaOH solution and placed in a water shaker bath at 50 °C for 5 hr. The insoluble residue was delignified at pH3 and washed with distilled water in order to remove mineral traces. The treated fibre obtained was later dried in an oven at 60 °C for 2 days to remove moisteres from the fibre while some untreated *Entada mannii* fibres were also retained for control experimentation.

2.2.3 Composite fabrication
NaOH treated and untreated dried *Entada mannii* fibres of 1,3,5 and 7 wt % of the polypropylene based composites were chopped into 2 mm length and mixed with 5% Maleic anhydride polypropylene (MAPP) and homo polypropylene as the matrix. The mixtures were fed into a Jones high speed mixer for proper mixing of the fibre and the matrix. The mixtures were dried in an air circulated oven at 60 °C for 8 hr to remove moisture before they were extruded using a Twin-Screw extruder. The barrel temperature was in the range of 130-190 °C and the screw speed was fixed at 60 rpm. The extrudate was granulated in an industrial granulator into pellets dimensioning 3 to 5 mm and randomly oriented and distributed in a metallic mould. The composites were compounded for 10 minutes at a temperature of 190 °C under a constant pressure allowing thorough penetration and dispersion of the fibre into the matrix. Afterwards, the mould was transferred to another compression moulding machine and cold-pressed at 100 MPa for 12 min. The composites sheets produced were approximately 150 mm by 150 mm by 2 mm in thickness for both untreated and treated composites (see Figure 2). Polypropylene sheets of same dimensions were also prepared for control experimentation.

2.2.4 Tensile testing
Tensile test were performed on the composites produced using a universal tensile testing machine operated at a strain rate of 10mm/min with 10 KN load cell. The sample preparation, testing procedure and determination of the tensile strength and tensile modulus were in accordance with ASTM D638 (Al Maadeed *et al.*, 2013).

Six repeat tensile tests were carried out to guarantee the reliability of the results obtained.

2.2.5 Impact Strength
The impact strength of the *Entada mannii* fibre composite was evaluated using an Izod impact test machine. The sample preparation and testing procedure were in accordance with ISO 179 standard. All composite specimens were notched and the test specimen supported by a cantilever beam. Hammer head of 7.5 J was released with impact velocity of 2m/s to strike and break the notch specimens. Six specimens were tested at room temperature and the values were recorded.

2.2.6 Flexural strength
Flexural testing commonly known as three-point bending test was carried out on the composites using a universal tensile testing machine. The sample preparation and testing procedure were in accordance with ASTM D790. The test was performed by supporting the composite specimens on a beam and load was applied at the center. The test was carried out at temperature of 23 °C with a cross head speed of 2 mm/min. 6 samples were tested and the results were documented.

2.2.7 Morphology analysis (Scanning Electron Microscope analysis)
The surface morphology and fracture morphology of composites after tensile test were examined using a JEOL JSM-7600F model scanning electron microscope. Secondary electron was used while sample was placed in vacuum chamber, air dried and coated with 100A thick irradium in JEOL sputter ion coater at 15Kev.

3. Results and Discussion
3.1 Chemical treatment
Table 1 shows the fibre constituents of the NaOH treated and untreated *Entada mannii* fibre. The untreated fibre consists of cellulose (41.18%), hemicellulose (46.79%), lignin (8.12%), Ash content (5.81%) and moisture content (7.83%). It is evident that the cellulose content (54.79%) increases after the alkaline treatment as compared to that of untreated fibres (41.18%). This was due to the removal of hemicellulose and lignin contents from the fibre surfaces which increases the relative amount of the cellulose contents on the treated fibre. These changes in fibre properties were due to the alkaline treatment (Kabir *et al.*, 2013).

The results reveal that after the treatment of *Entada mannii* fibre, NaOH removes the fibre constituents (Lignin and hemicellulose from the fibre surface and thereby reduces the hemicellulose and lignin contents). Similar work was reported by Balogun *et al.*, (2016) on the effect of chemical treatment of tensile properties of soil retted *Entada mannii* fibre and found that, alkali
treatments have higher reactivity in removing hemicellulose and lignin constituents from the fibre.

Table 1. *Entada mannii* fibre constituents for treated and untreated fibre

<table>
<thead>
<tr>
<th>Samples</th>
<th>%Lignin</th>
<th>%Ash Content</th>
<th>%Cellulose</th>
<th>% Hemicellulose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated (NaOH)</td>
<td>6.29</td>
<td>4.35</td>
<td>54.79</td>
<td>40.88</td>
</tr>
<tr>
<td>(Untreated)</td>
<td>8.12</td>
<td>5.81</td>
<td>41.18</td>
<td>46.79</td>
</tr>
</tbody>
</table>

### 3.2 Tensile Strength

The variation in the tensile strength of the polypropylene based composites reinforced with NaOH treated and untreated *Entada mannii* fibres that are presented in Figure 3a. It is evident that the tensile strength varies with fibre wt % for both treated and untreated fibres. It is observed that on the average, the tensile strength of the composites reinforced with NaOH treated *Entada mannii* fibre improves significantly over the composites reinforced with untreated fibres and PURE PP composites.

This improvement is largely due to the appreciable removal of lignin and hemicellulose from the fibre surface which has been reported to contribute to poor fibre/matrix adhesion (Ashori *et al.*, 2008). The tensile strength of 5wt% (56.8 MPa) NaOH treated composites is also observed to increase by 20% and 12% than PURE PP and untreated composites due to good adhesion between fibre and the matrix. This is consistent with the research work of Asumani *et al.* (2012) who attributed that the increase in tensile strength of the composites was due to the removal fibre surface constituents such as lignin and hemicellulose that could be detrimental to the fibre-matrix interfacial bonding and enhances better fibre adhesion.

It is also noted that the NaOH treated fibre reinforced composites increases significantly in stiffness for the 1 %, 3 % and 5 %wt fibre than the untreated fibre due to better dispersion of the fibre into the matrix. Arrakhiz *et al.* (2013) reported that treated fibre exhibited good interaction between the fibre and the matrix which makes better improvements in the stiffness imparted from the fibre to the composites. Hence, this is an indication that the NaOH treatment promotes evenly distribution and better fibre-matrix adhesion, allowing efficient stress transfer between the fibre and the matrix.

The modulus of the *Entada mannii* fibre reinforced composites is shown in the Figure 3b. It is observed that the variation in tensile modulus with the composite is similar to that tensile strength in Figure 3a. The tensile modulus of the fibre reinforced composite for treated and untreated composites improves over that of the unreinforced composites with increase in the fibre wt %. The maximum value of the tensile modulus (16.416 GPa) was exhibited by the composite grade containing 5wt% of NaOH treated composites by 29% than PURE PP. This improvement was due to the removal of the fibre constituents from the fibre surface which improves the fibre-matrix adhesion of the treated composites than the untreated and PURE PP. Bledzki *et al.* (2012) reported that increase in tensile modulus of the kenaf treated fibre reinforced composites improves over the untreated fibre reinforced composites due to alkaline treatment attributed to improved bonding between the fibre and matrix.

### 3.3 Percentage Elongation

Figure 4 shows the percent elongation for the NaOH treated and untreated *Entada mannii* fibre reinforced composites. It is observed that the percent elongation reduces with increase in the fibre wt% which is in contrast to the trend observed for tensile strength and tensile modulus. Generally, for the polymer composites, the percentage elongation at break decreases with the addition of fibres to polymer matrix despite the interface between the polymer and the fibre (Morsyleide *et al.*, 2009). Almaadeed *et al.* (2013) reported that increase in fibre
loading would translate into higher tensile strength and lower elongation due to higher crystallinity of the polypropylene composites.

3.4 Impact properties

The notched Charpy impact strength of the (treated and untreated) *Entada mannii* fibre reinforced composites is presented in Figure 5. It is observed that the treated *Entada mannii* fibre reinforced composites increased with increase of 5wt% (7.88KJ/m²) fibre composites by 70% than PURE PP. This progressive improvement in the strength was due to the modification of the fibre which led to an increase in the toughness of the composites compared to PURE PP and untreated composites (Arrakhiz et al., 2013; Bledzki et al., 2012; Morsyleide et al., 2009). A slight drop in the impact properties was observed for the 7% wt fibre composites. The reduction in the impact strength was due to poor fibre-fibre interface as a result of increase fibre density that leads to a poor interaction of the fibre with the matrix.

3.5 Flexural Strength and Modulus

Flexural strength of the composites reinforced with treated and untreated *Entada mannii* fibre is presented in Figure 6a. It can be seen that the flexural strength of the NaOH treated composites has a significantly higher flexural strength than the untreated and PURE PP. The peak in flexural strength is observed for the 7wt% NaOH treated composites of 73.64MPa of 71% increase than PURE PP. The increase in the flexural strength was due to the NaOH treatment of the fibre which removes fibre constituents such as lignin and hemicellulose that reduce the fibre-matrix interfacial bonding. Carvalho et al. (2010) reported that the use of alkaline treatment is greatly beneficial in the removal of dirt and fibre constituents which improves the better fibre-matrix adhesion. Figure 6b shows the flexural modulus comparison for the NaOH treated and untreated *Entada mannii* fibre reinforced polypropylene composites. The result also indicates that the flexural strength of alkaline-treated composites improves significantly over the untreated and pure PP.
Flexural modulus of *Entada mannii* fibre reinforced composites increases with the increase in the fibre weight percent for both treated and untreated fibre reinforced composites. This indicated that *Entada mannii* fibre provided good reinforcement to the pure PP matrix. Mohammed *et al.* (2011) worked on the effect of removing polypropylene fibre surface finishes on mechanical performance of kenaf/polypropylene composites that reported that the average the chemical treatment of the fibre provided a significant improvement over the untreated fibre reinforced composites with considerable increase in flexural modulus.

### 3.6 Fracture Analysis

Figure 7 shows the fracture surface of the pure polypropylene polymer. The image shows that the matrix phase has a complete homogeneous phase. Figure 8 shows the fracture images of the untreated *Entada mannii* fibre reinforced composites. It can be seen that the tensile rupture is accompanied by fibre debonding, fibre pullout and deposition of pores/holes which is indicative of weak adhesion between the fibre and the matrix. The fibre pullout was due to poor interfacial adhesion between the fibre and the matrix.

Figure 9 shows the SEM fracture images of the NaOH treated *Entada mannii* fibre reinforced composites. Significant improvement in the fibre/matrix adhesion is observed between the fibre and the matrix, indicated a better fibre-matrix bonding. This might be due to the removal of some fatty substance and impurities from the fibre surfaces deposited pores on the fibre. These pores enhanced bonding characteristics of the fibre during lamination (Sherely *et al.*, 2008; Beckermann and Pickering, 2008). It shows that there is reduction in fibre pullout, suggesting that polypropylene matrix and the fibre adhere strongly to the fibre. Very few fibres can be observed on the fracture surfaces due to fibre concealment by the matrix material, although a few severely damaged fibres can be seen protruding out of the matrix (Beckermann and Pickering, 2008). This also indicated the higher interfacial shear strength for treated fibres and good interfacial adhesion between the fibres and matrix (Morsyleide *et al.*, 2009).

![Figure 7. SEM micrographs for the unreinforced polypropylene](image)

![Figure 8. SEM micrographs for (a) 1%, (b) 3%, (c) 5% and (d) 7% untreated *Entada mannii* composite](image)

![Figure 9. SEM micrographs for (a) 1%, (b) 3%, (c) 5% and (d) 7% Alkaline-treated *Entada mannii* composite](image)

### 4. Conclusion

The mechanical behaviour of the thermoplastic composites reinforced with *Entada mannii* fibre was investigated.

- Alkaline treatment improved the surface modification of the fibre and enhanced better fibre-matrix interfacial adhesion than the untreated fibres.
- Tensile strength and elastic modulus of the composites were improved with the treated and untreated fibre reinforced composites than unreinforced composites as the fibre loading increases.
- Reduction in the % elongation was observed as the fibre loading increases for all the treated and untreated composites.
• A remarkable improvement in impact strength was observed for the Alkaline-treated composites than the unreinforced and untreated fibre reinforced composites.

• Flexural strength and flexural modulus of the alkaline-treated composites improved significantly than the untreated and unreinforced composites. The peak in flexural strength and flexural modulus for both the treated and untreated composites increases with increase in fibre loading at 7%wt.

• The fracture surface morphology of the unreinforced composites revealed fibre pullout, fibre debonding, and deposition of pores/holes indicated a weak adhesion between the fibre and the matrix. Alkaline-treated fibre reinforced composites revealed significant improvement in the bonding of the fibre to the matrix.

• Incorporating Entada mannii fibre into polypropylene matrix has shown an improvement in mechanical properties of the composites and this could be utilised where lightweight materials is required in automobile application.

Acknowledgements:
The authors wish to acknowledge the following organisations for their support: African Materials Science and Engineering Network (AMSEN), Regional Initiative in Science Education (RISE), Science Initiative Group (SIG); and Prototype Engineering Development institute (PEDI-NASENI), Ilesha, Osun State, Nigeria.

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Development of Battery Operated Evaporative Cooling System for Storing Perishables

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(Received 8 February 2017; Revised 13 April 2017; Accepted 13 June 2017)

Abstract: A study was conducted to develop a battery operated evaporative cooling structure for storing perishable fruits (pears). The structure consists of a cooling chamber made of aluminium which is inserted inside the galvanized steel interspaced with river bed sand of 7cm. The interspace soil is constantly wetted with water at room temperature to keep the soil moist condition. The other components attached are fan blades which are connected to 12 voltage battery and control by on and off switch to reduce temperature and increase relative humidity of air, electric wires and battery holder. The fan is designed in a way to suit the required operation. It consists of a stator (stationary part) and the rotor (rotary part). The fan blades are attached to the rotor which results in blowing of air due to electromagnetic induction. The capacity of the cooling chamber, amount of air moved in one revolution and fan pressure were 14,888,367 mm\(^3\), 95.5 rpm and 14.96 N/m\(^2\), respectively. Freshly harvested but matured pears were used for the experiment. The mean temperature in the storage structure and ambient were 24.93°C and 31.14°C respectively, while the mean relative humidity in the ECS and ambient were 89.5% and 61.14% respectively. Results showed that the constructed evaporative cooling structure (ECS) was able to maintain store produce at the temperature close to room temperature.

Keywords: Battery, Perishables, Fan, Blade, Cooling, Pears.

1. Introduction

Losses in post-harvest of fruits and vegetables in developing countries are mostly due to the improper storage facilities. While refrigerated cool stores are the best method of preserving fruits and vegetables, they are expensive to buy and run. Consequently, in developing countries there is an interest in simple low-cost alternatives, many of which depend on evaporative cooling which is simple and does not require any external power supply (FAO, 1990). The effect of lack of adequate storage facilities for fresh fruits and vegetables after being harvested leads to the reduction in the quantity of fruit and vegetable that get to the market. This has a direct effect the distribution and consumption of the needed quantity for healthy living. Adequate storage involves proper regulation of temperature, humidity, air calculation, proper stacking pattern, regular inspection and prompt produce disposal as soon as storage life has been attained (Benzionic, 2008).

Fruits and Vegetables are vital agricultural products for human consumption worldwide. They are rich in vitamins and minerals such as carotene (provitamin A), ascorbic acid, riboflavin, iron, iodine, calcium, etc (Ihekoronye and Ngoddy, 1985). Fruits and vegetables are important sources of minerals and vitamins especially A and C. They also provide carbohydrates and protein, which are needed for normal healthy growth (Abdul, 1989; Salunkhe and Kadam, 1995; Adetuyi \textit{et al.}, 2008; Olusunde \textit{et al.}, 2009). Fruits and vegetables are of good importance in human health.

Evaporative cooling is the process by which the temperature of a substance is reduced due to the cooling effect from the evaporation of water. The conversion of sensible heat to latent heat causes a decrease in the ambient temperature as water is evaporated providing useful cooling. This cooling effect has been used on various scales from small space cooling to large industrial applications. The water evaporates into the air raising its humidity and at the same time reducing the temperature of the air (FAO, 1995). The basic principle relies on cooling by evaporation. When water evaporates it draws energy from its surroundings which produced a considerable cooling effect. Different designs of evaporative coolers have been reported in literature for the preservation of fruits and vegetables (Redulla, 1984a; Redulla 1984b; Sanni, 1999; Acedo 1997; Vakis, 1981;FAO, 1986; Roy 1989; Rusten, 1985; Alebiwu, 1985; Abdalla and Abdalla, 1995). However, none of these designs has made use of a battery that can cater for cases where there are irregular supplies of electricity.

Apart from the epileptic power supply and low income of farmers in the rural areas to purchase a
refrigerator, there is need to develop a battery operated evaporative cooling structure for fruits and vegetables in order to reduce the spoilage of agricultural materials.

2 Materials and Methods

2.1 Material Selection

The knowledge of the properties of materials and the way they behave under load is necessary. Example of this characteristic may include strength, stiffness, flexibility, durability, weight, resistance of heat and welding, ability to cast or hardening, machine ability, electrical conductivity, resistance to corrosion, availabilities of materials from local market, protection of food etc.

2.2 Convenient and Automatic Features

The control switch for starting the device as well as the stopping lever should be placed at convenient location and within the reach of the operator. Cases of replacement of worn or damage part easy access to these operation of a machine in term of maintenance and consistent functioning at full capacity were considered.

