Editorial…………………………………………………………………………………………………………………… 2
Factors Affecting Construction Labour Productivity in Trinidad and Tobago ..................... 4
Effect of Bagasse Fibre Reinforcement on the Mechanical Properties of Polyester Composites ................................................................................................................................. 12
Investigating into Automated Filler Solutions in Manufacturing: A Case Study ............ 16
Analysis of Gas Expansion Required for Hydrate Formation ........................................ 22
Basic Design Characteristics of a Hydrate Formation Vessel ........................................... 27
Effect of Storage Condition and Duration on Selected Physical and Mechanical Properties of Star Apple Fruit (Chrysophyllum spp) ........................................................................ 33
A Five-Stage Approach for Improving the Processes of Student Admissions Application for Postgraduate Programmes at UWI ................................................................. 40

Conference Announcement and Call for Papers:
The Third Industrial Engineering and Management Conference 2014
The University of the West Indies, Trinidad & Tobago, West Indies, 5-6 December 2014 .... 46
### PRESIDENTS OF THE ASSOCIATION OF PROFESSIONAL ENGINEERS OF TRINIDAD AND TOBAGO

<table>
<thead>
<tr>
<th>Year</th>
<th>President</th>
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<td>1975-1976</td>
<td>Harry O. Phelps</td>
<td>2000-2001</td>
<td>Imtiaz Hosein</td>
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<td>1991-1992</td>
<td>Emile S. Charles</td>
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### FOUNDATION MEMBERS OF THE ASSOCIATION OF PROFESSIONAL ENGINEERS OF TRINIDAD AND TOBAGO IN 1959

<table>
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<th>Member</th>
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<tr>
<td>Rupert V.S. Aleong (Founding President)</td>
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<tr>
<td>Keith I. Allahar</td>
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<tr>
<td>Rupert D. Archibald</td>
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<td>Don D. Ash</td>
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<td>Rudolph Balgaroo</td>
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<td>Luther A. Boyce</td>
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<td>Leslie G. Dookie</td>
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<td>Winston Manson-Hing</td>
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<td>Basil Pashley</td>
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<td>Harry O. Phelps</td>
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<td>Karl F. Seheult</td>
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<td>Cecil R. St. Hill</td>
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<td>Peter F. Walker</td>
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<td>Errol A. Williams</td>
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**Note:** APETT's logo was designed by Derek Aleong.
2 Editorial

4 Factors Affecting Construction Labour Productivity in Trinidad and Tobago
by Brent G. Hickson and Leighton A. Ellis

12 Effect of Bagasse Fibre Reinforcement on the Mechanical Properties of Polyester Composites
by Isiaka Oluwole Oladele

16 Investigating into Automated Filler Solutions in Manufacturing: A Case Study
by Nadine Sangster, Terrence R.M. Lalla, Roma Jagat, and Leonard Ochoa

22 Analysis of Gas Expansion Required for Hydrate Formation
by Jerome Rajnauth

27 Basic Design Characteristics of a Hydrate Formation Vessel
by Jerome Rajnauth

33 Effect of Storage Condition and Duration on Selected Physical and Mechanical Properties of Star Apple Fruit (Chrysophyllum spp)
by Ademola K. Aremu, Rahman Akinoso, and Oluwatoyin M. Olasoji

40 A Five-Stage Approach for Improving the Processes of Student Admissions Application for Postgraduate Programmes at UWI
by Kit Fai Pun and Avielle Cooper

46 Conference Announcement and Call For Papers:
The Third Industrial Engineering and Management Conference (IEM3-2014), 5th-6th December 2014, University of the West Indies, St. Augustine Campus, Trinidad and Tobago
Editorial

I. From the Editor

A. Editor’s Note

In the past two years, the APETT Journal had been encountering difficulties of one kind or another in its effort to publish its scheduled issues. The most challenging tasks are to encourage new scholarly inputs and technical papers for publishing in the journal, and to formulate workable strategies for taking the journal forward, particularly with regard to improving a wider and more reader and authorship.

We hope that this Volume 42 would signal a new page for the Journal. It is anticipated that the Journal would be coming off the press regularly with 2 issues per year, Issue No.1 being in April/May and then Issue No.2 in October/November.

To support this initiative, the Journal is going to publish a Special issue for Volume 42 No.1 on selected papers presented at the APETT Technical Conference 2014 with the theme on “Engineering for Disaster Preparedness and Management”. This extends the Conference objective to determine the technological capacity to prevent, manage and recover from disasters in Trinidad and Tobago and the wider Caribbean Region.

Moreover, the APETT would serve as one of the co-organisers/sponsors of the forthcoming third Industrial Engineering and Management Conference that is carded for 5th-6th December 2014. The conference theme addresses the “Challenges of Project Engineering and Management in a Sustainable World”. A ‘Call for Papers’ is included in this issue. Strong papers would be recommended for fast track publication at the APETT Journal, subject to the results of peer review exercises.