2.3 Noise requirement

The design eliminates noise and vibration as much as possible. The use of soft materials that can absorb vibration and enable the device to operate without vibrating was considered.

2.4 Capacity of the Cooling Chamber

Each cooling chamber has diameter of 270mm (inner cylinder), 390 mm (outer cylinder) and height of 260 mm (inner cylinder) and 320mm (outer cylinder). The capacities of the cooling chamber were mathematically determined by

\[ V = \frac{\pi r^2 h}{4} \] .......................... (1)

Where \( r \) is the radius of inner cylinder and \( d \) is diameter. Hence,

\[ r = \frac{d}{2} \]

\[ = \frac{270}{2} = 135\text{mm} \]

\[ V = \frac{\pi \times 135^2 \times 260}{4} = 14,888 \text{ mm}^3 \]

2.5 Amount of Air Moved in One Revolution

\[ Q = \text{Swept Area of the blade} \times \text{Velocity} \]

\[ Q = \pi D^2 / 4 \times \text{Velocity}, \text{ with assumed velocity of 1m/s} \]

.......................... (2)

And \( D \) is the diameter of fan blade.

The diameter of the fan blade is 200mm (0.2m)

Radius (\( r \)) = \( D / 2 = 0.2 / 2 = 0.1 \text{mm} \)

\[ Q = \frac{3.142 \times 0.1^2}{4} \times 1 = 0.0314 \text{ m}^3/\text{s} \]

But, Velocity \( V = r \times \frac{\pi}{90 \times n} \) .......................... (3)

Where \( r \) is the radius of fan blade, \( n \) is the velocity in rotation per minute.

\[ n = \frac{30 \times V}{\pi r} = \frac{30 \times 1}{3.142 \times 0.1} \]

\[ n = 95.5 \text{ rpm} \]

2.6 Fan Pressure

The fan pressure is determined by the relation;

\[ P = \frac{K \rho n^2}{D^2} \] .......................... (4)

Where \( n \) is the fan speed (rpm)

\( D \) is the diameter of fan (m) and \( P \) is the air density (kg/m³)

Where \( K \) is the constant of proportionality (dimensionless) and is given by:

\[ K = \frac{0.03142}{1000 \times 95.5 \times 0.2^2} = 4.1 \times 10^{-5} \]

Recall fan pressure

\[ P = \frac{K \rho n^2 D^2}{D^2} = 4.1 \times 10^{-5} \times 1000 \times 95.5 \times 0.2^2 = 14.96\text{N/m}^2 \]

2.7 Description of Battery Operated Evaporative Cooling Structure (ECS)

The cooling chambers was made with cylindrical aluminum sheet inserted inside another cylindrical galvanized steel and inter spaced with clay as lagging material. The soil is constantly wet with water at room temperature to keep the soil in moist condition that six blades were constructed inside the cooling chamber with plastic material. Figure 1 show the isometric view of the battery-operated evaporative cooling structure. The orthographic projection and exploded view of the battery-operated evaporative cooling structure are shown in Figures 2 and 3, respectively.
The fan is designed to suit the required operation. It consists of stator (stationary part) and the rotor (rotary part). Stator is a part which contains pairs of slotted cores that is made up of thin section of soft iron. The cores are wound with insulated copper wire to form one or more pairs of definite magnetic pole. This stator winding is connected to direct current source to form an electromagnet and the rotor is inserted in stator. The north pole of the stator will induce the north pole at the upper portion of the rotor while south pole of the stator will induce the south pole at the lower portion of rotor. The fan blades are attached to the rotor which results in blowing of air due to electromagnetic induction.

A slot which is of the same size as the motor of was made to give room for inserting the motor of the fan and attached to the cover of the aluminum with the use of bolt and nut. The wire from the source of electricity (Battery 12v) was run to the main switch (single step control) and the wire of thickness 1 mm from the fan motor met at main switch. The circuit was closed and the current flow led to rotation of the fan blade inside the Battery operated evaporative cooling structure. This served as a cooling aid to the pear inside the cooling chamber in addition to cooling resulted from evaporation of water from the wet surface (moist riverbed sand) by air that is not too humid.

3. Results and Discussions

Table 1 shows the summary statistics of temperature and relative humidity of the storage conditions. The results show that, the temperature in the evaporative cooling structure is lower than that obtained from the ambient for stored pears while the relative humidity was observed to be higher in Evaporative Cooling Structure. This is in line with the finding of Samuel et al. (2013).

<table>
<thead>
<tr>
<th>Storage Condition</th>
<th>AMBIENT CONDITION</th>
<th>ECS CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature (°C)</td>
<td>Relative Humidity (%)</td>
</tr>
<tr>
<td>Ambient</td>
<td>Mean 30.33</td>
<td>61.67</td>
</tr>
<tr>
<td></td>
<td>SD 0.58</td>
<td>2.89</td>
</tr>
<tr>
<td></td>
<td>Mean 25.00</td>
<td>65.00</td>
</tr>
<tr>
<td></td>
<td>SD 1.00</td>
<td>5.00</td>
</tr>
<tr>
<td>ECS</td>
<td>Mean 32.00</td>
<td>61.00</td>
</tr>
<tr>
<td></td>
<td>SD 1.00</td>
<td>1.73</td>
</tr>
<tr>
<td></td>
<td>Mean 29.67</td>
<td>64.67</td>
</tr>
<tr>
<td></td>
<td>SD 0.58</td>
<td>4.04</td>
</tr>
<tr>
<td>Ambient</td>
<td>Mean 31.00</td>
<td>60.67</td>
</tr>
<tr>
<td></td>
<td>SD 1.00</td>
<td>1.15</td>
</tr>
<tr>
<td>ECS</td>
<td>Mean 30.67</td>
<td>62.67</td>
</tr>
<tr>
<td></td>
<td>SD 1.15</td>
<td>2.52</td>
</tr>
</tbody>
</table>
Figure 4 shows the overview of the storage conditions as determined by temperature and relative humidity. The relative humidity of the ECS appears to be stable along the storage days and was higher compared to the relative humidity of the ambient. This may imply that the ECS improved or increased the relative humidity of the storage environment by at least 20% on the average. A significant difference in temperature (10°C) was observed between the Evaporative Cooling Structure and ambient. Generally, it can be concluded that ECS increases the relative humidity and decreases the temperature of the storage environment (Acedo, 1997).

The temperature and relative humidity of the ECS and Ambient shows variations which might be a function of the direct effect of the storage structure. These may imply that the nutritional qualities of stored pear fruits under these varied storage condition are not the same.

4. Conclusions and Recommendations

It can be concluded at the end of this research that the constructed evaporative cooling structure (ECS) was able to maintain store produce at the temperature close to room temperature. From the result obtained, the average temperature of ECS is 24.93°C and relative humidity is 89.50%, while the ambient temperature is 31.14°C and relative humidity is 63.14%. It is however recommended that different size of fan blades of the ECS should be designed and the effect of cooling rate should be considered in further research.

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Alebiowo, O.O. (1985), “Storage facilities and requirements for fruits and vegetables”, Proceedings of the Nigeria Society of
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Assessment of Termite Mound Additive on Soil Physical Characteristics

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(Received 8 February 2017; Revised 13 April 2017; Accepted 06 June 2017)

Abstract: This study was performed to assess termite mound inherent property as additive for improvement of soil strength in Nigeria. Termite mound sample was mixed with the two soils separately, that is, termite mound and clayey soil in one part and termite mound and laterite soil in another part. Twenty (20) trial experiments were conducted on the soils during compact test for soil mix ranging from 0 to 100 % at interval of 5 %. The optimum moisture content obtained from the compaction test was used to carry out compressive strength test. The Triaxial machine model HM-5020 was used for determination of the compressive strength. The findings indicated that termite mound was classified as sandy clay loam soil and laterite soil was sandy loam. The termite mound has obtained the highest maximum dry density and compressive strength than other two soil samples. Results show that increases in termite mound ratio have significant increase in maximum dry density and little effect on optimum moisture content for both soil samples. Besides, termite mound as an additive is more effective in laterite soil than clay soil in term of compressive strength. The compressive strength of the laterite almost doubled that of the clay soil at the same termite ratio. It is recommended that termite could be used as an additive for laterite soil for building construction.

Keywords: Termite mound, Additive, laterite soil, clay soil, Physical characteristics.

1. Introduction

The infrastructure development and food security are two major challenges facing developing countries, including Nigeria. High cost of agricultural products was being linked to high transportation cost and coupled with lack of access road in the rural areas where those commodities were being produced. The rural farmers made it clear and loud that high transportation has multiplier effect on the cost of agricultural produce. Due to economy recession and high inflation, the engineering profession had to look for local material for road construction and how to improve the strength of the laterite soil that is commonly used especially local road.

This has challenged road authorities to make optimum use of naturally occurring materials which are often rejected by traditional specifications for use in the upper layers of road pavements. One such naturally occurring material is laterite. Laterite is a type of residual soil that occurs extensively in the humid tropical and sub-tropical zones of the world, including much of central, southern and western Africa. Fortunately, research carried out in the late 1960s in a number of countries, notably in Angola, Mozambique, Brazil, Australia and Nigeria indicates that the performance of laterite has often been better than expected on the basis of traditional specifications. However, if successful use is to be made of this material, the conditions under which it can be successfully used must be specified.

To fix the roads at avoidable cost researches have been intensified on alternative materials that can be used to replace cement partially or wholly for construction purposes (Okoli and Zubairu, 2002; Adam and Agib, 2003). The prominent material of construction in many African countries is the laterite, and often contains some reasonable amount of clay minerals that can affect its strength and stability, hence the need for its improvement. However, there are few undesirable properties such as loss of strength when saturated with water, erosion due to wind or driving rain and poor dimensional stability. These draw backs can be eliminated significantly by stabilising the soil with a chemical agent (such as cement and other additives).

Termites are used for enhancing the content of organic carbon, clay and nutrients (King, 2006). They are found mostly in savannah areas and the weight of termite soil in the savannah is greater than the weight of animals above ground (King, 2006). Termites commonly found in Nigeria are light brown (Isoptera: Termitidae). They are major agents of decomposition, and play an important part in nutrient and carbon fluxes (Jouquent, 2004), redistribute organic matter, improve soil stability and its physical and chemical properties (Manuwa, 2009), and improve water absorbing and storing capacity (Holt and Lepage, 2000; Jude and Ayo, 2008).

Regarding the characteristics of termite mound, it cannot be easily broken. Anthill soil is very strong material most especially in the dry season, this makes it
very difficult to work upon; termite mound change in structure with climatic condition: During dry season, termite mound is very dry, while it becomes wet or sticky during rainy season, and possesses concrete material (Lavelle and Spain, 2001).

Recent studies (e.g., Lavelle and Spain (2001) and Frederic (2003)) suggested some applications of termite mound in different forms, for instance:
1) For plastering purpose and brick making - it is used for brick stoves;
2) For repair of Wood boats - it is used as soil amendment;
3) For pit latrines construction - it is used as water proof liner;
4) For making footpath and driveway – it is used as additive added to the soil to make it stabilised.

The economic importance of additive on the soil is to prevent excessive settlement of soil. It could enhance soil stiffness, shear strength and soil bearing capacity (Lavelle and Spain, 2001). Moreover, researchers, like Mijinyawa et al. (2007) and Yohanna et al. (2003) reported that Termite clay power has higher values of Clay, Liquid limit, plastic limit and Maximum dry density than laterite soil. They are better material than the ordinary clay in terms of utilisation for moulding lateritic bricks (Odumodu, 1999; Mijinyawa et al., 2007) and this type of clay has been reported to perform better than ordinary clay in dam construction (Yohanna et al., 2003).

Previous study by the Nigerian Building and Road Research Institute (NBRRI) involved the production of laterite bricks which were used for the construction of a bungalow (Madedor, 1992). NBRRI proposed the following minimum specification as requirements for laterite bricks: bulk density of 1,810 kg/m³, water absorption of 12.5%, compressive strength of 1.65 N/mm² and durability of 6.9% with maximum cement content fixed at 5%. Brick selection is made according to the specific application in which the brick will be used. Standards for brick cover specific uses of brick and classify the brick by performance characteristics.

The physical and chemical properties such as particle size distribution, bulk density and compaction properties (optimum moisture content (OMC), maximum dry density (MDD), Compressive strength (CS) and ultimate compressive strength) are important in construction. ASTM International publishes the most widely accepted standards on brick that is presented in Table 1.

![Table 1. Physical Properties in Brick Standard Specifications](image1)

<table>
<thead>
<tr>
<th>Grade/Class</th>
<th>Minimum compressive strength (Mpa)</th>
<th>Maximum absorption (%)</th>
<th>Maximum saturation coefficient (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C52</td>
<td>SW: 17.2 – 20.7</td>
<td>17.0 – 20.0</td>
<td>0.78 – 0.80</td>
</tr>
<tr>
<td></td>
<td>MW: 15.2 – 17.2</td>
<td>22 – 25</td>
<td>0.88 – 0.90</td>
</tr>
<tr>
<td></td>
<td>NW: 8.6 – 10.3</td>
<td>No limit</td>
<td>No limit</td>
</tr>
<tr>
<td>C62</td>
<td>SW: 17.2 – 20.7</td>
<td>17.0 – 20.0</td>
<td>0.78 – 0.80</td>
</tr>
<tr>
<td></td>
<td>MW: 15.2 – 17.2</td>
<td>22 – 25</td>
<td>0.88 – 0.90</td>
</tr>
<tr>
<td></td>
<td>NW: 68.6 – 103</td>
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<td>No limit</td>
</tr>
<tr>
<td>C216</td>
<td>SW: 17.2 – 20.7</td>
<td>17.0 – 20.0</td>
<td>0.78 – 0.80</td>
</tr>
<tr>
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<td>0.88 – 0.90</td>
</tr>
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<td>17.0 – 20.0</td>
<td>0.78 – 0.80</td>
</tr>
<tr>
<td></td>
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<td>22 – 25</td>
<td>0.88 – 0.90</td>
</tr>
<tr>
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<td>0.8 – 0.80</td>
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<tr>
<td></td>
<td>MX: 17.2 – 20.7</td>
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<tr>
<td>C1272</td>
<td>SX: 60.7 – 69.9</td>
<td>6.0 – 7.0</td>
<td>No limit</td>
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<tr>
<td></td>
<td>MX: 4.3 – 55.2</td>
<td>6.0 – 7.0</td>
<td>No limit</td>
</tr>
</tbody>
</table>


2. Materials and Methods
2.1 Site Selection
The study site was made of the Rhodic Acrisol type of soil - laterite that also served as control because it was about 150 m afar from termite mound. In each location, replications of three termite mounds were selected on a uniform slope. In order to evaluate soil physicochemical properties of termite mounds in relation to the surrounding soils, a total of three (3) adjacent (control) soils, three in each location were sampled for this study.

2.2 Field Investigations and Sampling
One model profile and a nearby termite mound on each of the two soil series were selected for characterisation and sampling. For each soil, a profile pit was dug then disturbed and undisturbed samples were collected from each genetic horizon. Three (3) representative samples were taken from each mound after the surface had been carefully scrapped to get below the crusted outer layers. The mound on the Rhodic Acrisol was sampled from top at 0-60 cm, 60-120 cm and 120-180 cm intervals through a vertical section. For the Rhodic Acrisol, the samples were made from depth at 0-60 cm, 60-120 cm and 120-180 cm intervals through a vertical section.

2.3 Laboratory Investigations
The disturbed soil samples were air-dried and ground gently to pass through a 2 mm sieve for analyses of selected physical and chemical properties. Laboratory analyses were carried out on the samples collected from the termite mounds, laterite and clay profiles. Physical properties determined included bulk density (on the undisturbed soil cores), particle size distribution, optimum moisture content (OMC), maximum dry density (MDD),
compressive strength (CS) and unconfined compressive strength (UCS).

2.3.1 Optimum Moisture Content (%)

Three soil samples were randomly taken with soil auger at various depths and intervals. Soil samples were weighed, oven dried at 105°C for 24 hours and weighed again to determine the gravimetric moisture content. The result is presented in Table 1.

\[
\text{Optimum moisture Content (Dry basis)} = \frac{\text{Weight of moist soil} - \text{Weight of dry soil}}{\text{Weight of moist soil}} \times 100 \quad \text{(1)}
\]

2.3.2 Bulk Density (kg/m³)

Bulk density was determined by gravimetric method. The samples were weighed empty, and later weighed with the soil. The sample was placed in an oven at a temperature of 105°C for 24 hours and allowed to cool in a desiccator. The bulk density was determined using the formula given by FAO/IIASA (2008).

\[
\text{Bulk density of soil (kg/m³)} = \frac{\text{Mass of oven dry soil}}{\text{Volume of core}} \quad \text{(2)}
\]

2.3.3 Soil Texture

One hundred grams of air-dried finely powered soil were put in a 500ml of conical flask and 15ml of 0.5N sodium oxalate (Na₂SiO₃) was added. 200ml of distilled water was added to the mixture and shake for 20 minutes. The content was transferred to one litre capacity measuring cylinder and make it up to one litre by adding enough water. Stir the suspension thoroughly, then stop stirring and note the time. Hydrometer was dipped into the suspension after 5 minutes giving direct reading of the percentage of Clay + Silt. Hydrometer reading after 5 hours of sedimentation provided the reading (i.e., the percentage of Clay directly) in g/L. percentage of sand was determined by deducting the percentage of Clay + Silt from 100 %. Similarly percentage of silt was determined by subtracting the hydrometer reading from clay + silt (APHA, 2005).

2.3.4 Maximum Dry Density (kg/m³)

Optimum moisture content was used to determine maximum dry density using Proctor model ASTM D698-78 (Standard). The experiment was repeated 5 times and then dry density of soil was calculated (FAO/IIASA, 2008).

2.3.5 Sample Preparation and Compressive Strength Test

A 6 kg of clayey soil and laterite soil was kept in respective labelled two metal bays. Air dried 6 kg of the respective sample that was mixed with 5% of water in a metal bay and its weight of the respective sample was recorded. 12 kg of anthill mounds was also kept in a labelled metal bay and mixed with 5% of water and it’s recorded. Samples of termite mound and clayey soil were mixed in the percent ratio of 5:95; 10:90; 15:85; 20:80; 25:75; 30:70; 35:65; 40:60; 45:55; 50:50; 55:45; 60:40; 65:35; 65:35; 70:30; 75:25; 80:20; 85:15; 90:10; 95:5; 100:0

Similarly, termite mound and laterite soil of the ratios were presented in the same as anthill and clayey soil. The optimum moisture content (OMC) from the compaction test was used to compacted soil for determination of the compressive test. The samples were taken to triaxial machine model HM-5020 to determine its failure load.

2.3.5 Data Analysis

Physical and chemical properties of soil samples were determined in accordance with the American Public Health Association Standards (APHA, 2005). Data were analysed using descriptive statistics. Means of each parameter was compared using Duncan’s multiple range test. The statistical inference was made at 0.05 (5%) level of significance.

\[
\text{CS} = \frac{\text{Failure X PRC}}{\text{Area}} \times KN/mm² \quad \text{(3)}
\]

Where,

- \( \text{CS} \) = Compressive strength, KN/mm²
- PRC = providing ring constant, is given as 0.025
- \( A = \text{area of sample} = \frac{\pi d^2}{2} \); \( d = \text{diameter of sample} \) extruded from the mould trimmed = 38 mm

\[
\text{UCS} = \frac{\text{CS}}{2}, \text{KN/mm}² \quad \text{(4)}
\]

Where,

- UCS = Unconfined compressive strength, KN/mm²

3. Results and Discussion

The particle size distribution and physical properties of soil samples are presented in Table 2. The compaction test was carried out for determination of the soil optimum moisture content (OMC) and maximum dry density (MDD). The results of compaction test for optimum moisture content and maximum dry density for the mixed ratio of anthill and clayey soil for compaction test and also for optimum moisture content and maximum dry density for the mixed ratio of anthill and laterite soil are detained in the Tables 3 and 4, respectively.

Table 5 shows the results of compressive test for dial gauge reading, compressive strength (CS) and unconfined compressive strength (UCS) for the mixed ratio of anthill and clayey soil. Table 6 shows the results for dial gauge reading compressive and unconfined compressive strength for the mixed ratio of anthill and laterite. Values are means of four replicates \( (n = 4) \) in all Treatment Results presented are means values of each determination ± standard error means (SEM). Means indicated by the same letter did not differ \( (p \geq 0.05) \) as assessed by Duncan’s multiple range test (horizontal comparisons only).
Table 2. Particle Size Distribution and Physical Properties of the Soil Samples

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Termite mound Height (cm)</th>
<th>Laterite Soil Depth (cm)</th>
<th>Clay Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 – 60</td>
<td>60 – 120</td>
<td>120 - 180</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>68.5 ± 4.1a</td>
<td>67.7 ± 3.7a</td>
<td>67.8 ± 3.8a</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>14.3 ± 1.2a</td>
<td>14.5 ± 1.1a</td>
<td>15.0 ± 1.1a</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>120 ± 3.82a</td>
<td>178 ± 3.1a</td>
<td>17.2 ± 3.1a</td>
</tr>
<tr>
<td>Texture</td>
<td>SCL</td>
<td>SCL</td>
<td>SCL</td>
</tr>
<tr>
<td>BD (g/cm³)</td>
<td>1.46 ± 0.1a</td>
<td>1.54 ± 0.1b</td>
<td>1.54 ± 0.1b</td>
</tr>
<tr>
<td>OMC (%)</td>
<td>19.2 ± 0.2a</td>
<td>18.5 ±0.3b</td>
<td>18.5 ±0.3b</td>
</tr>
<tr>
<td>MDD (g/cm³)</td>
<td>1.85 ±0.2a</td>
<td>1.39 ± 0.3b</td>
<td>1.39 ± 0.3b</td>
</tr>
<tr>
<td>CS (Kpa)</td>
<td>6.26 x 10⁻⁴</td>
<td>2.99 x 10⁻⁴</td>
<td>2.99 x 10⁻⁴</td>
</tr>
<tr>
<td>UCS (Kpa)</td>
<td>3.13 x 10⁻⁴</td>
<td>1.49 x 10⁻⁴</td>
<td>1.49 x 10⁻⁴</td>
</tr>
</tbody>
</table>

Key: SCL = Sandy Clay Loam; SL = Sandy Loam

Table 3. Optimum Moisture and Maximum Dry Density for the Mixed Ratio of Termite Mound and Clayey Soil for Compaction Test

<table>
<thead>
<tr>
<th>Termite soil sample (%)</th>
<th>Clayey soil sample (%)</th>
<th>Optimum moisture content (OMC) %</th>
<th>Maximum dry density (MDD) kg/m³</th>
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</thead>
<tbody>
<tr>
<td>5</td>
<td>95</td>
<td>19.75</td>
<td>1087.50</td>
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<td>5</td>
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Table 4. Optimum Moisture and Maximum Dry Density for the Mixed Ratio of Termite Mound and Laterite Soil for Compaction Test

<table>
<thead>
<tr>
<th>Termite mound sample (%)</th>
<th>Laterite soil sample (%)</th>
<th>Optimum moisture content (OMC) %</th>
<th>Maximum dry density (MDD) kg/m³</th>
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Table 5. Dial Gauge Reading, Compressive and Unconfined strength for Mixed Ratio of Anthill and Clayey Soils

<table>
<thead>
<tr>
<th>Termite soil sample (%)</th>
<th>Clayey soil sample (%)</th>
<th>Dial gauge reading</th>
<th>Compressive strength (C$)$ KN/mm$^2$</th>
<th>Unconfined compressive strength (UCS) KN/mm$^2$</th>
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</thead>
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</table>

Table 6. Dial Gauge Reading, Compressive and Unconfined Strength for Mixed Ratio of Anthill and Laterite Soils

<table>
<thead>
<tr>
<th>Anthill soil sample (%)</th>
<th>Laterite soil sample (%)</th>
<th>Dial gauge reading</th>
<th>Compressive strength(C$)$ KN/mm$^2$</th>
<th>Unconfined compressive strength (UCS) KN/mm$^2$</th>
</tr>
</thead>
<tbody>
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<td>8.60 x 10$^4$</td>
<td>4.30 x 10$^4$</td>
</tr>
<tr>
<td>75</td>
<td>25</td>
<td>41.50</td>
<td>9.15 x 10$^4$</td>
<td>4.58 x 10$^4$</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
<td>43.50</td>
<td>9.48 x 10$^4$</td>
<td>4.74 x 10$^4$</td>
</tr>
<tr>
<td>85</td>
<td>15</td>
<td>44.50</td>
<td>9.81 x 10$^4$</td>
<td>4.91 x 10$^4$</td>
</tr>
<tr>
<td>90</td>
<td>10</td>
<td>45.50</td>
<td>1.00 x 10$^5$</td>
<td>5.00 x 10$^5$</td>
</tr>
<tr>
<td>95</td>
<td>5</td>
<td>47.00</td>
<td>1.04 x 10$^5$</td>
<td>5.20 x 10$^5$</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>48.60</td>
<td>1.07 x 10$^5$</td>
<td>5.35 x 10$^5$</td>
</tr>
</tbody>
</table>

3.1 Particle Size Distribution
The textural class of the termite mound was sandy clay loam, while surrounding soil (Laterite soil) was sandy loam. There is no significant difference (p ≥ 0.05) within the soil profiles for the soil samples (see Table 2).

3.2 Physical Properties of the Soil Samples in the Study Area
The bulk density (BD) of the laterite soil has the highest values of 1.54 g/cm$^3$ (1540 kg/m$^3$) followed by termite mound of 1.46 g/cm$^3$ (1460 kg/m$^3$) and clay with the least value of 1.34 g/cm$^3$ (1340 kg/m$^3$). Clay soil has the highest optimum moisture content (OMC) of 21.1 %, followed by termite mound of 19.2 % and laterite has the least value of 18.5 %. The termite mound has the highest values in terms of Maximum dry density (MDD) and compressive strength (CS), followed by laterite soil and least values was clay (see Table 2). The OMC of a soil at the time of compaction significantly affects the dry density which in turns affects at least the strength of the samples. The OMC serves as a guide for the preparation and mixing of the block units. Moisture contents affect strength development and durability of the material and have a significant influence on the long term performance of stabilised soil material especially on bonding with mortars at the time of construction. The compressive strength is the most universally accepted value for determining the quality of material for construction.
3.3 Optimum Moisture Content and Maximum Dry Density

For termite mound and clayey soil, the minimum value of optimum moisture content was 13.00% and it occurred at mixed ratio of 40% and 60%, while the maximum value was 24.00% and it occurred at mixed ratio of 30% and 70%. And also the maximum dry density minimum value was 1,087 kg/m³ and it occurred at mixed ratio of 5% and 95%, while the maximum value was 1,848 kg/m³ and it occurred at mixed ratio of 100% and 0% (see Table 3).

The trend of the Optimum moisture content and maximum density showed that increases of termite mound content in the mixed ratios lead to increases in maximum dry density but no significant affects the optimum moisture content (see Figure 1). For termite mound and laterite soil, the minimum value of optimum moisture content was 12.50% and it occurred at mixed ratio of 75% and 25%, while the maximum value was 27.50% and it occurred at mixed ratio of 60% and 40%. And also the maximum dry density minimum value was 1,420 kg/m³ and it occurred at mixed ratio of 5% and 95%, while the maximum value was 1,885 kg/m³ and it occurred at mixed ratio of 100% and 0% (see Table 4).

The optimum moisture content for both mixed ratios was not depend upon the inherent properties of the mixtures, similarly, the trend showed that increases of termite mound content, increase in maximum dry density (see Figure 2). The trend exhibits time- and environmental dependant, while the maximum dry density for both the mixed ratios was dependent upon the inherent property of termite mound only. Hence, MDD is direct proportional to termite mound content and inversely proportional to clayey and laterite soil contents (Mijinyawa, et al., 2007; Yohanna, et al., 2003). Table 5 shows the different values of both minimum and maximum for MDD recorded between the mixed ratios. They were not significantly different (p ≥ 0.05).

Both mixed ratios, the maximum dry density fell out of the minimum specified for base course and sub-base course of 2,000 kg/m³ (2.0 g/cm³) for road construction in Nigeria (Briges, 2007). However, the maximum dry density of laterite with termite started from 85-95% mixed ratios (1,825-1,880 kg/m³) has values greater than 1,810 kg/m³ recommended for building construction in Nigeria (Madedor, 1992; Oshodi, 2004).

3.4. Compressive Strength and Unconfined Compressive Strength

For termite mound and clayey mixed ratio, the compressive strength ranging between 1.43 x 10⁻⁴ and 6.71 x 10⁻⁴ KN/mm², the results of termite mound 5% mixed with 95% clayey soil gave the minimum compressive strength at which the soil failed in stress to be 1.43 x 10⁻⁴ KN/mm², while maximum compressive strength occurred at 95% termite mound mixed with 5% of clayey soil (see Table 5). Similarly, unconfined compressive strength ranging between 7.15 x 10⁻⁶ and 3.36 x 10⁻⁵ KN/mm² formed the same pattern with the compressive strength. For termite mound and laterite soil mixed ratio, the compressive strength ranging between 3.09 x 10⁻⁴ and 1.07 x 10⁻³ KN/mm², the results of termite mound 5% mixed with 95% clayey soil gave the minimum compressive strength at which the soil failed in stress to be 3.09 x 10⁻⁴ KN/mm², while maximum compressive strength was 1.07 x 10⁻³ KN/mm². It is occurred at 100% anthill mixed with 0% of clayey soil (see Table 6).

Moreover, unconfined compressive strength ranging between 1.55 x 10⁻⁴ and 5.35 x 10⁻⁴ KN/mm² formed the same pattern with the compressive strength. The compressive strength of termite mound only is higher than the values of the termite mound mixture at both. The relationship between compressive strength of clay and laterite soils at the same termite ration is presented in Figure 3.

Compressive strength values of the termite mound and laterite were almost double the values of termite mound and clayey soil (see Table 7). The difference would be attributable to:
i. Allotropic nature of clay soil,
ii. Impurity in the clayey soil,
iii. Difference composition of clay and laterite, and
iv. Difference retention of moisture content.

Despite of the above, difference values of both minimum and maximum for compressive strength and unconfined compressive strength were recorded between the mixed ratios and they were not significantly different (p ≥ 0.05).

4. Conclusion

The results from this study indicated that: The texture classes for the termite mound and laterite soil were sandy clay loam and sandy loam, respectively. The termite mound has the highest maximum dry density and compressive strength than other two soil samples. Increases in termite mound ratio increase significantly in maximum dry density for both the soil samples and also have little effect on moisture content for both soil samples.

Termite mound as additive, it increases strength of the soil samples. Termite mound as an additive is more effective in laterite soil than clay soil in term of compressive strength. The compressive strength of the laterite almost doubled that of the clay soil at the same termite ratio. Findings revealed that the termite mound as an additive with both the soil samples does not mean the required specification for road construction but, it can be used for building construction for laterite soil only.

References:


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**Design and Development a Small-scale Peanut Roaster**

Adesoji M. Olaniyan, Olayinka R. Karim, and Emmanuel O. Eromosele

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**Abstract:** In this study, a small-scale machine for roasting peanut (*Arachis hypogaea*) kernels into the form that can be eaten as snacks was designed, constructed and tested. Design considerations included high roasting capacity and efficiency, quality of roasted kernels and local availability of construction materials. The essential components of the machine are feed hopper, roasting chamber, discharge outlet, prime mover, speed reduction mechanism and main support and a 2 hp electric motor. The roasting chamber is double-wall cylindrical drum enfolded by four 250 W heating rods connected to thermocouple and an electronic temperature controller to regulate the heat supply. A temperature of 120°C was employed for roasting. The space between the inner and outer cylinders of the roasting chamber is filled with compacted insulation materials in order to conserve heat during roasting operation. The roasting chamber houses a screw conveyor of 20 mm diameter shaft with a uniform pitch screw blade arrangement. In operation, peanut kernel is fed through the hopper into the roasting chamber; the screw conveyor stirs the kernels in the chamber and then conveys them to the discharge outlet where they are collected after being roasted. The machine was tested using dried, shelled and winnowed peanut kernels and results revealed high efficiency of roasted kernels and local availability of construction materials. The essential components of the machine are feed hopper, roasting chamber, discharge outlet, prime mover, speed reduction mechanism and main support and a 2 hp electric motor. The machine was tested using dried, shelled and winnowed peanut kernels and results revealed high efficiency of roasted kernels while an estimate of USD105 was used to develop the machine.

**Keywords:** Design, peanut, roaster, temperature, sensory, evaluation.

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1. Introduction

Peanut (*Arachis hypogaea*) is an important food and cash crop among people of many countries and its oil is a highly valued vegetable oil. Peanut roasting prior to oil extraction is done to prepare the kernel in a good condition for the extraction of the oil. Roasting reduces the viscosity of oil to be extracted, ruptures the oil cells, adjusts the moisture content of the kernel to the optimum level for oil extraction and deactivates enzymes which inhibit the release of oil from the kernel. Oil-bearing materials with high protein content are usually roasted before (Adeeko and Ajibola, 1989; Fashina and Ajibola, 1989) pressing in order to coagulate the protein and free the oil for extraction. Besides, roasted peanut kernels are also eaten as snack and the residual cake from which the oil is extracted — groundnut cake (GNC) — is an excellent ingredient for livestock feed production.

Common roasting machines include drum, hot-air, packed bed, tangential and centrifugal roasters which can operate as a batch type or a continuous system. According to Davis (2003), roasters operate at temperatures of 240-275°C for between 3 to 30 minutes duration. Reamy and Lambelet (1982) confirmed that the initial stage of roasting process is endothermic but later becomes exothermic at a roasting temperature of about 175°C indicating that the products being roasted heat themselves in the process. Olaniyan et al. (2015) developed a 20 kg/h shea kernel roasting machine with a temperature-controlled electric heating coil as source of heat energy. Test result revealed that the kernels were of uniform deep-brown colour with clear film of oil on the surface after roasting indicating that they experienced uniform roasting. Akinoso et al. (2004) developed a 300 kg/h manual cashew nut roasting machine which uses charcoal as a source of heat energy. Performance evaluation showed that the roaster could roast 15 kg of raw cashew nut having a moisture content of 12 % wet basis for 3 minutes using 130°C as a roasting temperature.

Olopade and Akinoso (2004) developed a 2 kg capacity roaster for roasting cassia sieberiana seeds. Visual observation while testing the roaster revealed that physical changes on the seeds were time dependent; 200°C roasting temperature and 15 min roasting time gave the best samples of cassia sieberiana during the testing. Mahama et al. (2004) developed a machine for roasting crushed shea kernel in Northern Ghana. The roaster consists of an enclosed cylindrical drum with a lid welded to the opening to prevent the material from falling out.
during operation. Inside the drum are agitators which transfer the material into different positions in order to prevent burning, mixes the material in the drum for uniform roasting and sweeps the roasted materials properly in the drum in order to receive fresh one. However, the machine is very slow in operation and operates with much heat loss and too much heat to body contact with possibility of fire disaster during roasting (Mahama et al., 2004).

Traditionally, peanut is roasted over fire for a certain period of time using some local methods which include using a clay pot or a frying pan inside which the nuts are placed and then heated from the bottom with firewood. This traditional method is crude, tedious, labour intensive, has no provision for ergonomic factors and also exposes the operators to excessive smoking and heat radiation. Peanut processors in the rural communities need a roasting device that can easily be operated, used and maintained. Therefore, the objectives of this work are to design, construct and test a simple small scale machine for roasting peanut prior to oil extraction in the rural communities. Such a machine would remove the hazards involved in the traditional roasting of peanuts and eventually improve the efficiency of peanut extraction.

2. Description and Working Principles of the Roaster

Figure 1 shows the machine that consists of feeding hopper, screw conveyor, heater, roasting chamber with heating device, outer chamber with lagging material, machine stand and collection outlet. The feeding hopper is a reservoir which temporarily contains the peanuts before being fed into the roasting chamber. Housed in the roasting chamber, the screw conveyor is made up of a shaft of diameter 20 mm and length 600 mm with the screw blade arranged on the shaft at uniform pitch. In the roasting chamber, the peanut get roasted while being conveyed by the screw conveyor. It is a cylindrical drum of 160mm diameter and 550mm long with both ends covered.

The outer chamber, which is also cylindrical in shape, covers the roasting chamber attached with the heater which is lagged to reduce the amount of heat loss. Four 250 W heating elements are attached externally to the roasting chamber that are connected with a system of thermocouple and an electronic temperature controller to regulate the heat supplied for roasting. During operation, the screw conveyor stirs the fresh peanuts in the roasting chamber and at the same time conveys the roasted along the line of travel. In the process, the amount of heat required is supplied by the heating element and the roasted peanuts are discharged at the collection outlet.

The machine is powered by a 2hp single-phase electric motor through a speed reduction mechanism (gearbox).

3. Design Considerations

While designing the machine, considerations included: 1) machine capacity of 20 kg/h (having in mind a scaled-down device suitable for a micro and small-scale processor in the rural communities); 2) roasting chamber adequately insulated to prevent heat loss during roasting operation; 3) a speed-reduction mechanism to step down the motor to the desired shaft speed; 4) temperature-control device to regulate the roasting temperature; 5) a screw auger to serve the dual purposes of conveying and stirring the kernels in the roasting chamber thereby preventing burning of the peanuts; 6) roasting chamber designed to accommodate the required quantity of peanuts and ensure maximum contact of individual peanuts with the heat output, in order to increase efficiency and reduce heating time; and 7) a strong main frame to serve as structural support for the machine. These factors also influenced the selection of materials for the fabrication of the machine components.

4. Design Calculations

4.1 Hopper Design

The hopper was designed as a frustum of a pyramid; therefore, the volumetric capacity is given as:

\[ V = \frac{1}{3} (A_1 + A_2 + \sqrt{A_1 \cdot A_2})h \]

where, \( V \) is the volumetric capacity, \( h \) is the height in m, \( A_1 \) and \( A_2 \) are the areas of the bottom and top bases from
the hopper respectively. Substituting h = 25 cm, \( A_1 = 400 \text{ cm}^2 \), \( A_2 = 225 \text{ cm}^2 \), hence, \( V = 24,000 \text{ cm}^3 \).

### 4.2 Pulley and Belt Design

The specifications of the driving and driven pulleys were determined by the expression given below as:

\[
\frac{N_1}{N_2} = \frac{D_2}{D_1} \tag{2}
\]

where, \( N_1 \) is the rated speed of the motor in rpm, \( N_2 \) is the speed of the shaft in rpm, \( D_1 \) is the diameter of the motor (driving) pulley in mm and \( D_2 \) is the diameter of the shaft (driven) pulley in mm. Given that \( N_1 = 1,450 \text{ rpm}, D_1 = 90 \text{ mm}, D_2 = 450 \text{ mm}; \) hence, \( N_2 = 290 \text{ rpm} \).

The centre-to-centre distance and length of the transmission belt were determined by the Equations (3) and (4) respectively given below as:

\[
C = \frac{1}{2} (D_1 + D_2) + D_1 \tag{3}
\]

\[
L = \frac{1}{2} (D_1 + D_2) + 2C + [(D_1 + D_2)^2]/4C \tag{4}
\]

where, \( C \) is the centre-to-centre distance and \( L \) is the length of the transmission belt respectively in mm. Substituting \( D_1 = 90 \text{ mm}, D_2 = 450 \text{ mm} \) into Equations (3) and (4); hence \( C = 360 \text{ mm} \) and \( L = 1,658 \text{ mm} \).

### 4.3 Design of the Screw Conveyor

The screw conveyor is the main functional part of the roaster and is acted upon by weights of material being roasted, pulley and screw thread. In operation, the conveyor moves and stirs the material (peanuts) during roasting operation. Therefore, in order to safeguard against bending and torsional stresses, the diameter of the screw shaft was determined from the equation given by Shigley and Mitchell (2001) and Khurmi and Gupta (2008), as:

\[
d_3 = 16T / (0.27 \pi \delta_0) \tag{5}
\]

where, \( d_3 \) is the diameter of the screw shaft in m, \( T \) is the torque transmitted by the shaft in Nm, \( \delta_0 \) is the yield stress for mild steel in N/mm² and \( \pi \) is a constant. Given that \( T = 60 \text{Nm} \) and \( \delta_0 = 200\text{N/mm}^2 \), \( \pi = 3.142 \); hence, \( d_3 = 17.82 \text{ mm} \). Therefore, a mild steel rod of diameter 20 mm and length 600 mm was used for the screw conveyor.

### 4.4 Design for Machine Capacity

The theoretical capacity of the machine was determined using a modified form of the equation given by Onwualu et al. (2006) as:

\[
Q = 60 \times \frac{1}{4} \pi (D^2 - d^2) \rho N \phi \tag{6}
\]

where, \( Q \) is the theoretical capacity of the machine in \( \text{m}^3/\text{h} \), \( D \) is the screw diameter in m, \( d \) is the shaft diameter, \( \rho \) is the screw pitch, \( N \) is the shaft (rotational) speed of the screw shaft in rpm, and \( \phi \) is filling factor. Substituting \( D = 42 \text{ mm}, d = 20 \text{ mm}, \rho = 40 \text{ m}, N = 290 \text{ rpm}, \) and \( \phi = 0.8 \) into Equation (6); hence, \( Q = 0.596 \text{m}^3/\text{h} \).

### 4.5 Design for the Power Requirement

The power required to drive the machine was calculated using a modified form of the equation given by Onwualu et al. (2006) as:

\[
P = (Q \rho \pi F) / 3.6 \tag{7}
\]

where, \( P \) is the power required to drive the machine in W, \( Q \) is the volumetric capacity of the screw shaft in \( \text{m}^3/\text{h} \), \( \rho \) is the density of peanut in kg/m³, \( \pi \) is the acceleration due to gravity, and \( F \) is the material factor. Substituting \( Q = 0.596 \text{m}^3/\text{h}, \rho = 0.6 \text{m}, \pi = 9.81 \text{ m/s}^2, \) \( \rho = 641 \text{ kg/m}^3 \) and \( F = 0.4 \) into equation 3.9; hence, \( P = 249.9 \text{ W} \). To give allowance to power used in driving the pulley and other losses, the rated power was 300 W.

The power of the electric motor to drive the system was estimated as:

\[
P_m = P / \eta \tag{8}
\]

Where \( P_m \) is the power of electric motor in W and \( \eta \) is the efficiency of the motor in decimal. Given that \( \eta = 75 \% \) or 0.75, therefore, \( P_m = 400 \text{ W} \) or 0.536 hp. The machine can be driven by a 1 hp electric motor. However, a 2 hp single-phase electric motor was selected.

### 4.6 Design for Amount of Heat Energy Required for Roasting

The quantity of heat energy required to bring the roasting temperature to 180°C was determined using Equation (9) below as:

\[
Q = m_a (h_2 - h_1) \tag{9}
\]

where, \( Q \) is the amount of heat energy in kJ/s, \( m_a \) is the air mass flow rate in kg/s, \( h_1 \) is the specific enthalpy of air at inlet in kJ/kg-air and \( h_2 \) is the specific enthalpy of air at the heating temperature in kJ/kg-air. Substituting \( h_1 = 81.0 \text{ kJ/kg-air}, h_2 = 100 \text{ kJ/kg-air} \) and \( m_a = 0.152 \); hence, \( Q = 2.888 \text{kW} \). Therefore, 2 units of electric heater of 1.5kW each were required to supply heat energy for roasting the peanuts.

### 4.7 Design for Operating Capacity of the Roaster

The operating capacity of the machine was calculated from the energy equations used by other researchers who have worked in this area (Olopaade and Akinoso, 2004; Akinoso et al, 2004) as:

\[
Q_o = mc \Theta \tag{10}
\]

and

\[
t = Q_o / P_h \tag{11}
\]

Where \( Q_o \) is the quantity of heat required in kJ, \( m \) is the mass of peanut in kg, \( c \) is the specific heat capacity of peanut in kJ/kg °C, \( \Theta \) is the change in temperature in °C, \( t \) is the roasting time in s and \( P_h \) is the rated power of the heaters in kW. With \( m = 7 \text{ kg}, c = 1.507 \text{ kJ/kg °C}, \Theta = 120 °C \) and \( P_h = 1.5 \text{ kW} \) substituted into Equation 2.4, hence, \( Q_o = 1,265.88 \text{ kJ}, \) and \( t = 14.07 \text{ min} \). Therefore, the machine can roast 7 kg of peanut in about 15 min.
5. Materials Selection and Fabrication Process

The feeding hopper was fabricated from a standard length of 1.5mm thick mild steel sheet. Four pieces of dimension 200 x 150 x 250 mm were cut from the mild steel sheet and welded together by oxy-acetylene flame to form the four sides of the hopper. The screw conveyor was fabricated from a galvanized steel rod of diameter 25 mm and length 600 mm which was machined on the lathe to 20 mm base (shaft) diameter. The screw arrangement was machined at a screw depth of 25 mm thereby forming a screw conveyor of nine screw turns. The roasting chamber was fabricated from a 2 mm galvanized steel sheet and folded to form a cylindrical drum of 160 mm inside diameter, 2 mm thickness and 600 mm long which was cut and machined to 550 mm length.

Using oxyacetylene flame, a slot of 200 mm x 150 mm was made on the upper side of the roasting chamber to form the hopper base. 20 narrow slots were made on the lower portion of the roasting chamber to serve as collection channels for the roasted peanuts. The main frame and electric motor stand were fabricated from a mild steel angle iron of dimension 50 x 50 x 50 mm which was cut to the required dimensions by a power hacksaw and welded together. The heating element was welded spirally on the outer walls of the roasting chamber using oxyacetylene flame. The external cylinder was fabricated from a 1.5 mm mild steel sheet and folded to form a cylindrical drum of 200 mm inside diameter, thickness 1 mm thereby covering the heating element and heat insulator.

The specification of construction materials is shown in Table 1. Fabrication process included: marking out, machining, cutting, joining, drilling and fitting. The workshop tools and machines used included: scriber, steel rule, compass, centre punch and treadle-operated guillotine for cutting and welding machine for joining. The metal sheet was cut by a treadle-operated guillotine, while a rolling machine was used to fold the sheet into a cylindrical shape.

6. Materials and Methods Used For Performance Evaluation

Figure 2 shows the pictorial view of the machine after fabrication and assembly. The performance of the machine was tested in the Laboratory of Processing and Storage, Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria.

High grade peanuts were obtained from Oja Oba market in Ilorin-West Local Government Area of Kwara State where there is abundance of the produce. The machine was set into operation and the heater was set at a temperature of 120°C using the Electronic Temperature Controller. The roaster was pre-heated at the temperature of 120°C for 90 minutes. 3 kg of the peanuts was weighed and introduced into the machine through the feeding hopper, conveyed by the screw conveyor and roasted in the roasting chamber at 120°C for 5.0, 7.5 and 10.0 minutes, respectively. The roasted peanuts were collected through the collection outlet, sorted into broken and unbroken samples and weighed separately.

Table 1: Materials of Construction of the Peanut Roasting Machine and their Specifications

<table>
<thead>
<tr>
<th>Material of Construction</th>
<th>Specifications</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild steel sheet</td>
<td>1.5 mm thickness, standard size</td>
<td>1</td>
</tr>
<tr>
<td>Galvanized steel sheet</td>
<td>2 mm thickness, standard size</td>
<td>1</td>
</tr>
<tr>
<td>Galvanized steel rod</td>
<td>Φ 25 mm, 1 standard length</td>
<td>1</td>
</tr>
<tr>
<td>Mild steel angle iron</td>
<td>50 x 50 mm, standard length</td>
<td>1</td>
</tr>
<tr>
<td>Electric heater</td>
<td>250 W</td>
<td>4</td>
</tr>
<tr>
<td>TDC *</td>
<td>0-150 °C</td>
<td>1</td>
</tr>
<tr>
<td>Heat resistant cable</td>
<td>Φ 3 mm &amp; 2 mm</td>
<td>2 yards</td>
</tr>
<tr>
<td>Welding electrode</td>
<td>Gauge 12 ordinary</td>
<td>1 pack</td>
</tr>
<tr>
<td>Electric plug</td>
<td>15 A</td>
<td>2</td>
</tr>
<tr>
<td>Cast iron pulley</td>
<td>Φ 90 mm</td>
<td>1</td>
</tr>
<tr>
<td>Bolts and nuts</td>
<td>M12</td>
<td>117</td>
</tr>
<tr>
<td>Ball bearing</td>
<td>Φ 25 mm</td>
<td>2</td>
</tr>
<tr>
<td>V – belt</td>
<td>A 50, 12.5 X 1325 mm</td>
<td>1</td>
</tr>
<tr>
<td>Insulating materials</td>
<td>Fibre glass and cotton wool</td>
<td>5 kg</td>
</tr>
</tbody>
</table>

* TDC: Temperature Control Device
From the data obtained, the performance efficiency of the roasting machine was calculated based on unbroken peanuts as:

\[ E_p = \frac{100W_2}{W_1} \]  

(12)

where, \( E_p \) is performance efficiency of the machine in %; \( W_1 \) and \( W_2 \) are mass of raw peanuts before roasting and mass of unbroken peanuts after roasting respectively in kg.

The roasted peanuts were subjected to sensory evaluation in order to determine the aroma, taste and colour. Colour evaluation was based on visual examination. The panel of judges comprising of 20 assessors was drawn from within and outside the department for the sensory evaluation of the roasted peanuts at different roasting times. Each person in the panel observed the colour, perceived the aroma and taste of the roasted peanuts and scored the sensory parameters based on scale 1 to 5.

The panelists rated the taste, aroma, colour and overall acceptance using a five point hedonic scale, where 5 indicated ‘like extremely’ and 1 ‘dislike extremely’ (Iwe, 2002). Mean scores of the sensory evaluation were subjected to analysis of variance and Duncan multiple range test.

7. Results and Discussion of Performance Evaluation

The results of the tests at different roasting times are as shown in Table 2 for performance efficiency of the roasting machine based on percentage (by weight) of unbroken roasted peanuts. The table showed that the average performance efficiency of the machine were 73.54%, 71.27% and 69.47% for roasting times of 5.0, 7.5 and 10.0 minutes, respectively. This implies that the percentage (by weight) of unbroken roasted peanuts decreased as roasting time increased. The reason that can be adduced to this is that, as roasting time increases, the nuts become more brittle due to reduction in moisture content. Brittleness makes the nuts more susceptible breakage during roasting and conveyance. Hence, performance efficiency decreases with increase in roasting time. This relatively high percentages of unbroken roasted peanuts showed that the machine performed satisfactorily.

<table>
<thead>
<tr>
<th>Roasting Time (Minutes)</th>
<th>Performance Efficiency (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>73.54±3.36</td>
</tr>
<tr>
<td>7.5</td>
<td>71.27±3.18</td>
</tr>
<tr>
<td>10.0</td>
<td>69.47±0.73</td>
</tr>
</tbody>
</table>

* Each value is the mean of 5 replicates ± standard deviation.

Table 3 showed the results of the sensory evaluation based on colour, aroma and taste. It is shown that sample of peanuts roasted at 10.0 minutes was the best in terms of colour, aroma and taste. This is due to the fact that, during roasting, biochemical reaction in the nuts results in production of taste, aroma and colour changes peculiar to roasted nuts. Therefore, as roasting time increases, the potential to undergo this biochemical reaction increases. This is in line with the observation of Tairu et al. (2000) in Olaniyan (2012).

<table>
<thead>
<tr>
<th>Sensory Quality</th>
<th>Roasting Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
</tr>
<tr>
<td>Colour</td>
<td>2.4*a</td>
</tr>
<tr>
<td>Aroma</td>
<td>2.2*b</td>
</tr>
<tr>
<td>Taste</td>
<td>2.0*a</td>
</tr>
<tr>
<td>Overall Acceptability</td>
<td>2.3*a</td>
</tr>
</tbody>
</table>

* - Means with different alphabet along the same row are significantly different at p ≤ 0.05 using Duncan multiple range test.

The result showed that the sample roasted at 10.0 minutes was rated highest is colour, aroma, taste and overall acceptability. This indicates that the panelists placed preference for the sample than others. All the samples were also significantly different (p ≤ 0.05) from each other on all the parameters. The reason for these may be attributed to the performance efficiency of the machine based on percentage (by weight) of unbroken roasted peanuts.

8. Conclusion

A small scale machine for roasting peanuts was designed, fabricated and tested. The roaster was portable enough for local production, operation, repair and maintenance while all the construction materials were available locally and at affordable costs. Powered by a 2 hp single-phase electric motor through a gear reduction mechanism, the machine has a production cost of USD105. With average performance efficiency of 73.54 %, 71.27 % and 69.47% at the roasting time of 5.0, 7.5 and 10.0 minutes respectively, the machine is deemed to have performed satisfactorily.

The machine can be used for small scale peanut roasting in the rural and urban communities and can be scaled-up for industrial application. An improvement in the design of the screw conveyor of the roasting chamber is expected to improve the efficiency of roasting process; hence, this is recommended for further research. While testing the machine, the colour, aroma and taste peculiar with roasted peanuts were perceived.

References:


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Stable Geometry for Oil, Water and Gas Phases in Horizontal Pipeline

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(Received 25 March 2017; Revised 28 May 2017; Accepted 16 June 2017)

Abstract: Effort has been made to predict the interface configuration for stratified or static three-phase systems in a horizontal circular conduit. The minimum energy principle for two-fluid system adopted from past literatures has been employed to predict the stable interface. The total energy has been considered as the summation of the potential energies of the three (3) phases and their surface energies which arise due to the fluid wall interaction, as well as the interfacial shear forces at the common interfaces. Few sample graphs have been plotted to establish the total energy as a function of interface curvature. Additionally, work is done to predict the stable curvature as a function of known input parameters, namely pipe diameter and fluid properties. In other words, interface shapes are expressed as a function of Eotv\textsuperscript{s} number, wettability angle and hold up.

Keywords: Three phase flow, circular conduit, minimum energy, wettability angle, interface curvature

Notations and symbols

\begin{align*}
E &= \text{energy} \\
A &= \text{area} \\
Y &= \text{centre of gravity} \\
S &= \text{boundary} \\
R &= \text{radius of pipe} \\
a &= \text{area ratio} \\
P &= \text{potential} \\
S &= \text{surface} \\
T &= \text{total}
\end{align*}

Greek letters

\begin{align*}
\alpha &= \text{wettability angle of 1 and 2} \\
\beta &= \text{wettability angle of 2 and 3} \\
\Delta &= \text{change} \\
\varepsilon &= \text{Eotv\textsuperscript{s} no.} \\
\rho &= \text{density} \\
\rho &= \text{density ratio} \\
\sigma &= \text{interfacial tension} \\
\phi &= \text{angle at 1, 2 interface} \\
\psi &= \text{angle at 2, 3 interface}
\end{align*}

1. Introduction

Stratified flow pattern is considered as a basic flow configuration in horizontal and inclined two-phase systems of finite density differential. In such cases, model of stratified flow is needed for predicting the flow characteristics, such as pressure drop and in-situ holdup. Special importance is given to the interface curvature in two-phase flow systems. When the viscosity ratio is high, the interface curvature and its influence on wetted area may pose a crucial effect on the flow and pressure drop; for example, the performance of crude-oil/water transportation line (Russell and Charles, 1959), where viscosity drops with more dispersed water. Little information is available for the determination of the phase holdup of three phase flows (Taitel et al., 1995).

Traditionally, the consideration of interface configuration is related to capillary and small scale systems, where the effect of surface tension becomes comparable with gravity. In large scale system, however, the natural trend is to neglect surface phenomena. This is justified in high density differential systems, such as gas-liquid systems under earth conditions. In liquid-liquid systems with small density difference (such as oil-water systems), or in reduced gravity systems (even with high gravity difference), the surface phenomena may dominate, resulting in curved interface configuration (Brauner, 1990). In a majority of studies of stratified two-phase flows, plane interface has been assumed between the phases. This may be reasonable in gas-liquid (air-water) systems (Taitel and Dukler, 1976; Brauner and Moalem Maron, 1989).

Previous studies, focusing on liquid-liquid two-phase systems, point out the need to account for phases wettability properties and of the interface curvature in solving for the two-phase pressure drop, insitu holdup and the stability of the free interface (Russell et al., 1959; Bentwich, 1964).

Scientists (Neogi et al., 1994) came up with a model for predicting the thickness of oil and water phases in gas-oil-water systems in horizontal pipes. The predicted results were proven to be similar to the experimental ones. The experimental and predicted results show that the gas...
layer has a significant effect on the oil layer and that the oil layer does not affect the water film as much as the gas film affects the oil film. However, to postulate three-phase stable configuration in a conduit, two-phase flow theories should be followed strictly.

Studies by Brauner et al. (1996, 1998) for two-phase flow, energy consideration have been employed to predict the interface configuration in a circular pipe. In their study, the effect of the fluid physical properties, insitu holdup, tube dimension, wall adhesion and gravitation on the characteristic interface curvature have been explored. Their prediction of interface curvature has provided the closure relation required for a complete solution of stratified flows with curved interfaces for a variety of two-fluid systems.

Gorelik and Brauner (1999) have obtained the exact analytical solution of Euler-Lagrange equation. Researchers have addressed the problem of predicting the interface location in stratified flows. Analytical expressions have been obtained for the interface shape and for the capillary pressure by using the variational problem of minimising the system free energy (potential and surface energies). They have shown that the variational principle is consistent with the hydrodynamic equations of unidirectional fully developed axial laminar two-phase flow in a conduit. Under these conditions, their solution is exact and is determined by three dimensionless variables: the holdup, fluid/wall wettability and the Eotvos No ($\varepsilon_{\text{E}}\equiv \sigma \varepsilon_{\text{U}} = \frac{2\sigma}{gR^2} \Delta \rho$), the ratio of surface energy to gravitational energy i.e., $\varepsilon_{\text{E}} = 2\sigma/gR^2\Delta \rho$, where, $\sigma =$ interfacial tension;

$\Delta \rho =$ density difference of respective phases

When gravity predominates over surface energy, $\varepsilon_{\text{E}} \rightarrow 0$, whereas for strong surface energy field $\varepsilon_{\text{E}} \rightarrow \alpha$. Ranges of parameter values, for which either the model of flat interface, or the model of constant curvature occurred, are explored in that study. It has been also shown that the model of constant characteristic curvature (Brauner et al. 1996, 1998) provides a good description of the interfacial shape and enables extending the parameter space where analytical solutions of stratified flow can be obtained.

Researchers (Ng et al., 2001, Chakrabarti et al., 2005, 2010, 2014, Raj et al., 2005, Pandey et al., 2006, Shirley et al., 2012) have extended the studies by Brauner et al., (1996) and Gorelik and Brauner (1999) to predict the possible stratified stable interface shapes for two phase flow system in horizontal circular pipes. The analysis has been carried out presently by considering the minimum energy principle (Brauner et al., 1996). The variations of the potential and surface energy terms are calculated with respect to a plane interface (taken as a configuration of reference). The total change in the potential energy is given by:

$$\frac{\Delta E_p}{L} = \frac{1}{L} (A_1 \rho_1 + A_2 \rho_2 + A_3 \rho_3) (Y_{G123}^{p} - Y_{G123}^*)$$

[1]

Where the centre of gravity of the phases with plane interface, $Y_{G123}^{p}$ and with curved interface $Y_{G123}^*$ are derived below in terms of curvature angles, view angles and insitu hold up ratios, where $\rho_1, \rho_2, \rho_3$ are densities of phase 1, 2, 3 respectively, and $A_1, A_2, A_3$ are cross sectional areas in the circular tube occupied by respective phases (see Figure 1). The total change in surface energy terms is given by:

$$\Delta E_s = (\Delta E_s)_{1W} + (\Delta E_s)_{2W} + (\Delta E_s)_{3W} + (\Delta E_s)_{12} + (\Delta E_s)_{23} =$$

$$\sigma_{1W} \Delta S_{1W} + \sigma_{2W} \Delta S_{2W} + \sigma_{3W} \Delta S_{3W} + \sigma_{12} \Delta S_{12} + \sigma_{23} \Delta S_{23}$$

[2]

$\Delta E_s$ represents the change in surface energies involved due to variation of the contact areas of each phase with the solid wall, $(\Delta E_s)_{1W}, (\Delta E_s)_{2W}, (\Delta E_s)_{3W}$ and between themselves, $(\Delta E_s)_{12}, (\Delta E_s)_{23}$ as the interface switches to its natural curved configuration (from the reference plane configuration). Where $\sigma$ is the interfacial tension and $\Delta S$ is the length of curvature between the phases (see Figure 1). Subscript 1W, 2W, 3W, 12 and 23 signify ‘between phase 1 and wall’, ‘between phase 2 and wall’, ‘between phase 3 and wall’, ‘between phases 1 and 2’ and ‘between phases 2 and 3’, respectively.

Figure 1. Pipe cross-section occupied by three fluids

A review of the past literature shows that few works have been carried out to predict the interfacial shape in the two phase flow systems. Moreover, no work has been reported for three phase systems. Considering the importance of interface curvature in modelling stratified three phase flows, the present project aims at an in-depth
study of the interface curvature of a three-phase system in a circular conduit.

2. Formulation

A plane interface is often encountered when gas liquid system is considered and hence modelling of a gas liquid system can reveal interesting facts. An attempt has been made to present the mathematical model as per the calculation of Brauner et al. (1996).

In view of Figure 1, subscript 1, 2, 3 are given to the phases in the increasing order of density (i.e., gas, oil, water). The areas are calculated in terms of the interface curvature angle ($\Psi$) at oil, water interface and wall view angle of the interface ($\psi_{o}$ and $\phi_{o}$).

$$A_1 = R^2 \left( \phi_0 - \frac{1}{2} \sin(2\phi_0) \right)$$  [3]

$$A_3 = R^2 \left( \psi_0 - \frac{1}{2} \sin(2\psi_0) - \frac{\sin^2 \phi_0}{\sin \psi_0} \left( \psi - \pi - \frac{1}{2} \sin(2\psi) \right) \right)$$  [4]

$$A_2 = \pi R^2 - A_1 - A_3$$  [5]

The hold up and density ratios are defined as:

$$a_1 = \frac{A_1}{A_2}; \quad a_2 = \frac{A_2}{A_3}$$  [6]

$$\tilde{\rho}_1 = \frac{\rho_1}{\rho_2}; \quad \tilde{\rho}_2 = \frac{\rho_2}{\rho_3};$$  [7]

The centre of gravity of the two phases with plane interface, $Y_{G123}^P$ and with curved interface, $Y_{G123}^P$, can be derived in terms of interface curvature angle and wall view angles along with holdup ratios, $a_1$, $a_2$ (Refer to Appendix A of Brauner et al., 1996).

$$Y_{G123}^P = \frac{\left[ \rho_1 \sin \theta \left( \rho_1 \rho_2 \rho_3 \right) \right]^P \rho_1 \sin \phi_0}{\rho_2 \sin \phi_0}$$  [8]

$$Y_{G123}^P = \frac{a_1 (\rho_1 - 1) + a_2 (\rho_2 - 1) \rho_2}{\rho_3 (\rho_1 \rho_2 - 1) + \rho_2 (\rho_2 - 1) \rho_3}$$  [9]

$$Y_{G123}^P = \frac{a_1 (\rho_1 - 1) + a_2 (\rho_2 - 1) \rho_2}{\rho_3 (\rho_1 \rho_2 - 1) + \rho_2 (\rho_2 - 1) \rho_3}$$  [10]

$$Y_{G123}^P = \frac{\left[ \frac{\sin \phi_0}{\sin \phi_0} \right] \rho_1}{\rho_2 \sin \phi_0}$$  [11]

$$Y_{G123}^P = \frac{a_1 (\rho_1 - 1) + a_2 (\rho_2 - 1) \rho_2}{\rho_3 (\rho_1 \rho_2 - 1) + \rho_2 (\rho_2 - 1) \rho_3}$$  [12]

2.1 Energy Expressions

From equations [1] to [12] total energy expression can be derived as under:

2.2 Potential Energy

As expressed earlier potential energy per unit length is given by:

$$\frac{\Delta E_p}{L} = \frac{\theta}{2} \left( A_1 \rho_1 + A_2 \rho_2 + A_3 \rho_3 \right) (Y_{G123}^P - Y_{G123}^P)$$  [13]

The final form of the equation [13], $\Delta E_p / L$, is:

$$g R^2 \left( \phi_0 - \frac{1}{2} \sin(2\phi_0) \right) \left[ \frac{\sin \phi_0}{\sin \phi_0} \left( \psi_0 - \pi - \frac{1}{2} \sin(2\psi) \right) \right]$$  [13]
Substituting the above mentioned terms in the energy expressions, we get the total energy.

### 2.5.1 Energy Expressions

#### 2.5.1.1 Potential Energy

The system is considered to be a horizontal cylindrical conduit occupied with three immiscible fluids in a stable stratification. The free interface may approach a plane or lunar configuration depending on the physical properties of the fluids, solid-fluid wettability, the geometrical dimensions and fluid hold up. The interface shape does not change along the axis of the pipe, on any cross-section perpendicular to the axis and all points can be assumed by an equation of a circle.

After the minimum energy has been evaluated as a function of interface curvatures, efforts have been made to plot the stable interfacial curvature for different values of wettability angle, Eotvos Number and hold up ratios.

#### 3. Results and Discussion

Few cases of energy estimation are illustrated in accordance with formulation described. How energy varies with other parameters has been explored with few results. These sample estimations are based on one plane interface e.g. oil air interface. This can be extended for other one plane interface and both as curved interface. The change in the potential energy of the phases with reference to the plane interface is shown in Figures 2, 3 and 4.

![Figure 2. Change in potential energy with interface curvature](image-url)
and $\psi^* < \pi$ represent convex or concave interfaces respectively. Any deviation from plane interface results in the change of centre of the gravity. Thus, in the absence of surface effects, the minimum of the potential energy also represents a minimum of the total system energy, which is at $\psi^* = \pi$. Hence, in three-phase systems which are absolutely dominated by gravity, a configuration of plane interface is predicted via energy considerations.

The variation of the surface energy with $\psi^*$ is shown in Figures 5 and 6, for the case of wettability angle $\beta = \pi/2$, corresponding to identical wettability of the phases with the solid wall. In this case, the “gain and loss” of the wall energy due to variation of the wall/fluids contact areas are equal. Thus, the net change of the total surface energy is merely due to variation of the interfacial energy between the phases. For $A_1/A_2 \neq 1$, the interfacial area increases between the phases as the phase of the lower holdup spreads over the lunar surface, while it decreases when the lower holdup phase shrinks into a convex shape. Thus for $A_1/A_2 > 1$, reduction of the interfacial energy takes place as $\psi^*$ decreases below $\psi^* = \pi$, and the minimal interfacial energy is obtained at $\psi^* < \pi$, corresponding to convex surface. On the other hand, for $A_1/A_2 < 1$, the minimum point is at $\psi^* > \pi$ with concave surface. The value of $\psi^*$ at the minimum of surface energy varies with the phases holdup ratio $A_1/A_2$.

Figures 7 and 8 represent the total surface energy for another particular case of ideal wettability of the lower phase ($\beta = 0$), for which equation [29c] becomes $\sigma_{1w} - \sigma_{2w} = \sigma_{12}$. For this case the reduction of the wall energy, as the lower wetting phase climbs along the wall, is always larger than the associated increase of the interfacial energy. In absence of any of these phases the energy expression will be reduced to a two phase expression (see Figure 9).

The total energy (potential and surface energies) as a function of the surface curvature, $\psi^*$, is shown in Figures 10 and 11, for a given set of parameters, i.e., the wettability angle $\beta$ and Eötvös number $\varepsilon_m$, and the phases holdup ratio, $A_1/A_2$ and $A_3/A_2$. 

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**Figure 3.** Change in potential energy with interface curvature ($A_1 = 0.2A$, $A_2 = 0.3A$)

**Figure 4.** Change in potential energy with interface curvature ($A_1 = 0.7A$, $A_2 = 0.2A$)

**Figure 5.** Surface energy curves for $A_1/A_2 \geq 1$ for $\beta = 90^0$

**Figure 6.** Surface energy curves for $A_1/A_2 \geq 1$ for $\beta = 90^0$
With reference to Figure 2 (which represents the changes of the system potential energy), the inclusion of the surface energy results in a shift of the location $\psi^*_{\text{min}}$ for which the system total energy is at its minimum.

This value of $\psi^*_{\text{min}}$ represents the ultimate interface curvature at which the phases will stabilise. Thus, $\psi^*_{\text{min}}$ stands for the predicted steady interface curvature. The wall wettability angle is varied from 0 to $\pi/2$ at different Eotvos Numbers. The findings confirm that at higher Eotvos Numbers surface effects are more dominant.

The analysis of the three phase system is far more challenging and complexity of the problem lies in the number of parameters required to define the system as well as setting the parameters such that hold up constraints are met with minimised energy. Inspired by the ‘bisection method’, solutions are attempted to the equations [17] to [20]. If $\phi^0$ and $\phi^*$ can be fixed for a particular $A_1$, different interface can be obtained at different values of $A_2$ and $A_3$. Some typical cases are analysed and results are given in the form of interface shape monograms. Figures 12, 13 and 14 describe interface shape variation with different $A_3/A_2$ ratios at $\beta = \pi/8$ and $\varepsilon_0 = 0.02$, $\beta = 3\pi/8$ and $\varepsilon_0 = 0.2$ and $\beta = 0$ and $\varepsilon_0 = 0.008$. It is noticed that a $\beta = \pi/2$, a shift in shape pattern is observed. After a particular hold-up ratio, the interface
shapes change from convex to concave, and beyond Eotvös number 0.2 no change in interface shapes is observed.

4. Conclusion

The characteristic of interface curvature is required in order to initiate the solution of stratified flow/steady configuration with a curved interface formed between the phases. Energy considerations are employed as done in previous studies to predict the interface geometry and configuration. Difference is that it is done previously for 2-phase flow and here for the first time it is applied for 3-phase flow. The changes in the system potential energy and surface energy are associated with the curving process of the interface in three phase system too.

The steady interfacial curvature corresponds to the configuration for which the total system energy is at its minimum. Therefore, minimum energy can give a stable geometry of three phases in a horizontal conduit. If the stable geometric configuration of phases is known, it will be easier to predict the hydrodynamic properties of three phase flow.

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Managing Wastewater Discharge of Dairy Processing Plants in Compliance with the Environmental Regulations: A Case Study in Guyana

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(Received 03 March 2017; Revised 03 June 2017; Accepted 20 June 2017)

Abstract: This paper presents a case study that assessed the status of effluent/wastewater discharged by three dairy processing plants, with the aim to provide a monitoring guide and an effluent/wastewater treatment system (ETS) for these plants in Guyana. Samples of effluent/wastewater discharge were collected and analysed with respect to the pollutants parameters stipulated in the GYS 207: 2002 Standard. It was found that the Chemical Oxygen Demand (COD) yielded the highest results in the Ice cream plant, followed by the Yogurt and then the Edible fats plant. The COD was 100% above the maximum allowable limit for the range of samples tested. Biological Oxygen Demand (BOD) for the Edible fats plant was below the target value of 75% while Ice Cream was above the maximum allowable limit of 50% and yoghurt ≥58% of the test conducted. The estimated amount of wastewater per production cycle was estimated to be 5.7 m³. COD, BOD, Oil and Grease (O&G) were found as the parameters of significant importance. This study provides information on the level of pollutants and what needs to be done to bring these plants in compliance with the environmental Regulation of 2000. By consolidating the findings from desk research with empirical data acquisition, an ETS with accompanied implementation guide was proposed for use at the dairy processing plants. Standard Operating Procedures (SOPs) and guideline were derived to monitor the ETS practices. An evaluation agenda was also proposed to assess the efficacy of the ETS and guide. Future research could validate the key ETS elements identified for dairy/food processing plants and examine their ETS processes not only in Guyana, but also in the wider Caribbean and global contexts.

Keywords: Effluent/Wastewater Treatment System, dairy processing plants, environmental Regulation, Guyana

1. Introduction

The dairy industry is considered to be one of the largest sources of industrial wastewater. Dairy processing effluents are generated mainly from cleaning of transport lines and equipment between production cycles, cleaning of tank trucks, washing of milk silos, and equipment malfunctions or operational errors (Danalewich et al., 1998; Narain, 2016). High Biological Oxygen Demand (BOD) typically characterises dairy processing wastewaters, and Chemical Oxygen Demand (COD) concentrations resulting from proteins, fats, and carbohydrates, including lactose, and high levels of nitrogen and phosphorus. Also included are various cleaning and sanitizing agents. Combined, these compounds result in the potential for environmental problems (Omil et al., 2003; Perle et al., 1995).

Environmental regulations and standards placed emphasis on the protection of waters by monitoring the release of any effluent into any of the waterways. In Guyana, legislation was developed in 2000 to introduce environmental permitting. The Environmental Protection Agency (EPA) is responsible for the development and enforcement of the Environmental Protection Regulation. This piece of legislation set out to protect the water resources in Guyana. The Regulations placed emphasis on water through the Environmental Protection (Water Quality) Regulations, and aimed to achieve this by controlling the discharge of effluent (waste matter) into any of Guyana’s coastal and inland waterways. In addressing the potential contamination of water supplies sources, the regulations stipulating proper disposal of effluent reduce threats to public health, and reduce or eliminate the possibility of actual or potential pollution to the water bodies in the country (Republic of Guyana, 2000).

In addition, there is a mandatory standard for industrial effluent discharge into the environment that was developed by the Guyana National Bureau of Standard (GNBS), in collaboration with the Environmental Protective Agency (EPA) in 2002. The standard states that: “The enforcing authority shall specify requirements for the design of the monitoring programme by which compliance with this standard shall be assessed.” The parameters and allowable limits of the standard are the same used by the EPA to issue environmental permits for industrial effluent. As effective from 2002, new industrial companies starting operation in Guyana have to follow the legal requirements established. The EPA is at present...
embarking on a process of bringing companies that existed prior to 2002 to gain compliance with the regulation and the standard. This paper presents the findings of a recent study on investigating the effluent/wastewater treatment practice at ICYE in Guyana. In such context, the study aims:
1. To determine the quality and quantity of dairy effluent discharges at the ICYE’s dairy processing plants;
2. To analyse the pollutants of particular process streams, thereby allowing corrective/mediation actions to be taken.
3. To develop an effluent/wastewater treatment system (ETS) and accompanied implementation/monitoring guide for dairy processing plants, in compliance with the Environmental Regulation in Guyana.

2. Literature Review
2.1 Effluent/Wastewater Treatments in Dairy/Food Processing
Wastewater generated from the food industry varies in strength and characteristics. Variation due to the amount of water usage, the type of product and different additives (like salt, sugar, gelatin, colours, oil and preservatives added) lead to the pollution load in the wastewater. The Dairy processing industry contains easily biodegradable organic substances. This process enables fermentation and uses up oxygen at a rapid rate resulting in significant decrease in pH. According to Tanik et al. (2002), the most widely preferred and applied treatment system for wastewater in dairy processing plants is said to be any biological one. Biological treatment of food-processing wastewater requires an extensive amount of large bacteria for removal of such high organic burden contained in the food wastewater (Chambers 1981; Narain, 2016). Bacteria are primary agents that are responsible for biodegradation in the active sludge process.

Lo and Hung (1995) conducted a study on a different type of treatment system using bio-augmentation in an effort to enhance the removal of organic pollutants in the food processing effluent. The study was intended to evaluate the effects of various performance parameters on activated sludge treatment process for food-processing effluent. This was based on the fact that food processing plant effluent is characterised by high levels of BOD and if disposed improperly would lead to surface water and ground-water pollution (Lo and Hung 1995). The parameters included were the concentration and type of the wastewater, time of aeration, dosage of live liquid micro-organism addition for bio-augmentation. The bio-augmentation would improve both the removal of total organic carbon (TOC) in effluents and the sludge reduction for treatment of food-processing wastewaters. The sludge concentration would vary based on the period of treatment.

Moreover, Posavac et al. (2010) improved the dairy wastewater treatment efficiency of Dukat Dairy Industry Inc., Germany by the addition of a bio-activator. The bio-activator was prepared according to the manufacturer’s protocol and periodically added in the appropriate quantity. The addition of bio-activator resulted in better formation of flocs and good settling of activated sludge, prevention of filamentous bacteria growth and stable quality of the effluent to the required values prescribed.

2.2 Factors Affecting Wastewater Treatments
Effluents from any industry in large volume and concentration that run off into the waterways are harmful to the environment. In the dairy industry, there is no difference as dairy effluents would lead to the depletion of dissolved oxygen level of the receiving body stream and would cause an imbalance to aquatic life (Aighewi, 2002). The high organic content of the effluent is reflected in its large BOD and COD concentrations, which was found to be especially true for the wastewater emitted from the Ice Cream Plant. This poses a risk to the environment with the continuous discharge without pre-treated hence the relevance of the national regulation and standard. Besides, effluent from dairy processing plant poses environmental problem like water and soil pollution, as these wastes are generally released into the nearby stream or land without any prior treatment and would lead to pollution (Narain, 2016).

Researchers have since been studying different aspects of monitoring the environment and the impact of dairy effluents. Understanding the impacts of the effluents on the environment has led to the development of ETS, including Effluent/Wastewater Treatment Facility (ETF) or Plant (ETP). These are not without challenges, some of the construction or establishment of an ETS for dairy industries would fall under the broad headings of 1) Infrastructure, 2) Financial sustainability, 3) Increasing/expanding regulations, and 4) Technology changes.

There are several indicators/criteria and factors affecting the development of an ETS. Some of these are specific for developing countries and for particular climatic conditions. Besides, the problems were lack of enforcement and poor practices (Narain, 2016). Moreover, Narain (2016) identified several challenges being faced by the dairy processing industries in Guyana. These include:
1. Companies see capital that would be utilised in core business activity rather than investing in treatment of wastewater,
2. Dairy effluent is categorised as industrial effluent and the cost for treating industrial effluent is high,
3. Dairy processing plants that adopt aerobic biological system are faced with sludge disposal challenges, and
4. Untreated wastewater could cause pollution when discharged into the environment.
2.3 Common Approaches of Effluent/Wastewater Treatments

The overall goal of any ETS is to reduce the level of pollutants in the wastewater before reuse or release into the environment, the standard of treatment is determined by the use and the location (United Nation, 2014). With the advance of scientific knowledge and various wastewater treatment system there has been tremendous development within this area. These systems developed included aerobic, anaerobic and physico-chemical and they range from the simple removal of gross solids to membrane systems to produce drinking water quality. They vary from the very simple to the highly complex systems, and several indicators such as efficiency, reliability, cost, affordability, energy consumption, sludge production, and land requirements, would be considered (United Nation 2014).

According to UN Water (2011), treatment strategies range along a continuum from high technology, energy-intensive approaches to low-technology, low-energy, biologically and ecologically-focused approaches. Coppen (2004) categories these different wastewater treatment systems as Primary, Secondary, and Tertiary Wastewater treatments. Performance attributes such as discharge criteria required the installation of facilities (i.e., primary wastewater treatment system). This type of system removes significant amount of materials from wastewater that float or settle. Secondary treatment system brings together waste, bacteria and oxygen in trickling filters or the activated sludge process. It utilises bacteria, which consume the organic matter of the wastewater. Table 1 provides a description of various ETS advocated by researchers and practitioners. These ETS include aerobic/anaerobic, chemical, electro-coagulation, vermifiltration, reverse osmosis, natural treatment and bio-activator. Amongst them, both aerobic and anaerobic ETS were commonly used in the dairy processing sector (Narain, 2016).

| Table 1. Wastewater Treatment Approaches Advocated by Researchers and Practitioners |

<table>
<thead>
<tr>
<th>Related Studies/ References</th>
<th>Type of Waste</th>
<th>Biological Treatment</th>
<th>COD %</th>
<th>BOD %</th>
<th>TSS %</th>
</tr>
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<tbody>
<tr>
<td>Chambers (1981)</td>
<td>Food Processing Wastewater</td>
<td>Aerobic/anaerobic</td>
<td></td>
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<td>Warburtona et al. (1981)</td>
<td>Dairy shed wastewater</td>
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<td></td>
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<tr>
<td>Tabak (1986)</td>
<td>Dairy Industry Wastewater</td>
<td>Aerobic/anaerobic</td>
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<tr>
<td>Rusten et al. (1990)</td>
<td>Dairy and Dairy Industry Wastewater</td>
<td>Chemical</td>
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<tr>
<td>Venkateramanand Satyanarayan (1992)</td>
<td>Dairy Wastewater</td>
<td>Aerobic/anaerobic</td>
<td>93.8-98.5</td>
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<td>Rusten et al. (1993)</td>
<td>Dairy Wastewater</td>
<td>Dissolved air flotation</td>
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<td>Cordobo et al. (1995)</td>
<td>Dairy Wastewater</td>
<td>Anaerobic/UA SB</td>
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<td>Rusten et al. (1996)</td>
<td>Cheese factory wastewater</td>
<td>Biological – chemical</td>
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<td>Donki (1997)</td>
<td>Milk powder Wastewater</td>
<td>AAO (anaerobic-anoxic-oxic)</td>
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<td>Williams (2003)</td>
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<td>Reverse Osmosis</td>
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<td>Vourch (2005)</td>
<td>Dairy Wastewater</td>
<td>Reverse Osmosis</td>
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<td>Xing (2005)</td>
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<td>Vermifiltration</td>
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<td>90</td>
<td>90-95</td>
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<td>Ziv et al. (2006)</td>
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<td>Anaerobic</td>
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<td>Vourch et al. (2008)</td>
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<td>Reverse Osmosis</td>
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<td>Chaudhari and Dhoble (2010)</td>
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<td>Posavac (2010)</td>
<td>Dairy Wastewater</td>
<td>Bio-activator</td>
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<td>Bhavsar (2010)</td>
<td>Dairy Wastewater</td>
<td>Water Hyacinth (Aquatic Plants)</td>
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<td>Harush and Hampannavar (2011)</td>
<td>Dairy Wastewater</td>
<td>Moringaoleifera (natural coagulant)</td>
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<td>Themozhi (2012)</td>
<td>Dairy Wastewater</td>
<td>UASB</td>
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<td>Silva et al. (2012)</td>
<td>Dairy Wastewater</td>
<td>Electro Coagulation</td>
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<tr>
<td>Nitin et al. (2013)</td>
<td>Dairy Wastewater</td>
<td>RBC (Rotating Biological Contactor)</td>
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<tr>
<td>Edris et al. (2013)</td>
<td>Dairy Wastewater</td>
<td>Electro-coagulation</td>
<td>98.84</td>
<td>97.95</td>
<td>97.75</td>
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<tr>
<td>Murali et al. (2013)</td>
<td>Dairy Wastewater</td>
<td>Water Hyacinth</td>
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<tr>
<td>Starkln et al. (2013)</td>
<td>Dairy Wastewater</td>
<td>Natural Treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xavier et al. (2013)</td>
<td>Dairy Wastewater</td>
<td>Vermifiltration</td>
<td>75-80</td>
<td>85-90</td>
<td>85-90</td>
</tr>
</tbody>
</table>

*Keys: COD - Chemical Oxygen Demand (COD); BOD - Biological Oxygen Demand; TSS - Total suspended solids

UASB – Up-flow anaerobic sludge blanket; AAO - Anaerobic-anoxic-oxic
3. Effluent/Wastewater Treatment at ICYE: A Case

According to the Republic of Guyana (2000), “All existing developments or industries are required by the EPA to obtain an Operations Permit. This permit will subject an Environmental Management Plan which must be approved by the EPA and implemented by companies. Existing companies will be given a compliance schedule to phase environmental management into their operations.” ICYE is one of those companies which had not applied for any environmental permit for effluent disposal in Guyana.

Dairy processing plants at ICYE have shown tremendous growth in size and number throughout the years. There are plans for future products such as flavored milk and drinkable yogurt, pasteurized cow’s milk and other dairy products. This translates to an increase in the wastewater generated, which is characterised by its high COD, BOD, nutrients, and organic and inorganic contents. Such wastewater currently discharged without any treatment, could cause severe pollution to the receiving water body, the Demerara River in Guyana and the surrounding environment. At present, there is no system established to monitor the level of pollutants discharged from ICYE’s dairy processing plants.

Since the demand for dairy products is increasing, the generation of wastewater for the plants cannot be avoided in Guyana. This study was initiated to examine the levels of effluent discharge, and design Standard Operating Procedures (SOPs) and guidelines for monitoring effluent/wastewater discharge at the ICYE’s diary processing plants. Waste minimisation audits should be conducted in order to identify the sources of waste which contribute to the heavy load of pollutants. Despite there is a pressing need to adopt and/or develop ETS, inappropriate system selection would yield minimal benefits with excessive cost. The use of biological system would be feasible but the treatability of the dairy wastewater produced needs to be determined. Alternatively, reverse osmosis process would achieve relatively high removal efficiencies and provide additional benefits such as the reuse of water. A combined system is also an option for ICYE.

This study incorporated sample collection, laboratory analysis, documented results, data analysis and interpretations. Pollutant parameters were tested in wastewater discharge from the dairy processing plants as stipulated in the Guyana Standard; GYS 207:2002 - Interim Guidelines for Industrial Effluent Discharge into the Environment (GNBS, 2002). Table 2 shows the parameters and maximum allowable limits.

### 3.1 Sample Collection Method

One approach is to identify the locations in complying with the study objectives of water quality analysis (APHA/AWWA/WPCF, 1999). Each monitoring objective entails its own diverse constraints. There are no fix rules or standard methods to be pursued in selecting sampling sites (Harmancioglu et al. 1999). For this study, two (2) sampling points were selected for each dairy processing plant. The criteria used in the selection of the sampling points were based on 1) the location of polluting sources, and 2) ease of access to the discharges from the polluting sources. Samples were collected on a weekly basis, for a period of four (4) weeks (Narain, 2016).

### 3.2 Analysis and Procedures

Analysis of the samples was determined by the procedures presented in the GNBS Standard (Narain, 2016). Some main analyses are summarised, as follows:

1. **COD level for this study was measured in accordance with the Guyana Standard: GYS 229-4: 2003 - Part 4: Chemical Oxygen Demand (GNBS, 2003a). The method used was the Open flux.**

2. **BOD level was measured in accordance with the Guyana Standard: GYS 229-3: 2004 – Part 3: Biochemical Oxygen Demand – Five days (BOD5) (GNBS, 2004a).**

3. **TSS level in this study was measured in accordance with the Guyana Standard: GYS 229-5:2003 - Part 5: Solids (GNBS, 2003b).**

4. **Nitrogen as ammonia level was measured in accordance with the Guyana Standard: GYS 229-7:2003 - Part 7: Nitrogen (Ammonium) (GNBS, 2003c).**

5. **Oil and Grease level was measured in accordance with the Guyana Standard: GYS 229-16:2004 – Part 16: Oil and Grease (GNBS, 2004b).**

6. **The pH was measured immediately after sampling, using a Frisher Scientific electrode of the Accumet AR 10 pH meter, and**

7. **The temperature was measured immediately after sampling, using mercury filled Celsius thermometer.**

### 4. Examination of Effluent Discharge - Results

#### 4.1 Water Consumption for Cleaning

Thirty (30) sample results were collected from a water meter after each wash from the three (3) dairy processing plants – Yogurt, Ice-cream and Edible Fats plants. The amount of water use fluctuates per plant and per production. Table 3 shows the analysis of data collected from water meter readings assigned to three plants.

<table>
<thead>
<tr>
<th>Sector</th>
<th>pH</th>
<th>Temp.</th>
<th>BODs</th>
<th>COD</th>
<th>TSS</th>
<th>N as NH₃</th>
<th>O and G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. limits</td>
<td>5.0-9.0</td>
<td>&lt; 40</td>
<td>&lt; 100</td>
<td>&lt; 250</td>
<td>&lt; 100</td>
<td>&lt; 50</td>
<td>&lt; 10</td>
</tr>
</tbody>
</table>

Source: Based on GNBS (2002)
It was assumed that the amount of water used for washing is equivalent to the amount of wastewater produced by these plants. The maximum water use to wash after a batch production of yogurt is 4 m$^3$ and minimum is 1 m$^3$. The average amount of water use for washing up after production is 2.57 m$^3$ with a standard deviation of 0.82 m$^3$. For the Ice-cream Plant, the maximum water use to wash after a batch production is 8cm$^2$ and minimum is 1 m$^3$. The average amount of water use for washing up after production is 5.2 m$^3$ with a standard deviation of 1.9 m$^3$. For Edible Fats plant, the maximum water use to wash after a batch production of edible fats is 9 m$^3$ and minimum is 2 m$^3$. The average amount of water use for washing up after production is 5.7 m$^3$ with a standard deviation of 1.6 m$^3$.

4.2 Water Consumption for Washing Plants after Production

Maximum volume of water use on a given production day to wash all three (3) plants is 20 m$^3$ and minimum is 7 m$^3$. Records show that the frequency lies between 10 m$^3$ to 15 m$^3$. There is a fluctuation in the water usage per production and per plant. Higher volume of water is used to wash the edible fats plant, while the yogurt plant utilises lower amount of water. A set of thirty (30) samples for each dairy processing plant were taken since the amount of water use has a high level of uncertainty. The mean was calculated and recorded (see Table 3).

4.3 Parameters Stipulated by the Guyana Standard of GYS 207: 2002

With respect to the GYS 207: 2002 Standard (GNBS, 2002), Table 6 provides a summary of laboratory analysis in seven (7) parameters, namely pH, temperature, BOD$\text{\text{\textsubscript{5}}}$, COD, TSS, N as NH$_3$ (mg/L), and Oil and Grease (O&G).

4.3.1 pH Testing Results

It was found that all the pH results fell to the minimum allowable limit (i.e., 5) stipulated in the standard. Figure 3 shows the results from pH testing, whilst Figure 4 shows that there is slight sample-to-sample pH variation (range from 6.24 to 7.01) which is slightly acidic to neutral. If this water was released as it is, it would not affect the pH of the receiving water body from Demerara River. However, if wastewater is not discharged immediately, it would be lodged in the drains until the sluice is open. This would give enough residence time for bacterial multiplication, hence causing changes in the pH of the wastewater being released.

4.3.2 Temperature Results

If the wastewater is not discharged immediately, its temperature is expected to remain the same as that of the environment, and would not affect the receiving water body. It is important in developing an ETS especially in biological treatment systems where temperature would influence both the ability and demand for oxygen from individual organisms. Hence, high temperatures would reduce the amount of dissolved oxygen held by water. It was found that the temperature varies per plant as the yogurt and ice cream plants fell below the maximum allowable limit for most samples tested. However, the temperature of the edible fats plant reached the maximum allowable limit, and thus would influence other parameters.

4.3.3 BOD$\text{\text{\textsubscript{5}}}$ Levels

Results show that the BOD$\text{\text{\textsubscript{5}}}$ Levels at the edible fat plant fell below the target value of 50, while that at both the Ice Cream and Yogurt plants were above the target value as recorded from the test. The BOD is important in determining the relative amount of oxygen that is available to aquatic organisms inhibiting the discharge site. The results would thus provide an estimate of the environmental effects of the effluents at ICYE.

4.3.4 COD Levels

Results obtained the yield higher than the maximum allowable limit stipulated by the Guyana standard. It is showed that the Edible fats plant yielded the lowest COD levels, followed by the Yogurt and then the Ice-cream plants. The degree of oxidation would depend on the type of substance, pH value, temperature, reaction time, and concentration of oxidizing agent, as well as the type of added accelerators, if any. In both Yogurt and Ice-cream plants, results show above the maximum allowable level and this could be associated with the products being produced in these plants having flavours and high content of fats and stabilisers added to them, as compared to that of the Edible Fats plant.

4.3.5 TSS Levels

Figure 4 shows the TSS Levels for Yogurt, Ice-cream and Edible Fats production in three (3) replications for four (4) weeks. It was found that the TSS Levels of these three plants fell below the minimum allowable limit as stipulated by the GYS 207: 2002 Standard. As suspended solids are a source of organic matter, they would affect water or wastewater quality adversely.

| Table 3. Analysis of data collected from Three Plants |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Amount of water used in: | Observations | Mean m$^3$ | Standard Deviation | Minimum Value m$^3$ | Maximum Value m$^3$ |
| Yogurt Production | 30 | 2.57 | 0.82 | 1 | 4 |
| Ice-cream Production | 30 | 5.2 | 1.9 | 1 | 8 |
| Edible Fats Production | 30 | 5.7 | 1.6 | 2 | 9 |
Moreover, the TSS level of the wastewater from the ICYE’s plants currently would not have a negative impact on the environment.

4.3.6 Nitrogen as Ammonia Levels
The presence of nitrogenous compounds in surface water generally indicates certain level of pollution. It was found that the Ammonia (NH₃) Levels of these three (3) plants were below the minimum allowable limit as stipulated by the GYS 207: 2002 Standard.

4.3.7 Levels of Oil and Grease
The O&G content of industrial wastewater would govern the handling and treatment of the materials for ultimate disposal. Effluent containing a high quantity of oil and grease would cause a serious problem if discharged into water body without treatment. Moreover, high level of O&G content would interfere with an aerobic and anaerobic biological process, and would inevitably affect the efficiency of production/operations. The wastewater O&G levels at these three plants reached the maximum allowable limit as stipulated by the GYS 207: 2002 Standard.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Sample Period</th>
<th>Sample</th>
<th>pH</th>
<th>Temp.</th>
<th>BOD₅</th>
<th>COD</th>
<th>TSS</th>
<th>N₅asNH₃ (mg/L)</th>
<th>O&amp;G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yogurt</td>
<td>Week 1</td>
<td>S₁</td>
<td>6.82</td>
<td>37.5</td>
<td>248</td>
<td>4960</td>
<td>9.1</td>
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<td>528</td>
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<tr>
<td></td>
<td></td>
<td>S₂</td>
<td>6.69</td>
<td>41.3</td>
<td>205.2</td>
<td>5151</td>
<td>10.2</td>
<td>nil</td>
<td>523</td>
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<tr>
<td></td>
<td></td>
<td>S₃</td>
<td>6.45</td>
<td>39.1</td>
<td>245.5</td>
<td>4911</td>
<td>9.8</td>
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<td>532</td>
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<tr>
<td>Ice-cream</td>
<td>Week 1</td>
<td>S₁</td>
<td>6.53</td>
<td>35.4</td>
<td>89.6</td>
<td>4480</td>
<td>8.2</td>
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<td>S₂</td>
<td>6.24</td>
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<td></td>
<td></td>
<td>S₃</td>
<td>6.59</td>
<td>40.4</td>
<td>42.10</td>
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<td>S₂</td>
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<td></td>
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<td>S₃</td>
<td>6.85</td>
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<td>Yogurt</td>
<td>Week 2</td>
<td>S₁</td>
<td>6.92</td>
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<td>11.6</td>
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<td></td>
<td></td>
<td>S₂</td>
<td>6.67</td>
<td>40.8</td>
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<td></td>
<td></td>
<td>S₃</td>
<td>6.88</td>
<td>40.6</td>
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Table 4. A Summary of findings from Laboratory Analysis

4.4 Summary of Findings
ICYE has presently no established system of managing wastewater discharge from its dairy processing plants. The wastewater is discharged into the Demarara River without any treatment, which is a breach of the environmental regulation. The company needs to put measures in place to meet these requirements to ensure that its manufacturing license is not revoked when the enforcing body (such as EPA) enforces the regulations. The results indicated that COD, BOD, and O&G were found as the parameters of significant importance in compliance with the GYS 207: 2002 Standard. The COD generally yield the highest results in the Ice Cream plant, followed by the Yogurt and then the Edible fats plant. Despite the differences in the readings for each plant, the COD was 100% above the maximum allowable limit of the test conducted. BOD for the Edible fats plant falls below the target value of 75%, while the Ice-cream plant
is above the maximum allowable limit of 50% and yogurt ≥58% of the test conducted. The O&G content was above the maximum allowable limit 100% of the time for the test conducted, for all three plants.

On the other hand, it was found that some of the parameters under the study were within the standard proposed by the GNBS for dairy effluent discharge. However, TSS, pH, Temperature and the NH₃ levels must continuously be monitored, with respect to possible change and variations in conditions. This is especially the case for pH and Temperature, for example, the change of a yogurt culture can change the pH, and a change in temperature can influence bacterial growth. It is to note that there were no pre-treatment activities carried out on the wastewater during this study.

5. Development of Effluent/Wastewater Treatment System (ETS)

5.1 ETS Performance Criteria and Indicators

There are various common ETS for dairy processing plants. Each ETS and respective process has advantages and disadvantages. The selection of ETS would depend significantly on the cost and capability to reduce pollutants to the acceptable level as stipulated in the GNBS Standard. The system performance can be categorised under four (4) major headings. These are:

1. Procedures for the plant evaluation: This is a systematic procedure for organising information before the plant is evaluated.
2. Wastewater treatment systems operational data: This contains data on the common operating parameters, loading rates, waste products accumulated from process operation, and the support systems used.
3. Sampling and testing: This contain information on the type of sampling to be done, location of sampling points, and analyses to be performed for the particular treatment system.
4. Common operating problems and suggested solutions: This is to identify problems, which occur in wastewater treatment plants and delineate which corrective measures should be implemented.

5.2 Setting up of ETS and Operations

The proposed ETS would have a capacity of 5.7 m³ of wastewater per production cycle and reduce the BOD level to less than 400, COD level to less than 20,000 and O&G content to less than 2,800. Since the treatment would not be practical if done after each production cycle and per plant separately, a plan would be developed to assist with the development of ETS for ICYE’s plants. Figure 1 shows the operations of the proposed ETS.

5.3 A Proposed Implementation Guide of ETS

A draft guide of ETS adoption and implementation was derived. The ETS elements include plant performance, operational problems, operating personnel, laboratory facilities, and maintenance data programme. Information and data for each element would be gathered and analysed in four (4) interrelated phases. These are: 1) preparation for evaluation, 2) inspection/internal audits, 3) problem identification, and 4) total plan evaluation.

The adoption and implementation of these elements and associated procedures would depend on the size and complexity of the plant and the amount of preparation. It is necessary to compile and review information at the plant level, so as to determine the characteristics of each plant’s influent and effluent. This should include both values of the parameters measured by the plant and flow quantity and variations with time. Records (such as flow rate, unit operational data, power consumption and maintenance data) should be analysed and then compared with the information and requirements stipulated by the GNBS Standard.

Regarding the procedures for problem identification and evaluation, the most common problems would be documented in a monitoring guide. These procedures would be used to address any problem that would arise. The first step for problem assessment is to determine whether the plant is meeting the design performance standards by comparing its effluent quality and overall removal efficiencies to the stipulations in the design. If the plant is not in compliance, it would be necessary to determine what the problem is.
According to USEPA (2004), several steps are identified to achieve this. These are:

1) The treatment plant operator is tasked with defining the problem, and then is to 1) verify problem(s) and common area(s) in process, maintenance or design and sampling problems; develop sampling and testing programmes; and 2) provide additional data to analyse the problem(s).

2) In case that effluent discharge does not meet required standards and the problem is not defined, it is recommended to:
   a) Review flow and process records again in detail,
   b) Re-check sampling and testing procedures required,
   c) Compare sampling and testing programme against specifications as given in the monitoring guide,
   d) Suggest modification of testing and sampling programmes against recommended programmes,
   e) Suggest modification of testing and sampling programme to furnish additional data for evaluation,
   f) Compare the data with the problem indicators stipulated in the guide, and
   g) Hire consultants to handle problems, if necessary.

Moreover, the design and executions of maintenance programmes are to compare with actual plant operations and recommend operations (USEPA, 2004). Upon the last phase, the Total Plant Evaluation would be made, and final report would contain 1) a summary of the assessment, 2) a list of problems encountered, 3) the solutions recommended, and 4) any proposed action(s).

6. Evaluation of the Proposed ETS

In order to maintain compliance, ICYE should stipulate record-keeping and reports on the quantity and nature of effluent discharge. Evaluations would be conducted by the EPA at ICYE on the ETS to determine compliance with permit requirements. By complying with the guidance of USEPA (2004), the objectives of an in-house inspection are to:

   a) Assess the conditions of the facility's current treatment processes and operations,
   b) Evaluate the ICYE’s operation and maintenance activities,
   c) Check the completeness and accuracy of the performance/compliance records,
   d) Determine whether the treatment units are achieving the required treatment efficiencies, and
   e) Review problem areas with effluent limitations, and evaluate overall ETS performance.

A post-interview was conducted with eight (8) managers and assistant managers who had directly involved in the decision-making on ETS implementation at ICYE. All interviewees agreed that the study findings provided good insights to ICYE’s position with its wastewater management. Most interviewees (i.e., 75%) rate high possibility that the company would implement the recommendations while the rest 25% also supported this initiative.

Two major opportunities identified were: 1) to meet the requirements of the standard, and 2) to maintain the company’s Corporate Social Responsibility and image. Besides, comments on the obstacles were made, addressing: 1) initial requirements for adopting new ETS technology, 2) the ability to acquire it, and 3) the capability to satisfy the needs or solve the problems.

While cost was a major concern, there were other technical areas (such as unconformity of raw wastewater). Six (6) interviewees said that all the indicators were equally as important. Two interviewees contended that economics and technical aspects would be the major concern. They all agreed that the implementation plan would be used with the opportunities for improvement necessary with consultation from experts. Some 50% of the interviewees agreed that ICYE has the capabilities, while others argued that the company would not have the expertise. Two interviewees (25%) suggested that an environmental consulting agency would be needed, while another two participants argued that persons within the company could be trained. There are also concerns that pilot implementations be made to check and monitor the operational efficiency of the ETS in treating wastewater and pollutants at ICYE.

The dangers posed by untreated dairy wastewater, discharged into the Demerara River and surrounding environment could be readily acknowledged. Pollution disrupts the normal equilibrium of the natural water, resulting in changes in species diversity and population size. It is therefore recommended that an environmental impact assessment be undertaken in the discharge area and immediate surroundings of the plants. The assessment would provide information that would in turn be utilised to devise remedial measures if needed, geared towards reversing the negative environmental impacts associated with the discharge of untreated dairy effluent.

The adaptation of effluent pretreatment of the waste generated by the dairy plants would prove beneficial in the reduction of the concentration of pollutants discharged. This would enable ICYE compliance with the 2000 EPA Regulation and the GNBS standards. It is anticipated the waste minimisation audit would determine the characteristics of the wastewater streams (dairy plant effluent) and bring significant impact on the ETS implementation. The setting-up of a pilot plant testing and implementation would help the plants to determine the suitability of the system/operating variables such as, treatment dosage, retention time and the number of treatment stage required.

7. Conclusion

There has been little work done on ETS in the Caribbean region to explore the applicability of ETS in the tropical
conditions. Most effluent/wastewater-related research had mainly been undertaken addressing the technical aspects and related issues of water quality improvements to minimise environmental and health impacts. There has been small amount of published literature on wastewater recycling from an economic and a social perspective. The costs and benefits would have been roughly estimated. The importance of economic perspective (such as costs and efficiency) in wastewater recycling would have been ignored. There would be a research venue for investigating these aspects and issues into the ETS adoption/development.

This case study addresses the level of effluent discharge by the ICYE dairy processing plants in Guyana. For this study, the quality of the wastewater was determined using the analysis parameters outlined by the GNBS standard, whereas the quantity of wastewater procedure was estimated by measuring the quantity of water use to wash plants after production. The findings claimed that the Edible Fats plant yielded the most desirable results, as compared to both Ice-cream and Yogurt plants. Individual plant processes were examined, and information was gathered on determining the level of pollutants and what actions to be made to reduce or mediate the pollutant levels and bring ICYE in compliance with the EPA’s Regulation of 2000.

Standard Operating Procedures and guidelines were derived to monitor the ETS practices. An action agenda would be needed to assess the efficacy/applicability of the ETS and the guide. Future study could validate the key ETS elements identified for diary/food processing plants of varied operations nature. Comparative evaluations and case studies are suggested to examine the critical ETS processes among various organisations across the sectors not only in Guyana, but also in the wider Caribbean and global contexts.

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Process Optimisation of Spiced African Locust Bean \((P.\ biglobosa)\) in Different Packaging Materials

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(Received 07 April 2017; Revised 04 August 2017; Accepted 31 October 2017)

Abstract: A study was carried out on the process optimisation of spiced African Locust Bean in different packaging materials. African locust bean seeds were soaked, steamed, dehulled and fermented naturally for three days. The untreated sample was first subjected to proximate analysis on the first day (0 week) to serve as the control. Thereafter, the remaining sample was divided into four equal portions (400g each) with each of the three portions preserved with ground ginger, garlic, a mixture of both at a uniform concentration of 4% of each portion size while the last portion had no treatment. Each of the 400g was further divided into 16 portions making each to be 25g and samples to be 64 altogether. In this study, a 44 factorial experiment in a Completely Randomised Design (CRD) was used. The number of replicates was three, and the total number of test trials was 768. The samples were packaged in four different packaging materials (Low-Density Polythene, Polypropylene, Aluminium foil and High-Density Polythene) with each having 0%, 3%, 6%, and 9% perforations respectively. The samples were stored in a refrigerator set at 100 °C temperature and 70% relative humidity for a period of four weeks. The values of moisture content, bulk density, vitamin A, Iron, Calcium content and pH value were determined at an interval of seven days for a period of four weeks. The result revealed the optimum values of output parameters as follows: minimum Moisture content (6.102 %), maximum Crude protein (39.345 %), maximum Bulk density (0.450 g/ml), maximum vitamin A (163.732 mg/100g), maximum Iron (52.109 mg/100g), maximum Calcium content (1429.249 mg/100g) and maximum pH value (8.46) of the stored product at various conditions.

Keywords: Optimum. Bean, bulk density, crude, protein

1. Introduction

African locust bean \((P.\ biglobosa)\) has long been widely recognised as an important indigenous multipurpose fruit tree whose uses include food, medicine, manure, tannin, shade, wind-breaks, bee food, stabilisation of degraded environment, livestock feeds, fuel, fibre, fish poison and several other domestic uses (Sadiku, 2010). The tree is widely recognised in West Africa as an important multipurpose tree of West Africa Savannah land. African locust bean \((Parkia\ biglobosa)\) tree is a perennial plant which belongs to sub-family mimosodee and family leguminosae (now fabaceae) (Akande et al., 2010). Locust bean tree is a leguminous crop peculiar to the tropics. The tree is not normally cultivated but can be seen in population of two or more in the savannah region of West Africa (Hopkins, 1983). It is prominent in the entire savannah region of West Africa (Yudkin, 1985). It grows in savannah region of West Africa up to edge of Sahel zone (Campbell-Platt, 1980). Dalziel (1963) and Keay (1989) reported that locust bean tree extends from Senegal to Sudan and its habitat is in savannah land as it is characteristic of transition areas from Sahelian to Sudanian eco-zones locally on farmlands. It is common in Nigeria particularly in the Northern and South Western parts (Odunfa, 1982). The most important part of the tree is found in its seeds and the processed seed is used as a condiment for soup. It is a source of natural nutritious condiment which features frequently in the traditional diet of the people (Akande, et al.; 2010). Apart from the flavouring, attribute of the processed locust bean also contributes significantly to the intake of protein, essential fatty acids, particularly Vitamin B, riboflavin and Vitamin A (Odunfa and Adewuyi, 1985).

A study was carried out on the process optimisation of spiced African Locust Bean in different packaging materials. The study aims at developing a simple and practical processing approach using electricity such that temperature is controlled during steaming, replacing common salt with natural spices (garlic and ginger). Efforts need to be put in place through optimisation of appropriate processing and storage conditions, development of a standard method for preservation with the view of providing an acceptable packaging material to prolong shelf life, as well as add value to the commodity for better income. An optimisation problem requires the determination of the optimal (maximum and minimum)
values of a given function called the objective function under a given set of constraints. Optimisation is the process of finding actions that maximise the value of an object function. This definition can also be adopted into storage process, by saying that, optimisation of storage is the process of finding the best conditions under which the storage of a given product can be done in order to get the best product after storage.

2. Literature Review

The application of various, evolving technological processes has resulted in modern methods of processing African locust bean (Audu et al., 2004; Adewumi et al., 1999). Boiling units such as steamers and pressurised vessels are employed in order to enhance good dehulling characteristics and high quality of final product. The use of gas and charcoal as fuel has also been embraced since this provides clean operation and sustained heat input during boiling. When pressure pot is used to carry out the boiling, it will make locust bean ready for dehulling in 30 to 50 minutes between temperature range of 121°C and 151°C (Oyewole and Odunfa, 1990). Adewumi and Igbeka (1993) reported that when locust bean seed is allowed to cool for 5 minutes after boiling, it possesses a dual advantage of both increasing the dehulling characteristics of dehulled surface and upon condensation, the water that migrated into the seed during the boiling process settles between the cotyledon and the testa thereby weakening the adhesive bond. An important mechanical property required for dehulling is shear strength (Mohsenin, 1970). Both dry and wet dehulling involve shearing of surfaces with dehulling medium (Adewumi and Igbeka 1996). Though some impact load is associated with dry dehulling when using mortar and pestle, the major strength responsible for dehulling is shear strength (Singh and Sokhansanj, 1984). Impact load on seed should not exceed shock load and compression load, otherwise the seed would be crushed and the efficiency of dehulling would be reduced (Reichert, 1987).

In lieu of impact loading and rubbing action on the wall of mortar carried out traditionally on boiled seeds, dehullers are used to achieving the same purpose with rubbing action (force) against the wall of dehulling chamber. Audu et al. (2004) reported that the guiding principles are very much the same as that of traditional process which is abrasion. This is usually accomplished with a rotating auger made of mild steel having a clearance of 6.5mm between the auger coil and the abrasive wall of the dehulling chamber. This is to allow shear force act on seeds whose average thickness is about 8mm, thereby obtaining dehulled seeds. Dehulling process seeks to impact the seeds with a shear force for separation to occur. Dry dehulling is carried out in some areas but this, though done with the mortar and pestle giving an impact, also seeks to provide the major required shear force. The impact force should be ensured not to exceed the compressive force on the seed otherwise; it may lead to crushing of the seeds to be dehulled and the efficiency of dehulling would be reduced (Owolarafe et al., 2011).

It is also important to look at packaging as an integral part of food processing and preservation because the success of most preservation methods depends on appropriate packaging to prevent microbiological contamination of heat-processed foods or moisture pick up by dehydrated foods. It is advisable that packaging materials for food products such as P. biglobosabe perforated because of their relatively high moisture contents and respiration rates which make them lose water to the atmosphere, resulting in loss of weight and fast deterioration in appearance and texture (Brennan and Day, 2006).

One of the most widely used optimisation techniques is the regression analysis (Olaniyi, 2006). Olayemi (1998) described a regression analysis as an attempt to measure the amount of change (in value) of the dependent variable which is derived from a unit change (in value) of the independent variable. In other words, a regression analysis is an attempt to find out, in a specific way, how one variable is related to the other and it involves a one-way cause and effect relationship. Mitral et al. (2011) carried out the optimisation of the drying process of onion slices in a vacuum dryer; with a temperature range of 50 – 70°C, onion slices of 1-5 mm thickness, and pre-treating in solution. It was discovered that the optimum conditions for the treated samples were 58.66°C drying temperature and 4.95mm slice thickness. Gajda and Biles (1978) stated that the optimum conditions are those that produce the best, most favourable or most beneficial result from a system or process.

A lot of research work has been done on the production of African locust bean seeds and related aspects such as storage, preservation, processing, the time taken to cook, packaging and other areas (Babalola, 2012; Non-Wood News, 2009). However, the optimisation of the storage conditions to make the best combination of selected variables in order to have the best result has not been fully investigated. Hence, it is of paramount importance and worthwhile to carry out the optimisation analysis to determine optimum storage conditions for packaged African locust bean for more acceptable preservation method, better packaging material and shelf life extension.

3. Materials and Methods

3.1 Experimental Materials

The African locust bean seeds (P. biglobosa) species used in this study were purchased from a local market in Odo Owa, Kwara State, Nigeria. These seeds were manually processed. A refrigerator (Haier Thermocool Mini Bar Fridge Model HR-142S TEC) was used for storage. The following instruments were used during the
experiment; digital thermo-hygrometer (Acurite - 00613), a
digital pH meter (InoLab - pH7310), electric oven
(Gallenkamp: BS. OV-330) and a sensitive electronic
weighing balance (Camry-Ek5350).

3.2 Experimental Procedure

Two thousand grammes (2000 g) of locust bean seeds
were measured with a weighing balance into a metal sieve
that was placed in a pot containing 16 litres of boiling
water. It was covered tightly and steamed to 100°C for 8
hours. The steamed beans were poured into the mortar and
dehulled using a pestle. The seed coats were decanted
along with washing and the cotyledons were parboiled for
50 minutes. The cotyledons were later drained through a
sieve, spread into calabash tray, covered with a wooden
tray, wrapped with jute sack and covered tightly to
undergo natural fermentation at 28°C temperature and
86% relative humidity for 72 hours. One thousand and six
hundred grammes (1,600g) of freshly prepared locust
beans were measured with an electronic sensitive
weighing balance and initially divided into four equal
portions making a portion to be four hundred grammes
(400g) each.

According to Amagase et al. (2001), garlic and ginger
as natural spices can be toxic if consumed in very high
dosages, so supplementation should never go beyond 5%
of the diet. Hence, considering a lesser percentage (4%),
the preservatives were prepared by adding 4% (16g) of
garlic powder to the first portion of the beans, 4% (16g) of
ginger powder to the second portion and a mixture of 2%
(8g) each of garlic and ginger powder (16g of garlic-
ginger powder) to the third portion respectively while no
preservative was added to the fourth portion.

After this, each of the four portions was measured and
further divided into sixteen equal portions, to make
twenty-five grammes (25g) each and sixty-four (64)
samples altogether. Each of the samples was packed in
four different sterilised plastic films (16cm × 8cm) each
having sixteen pieces with different thicknesses and same
number of perforation at the same diameters namely: Low
Density Polyethylene as M1 (LDPE 0.017mm with8, 16,
24and 0 perforations), Polypropylene as M2 (PP 0.015mm
with 8,16,24 and 0 perforations), Aluminium foil as M3
(AF 0.450mm with 8, 16, 24 and 0 perforations) and High
Density Polyethylene as M4 (HDPE 0.013 mm with 8, 16,
24 and 0 perforations) each at 3%, 6%, 9% and 0%
respectively. The total surface area of each film bag was
128cm².

Storage was done carefully by packaging, labelling
and storing the samples in a thoroughly sterilised
refrigerator (Haier Thermocool Mini Bar Fridge Model
HR-142S TEC) set at a constant temperature of 10°C
and relative humidity of 70% (monitored by a thermo-
hygrometer (Acurite Model 00613)) at the Food
Engineering Processing Laboratory of University of
Ilorin. During the period of storage (four weeks), the
environmental conditions such as temperature and relative
humidity of the storage environment were constantly
checked prior to proximate analyses. The nutritional
qualities were determined by subjecting the processed
product to proximate analyses in the laboratory using
AOAC (2002) nutritional guidelines. The nutritional
values determined were Vitamin A, Crude protein,
Calcium, Iron and pH value. There were four levels for
each of the factors, that is:

- Packaging materials - M1 as LDPE, M2 as PP, M3 as
  AF and M4 as HDPE;
- Percentage perforations - P1 as 3%, P2 as 6%, P3 as 9% and P4
  (no perforation);
- Preservatives - A1 as Garlic, A2 as Ginger, A3 as Mixture of garlic
  and ginger and A4 (no preservative);
- Time – T1 as Week 1, T2 as Week 2, T3 as Week 3 and T4 as Week 4.

Figure 1 shows the flow chart for steam method of processing
African Locust Bean Seeds while Figure 2 shows the
exploded view of the steaming set-up.

![Figure 1. Flow Chart for Steam Method of Processing African Locust Bean Seeds](image-url)

Also, Figures 3 and 4 show the sample preparation as well
as experimental set-up and arrangement of pot, sieve and
thermocouple, respectively. The packaged and labelled
samples before storage and during storage are presented in
Figures 5 and 6.
3.3 Optimisation Analysis

The optimum storage conditions for the stored produce were determined using optimisation technique with the aid of Essential regression software package. Optimisation of storage is the process of finding the best conditions under which the storage of a given product can be done in order to get the best product after storage.

4. Results

Optimisation deals primarily with finding the optimum (maximum or minimum) settings of parameters (process conditions) in mathematical model in order to obtain a desired output or response value. The optimised values of process conditions namely; Storage Time, Packaging Material, Percentage Perforation and Preservative agent present at their various levels and the optimum values of the process output or measured parameters are as presented in Table 1. All process parameters and process output were optimised to maximum and minimum extent possible. The optimised value of process conditions and the optimum values of the output are depicted. The desirable optimum conditions for this study are minimum moisture (%), maximum crude protein (%),
maximum bulk density (g/cm$^3$), maximum vitamin A (mg/100g), maximum iron (mg/100g), maximum calcium (mg/100g) content and maximum pH value.

5. Discussion

As showed in Table 1, the optimum (minimum) value of Moisture content was achieved by combining African locust beans in Low-Density Polythene, garnished with Garlic, with no (0) perforation and stored for one (1) week. The combination yielded a value of 6.102 %. The optimum value of Crude protein was generated by combining African locust beans in High-Density Polythene, with no preservative, no (0) perforation and stored for one (1) week. This combination gave a maximum value of 39.345 %.

The optimum Bulk density was achieved by combining African locust beans in High-Density Polythene, with no preservative, no (0) perforation and stored for four (4) weeks. This combination yielded a maximum value of 0.450 g/cm$^3$. Similarly, the optimum Vitamin A content was generated by combining African locust beans in High-Density Polythene, with no preservative, no (0) perforation and stored for four (4) weeks. This combination gave a maximum value of 163.732 mg/100g.

Moreover, the optimum Iron content was derived from combining African locust beans in Polypropylene material, garnished with Ginger, with 9% (24) perforations and stored for four (4) weeks. This combination yielded a maximum value of 1429.249 mg/100g. For higher Calcium content, however, the maximum value of 1425.422 mg/100g was achieved by combining African locust beans in High-Density Polythene, garnished with Garlic, with 3% (8) perforations and stored for two (2) weeks. This combination gave the maximum value.

Finally, the optimum pH value was also generated by combining African locust beans in Low-Density Polythene, with no preservative, with 9% (24) perforations and stored for four (4) weeks. This combination yielded a maximum value of 8.46. For the seven outputs considered (moisture content, crude protein, bulk density, vitamin A, Iron, Calcium and pH), the higher their values in the spiced products, the better the product and the better the application in improving the nutritional qualities of the stored locust beans since the goal of the optimisation process for the seven (7) outputs was to maximise them in the spiced African locust beans. It is possible to control the packaging conditions by fixing the values of different parameters needed to achieve optimum nutritional values of packaged African locust beans.

6. Conclusion

The study focused on the optimisation of spiced African Locust Bean (P. biglobosa) in different packaging materials. It was established that useful information on the optimum values of output parameters with respect to process conditions of African Locust Beans (P. biglobosa) was provided from optimisation analysis. The High Density Polythene and 6% perforation best improved the nutritional qualities of the stored locust beans at the end of the storage period. The preservative agents (garlic, ginger and mixture) and storage time used were seen to improve the nutritional qualities of the stored locust beans depending on the packaging material and percentage perforation. Ginger increased most of the nutritional qualities and other parameters compared to garlic but the mixture of ginger and garlic best increased the output parameters for four (4) weeks higher than either ginger or garlic alone. This optimisation analysis would help in selecting the optimum nutritional value of processed materials.
African Locust Beans (*P. biglobosa*) under various packaging and storage conditions.

**References:**


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