Further to the initiative of the APETT Journal, proposals for special issues on topics of current interests in engineering and associated disciplines and applications are always welcome. Please write to the Editor-in-Chief (KitFai.Pun@sta.uwi.edu) and/or the Head Office of the Association, with a brief description or a concept note of any intended proposal(s). Upon receipt, the Editorial Committee and/or the Editor would review the suitability of the proposal(s). If the review outcomes are positive, the Editor would work with the proposer(s) on developing a detailed plan for proceeding the proposed special issue(s).

II. About This Issue

Volume 42 Number 1 of the Journal includes seven (7) research articles. The relevance and usefulness of respective articles are summarised below.

B.G. Hickson and L.A. Ellis, “Factors Affecting Construction Labour Productivity in Trinidad and Tobago”, present a recent study on acquiring views from members of the Trinidad and Tobago Contractors Association via a questionnaire survey. A host of 42 factors affecting construction labour productivity are grouped under 4 categories (Management; Technological; Human/Labour and External). The relative importance of indices is used to determine the ranking of these factors. The authors also present recommendations on improving construction labour productivity with respect to importance of these factors.

I.O. Oladele, “Effect of Bagasse Fibre Reinforcement on the Mechanical Properties of Polyester Composites”, reports a study on exploring the use of bagasse/sugarcane fibre to reinforce unsaturated polyester material for engineering applications. For the study, sugarcane fibres particles were sieved into 75 µm and added to the polyester in predetermined proportions of 5, 10, 15 and 20 weight percent (wt%) for the production of the composites. Mechanical tests (tensile and hardness) were carried out on the samples. It was found that the reinforcement was able to enhance the mechanical properties of the developed composites with a verge point value of 10 wt% reinforcement.

N. Sangster, T.R.M. Lalla, R. Jaggatc, and L. Ochoa, “Investigating into Automated Filler Solutions in Manufacturing: A Case Study”, investigated into the need for automating a filler to tackle the problems occurring upstream of the production at a manufacturing plant in Trinidad and Tobago. Methods of automating the filler speed to accommodate manual air blowing and loading were analysed, and alternatives of solutions were devised. The recommendation was to install a Programmable Logic Controller system that would allow the plant to automate the control of the filler speed on the line, resulting in greater operating efficiencies and lesser wear and tear of the filler.

J. Rajnauth, “Analysis of Gas Expansion Required for Hydrate Formation”, discussed the potential of natural gas hydrate technology that would capture and transport natural gas on a small scale utilising a conceptual floating hydrate formation vessel. For capturing natural gas from the wellbore, expansion would be used to expand the gas to new pressure and temperature values. The expansion process must ensure the gas sample remains in the single phase region of the phase diagram. If the gas goes into the two-phase region of the envelope, then additional gas separation would be required before formation of natural gas hydrate. This paper evaluates the expansion process, and reports the results that the expansion efficiency required to obtain the natural gas at 35°F may vary from sample to sample in the analysis.

In his second paper, J. Rajnauth, “Basic Design Characteristics of a Hydrate Formation Vessel”, describes a proposed hydrate formation vessel by exploring some of the basic design characteristics required for an effective and efficient vessel. The purpose of the vessel is to capture and transport natural gas in the form of hydrates.
The proposal is to use the same vessel to form the hydrate, being also used for storage and transport to its delivery point. Using one vessel gives operational flexibility for temporary storage and transportation. In the absence of pipeline infrastructure, hydrates could be transported in the vessel, by truck, railway or ship.

A.K. Aremu, R. Akinoso, and O.M. Olasoji, “Effect of Storage Condition and Duration on Selected Physical and Mechanical Properties of Star Apple Fruit”, present a technical paper on examining the change of properties on star apple fruit. Based on ambient and refrigerated conditions for 25 days at 5-day intervals using standard methods, the effect of storage condition and duration on some physical and mechanical properties of star apple fruit was determined. These properties include moisture loss, unit mass, size and shape, true and bulk densities, static angles of repose, coefficient of friction, as well as force at break, yield and peak. Using physical and mechanical properties as criteria, refrigeration at 5°C and 70% relative humidity is recommended for short-term storage of star apple fruit.

K.F. Pun and A. Cooper, “A Five-Stage Approach for Improving the Processes of Student Admissions Application for Postgraduate Programmes at UWI”, present the process improvement initiatives using the selected processes associated with student admissions application into postgraduate programmes of UWI. Problems and factors affecting these processes are identified and the process maps are re-designed. It is recommended for the School for Graduate Studies and Research (SGRS) to implement the re-designed processes and test the effectiveness and efficiency of the new processes in handling student admissions application. Future research could validate the adoption of 5-stage approach on mapping core processes at SGRS. The lessons accomplished would provide insights for other academic units and institutes in an attempt to improve the design and delivery of their processes with the initiative of process improvement.

III. Acknowledgements

On behalf of the Association, we gratefully acknowledge all authors who have made this special 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 practicing engineers and professionals from industry as listed below:

- **Dr. Abrahams Mwasha**, University of the West Indies (UWI), Trinidad & Tobago (T&T)
- **Dr. Albert H.C. Tsang**, Hong Kong Polytechnic University, Hong Kong
- **Dr. C. Osita Anyaeche**, University of Lagos, Nigeria
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- **Mr. Clyde Abder**, UWI, T&T
- **Dr. Jeffery A. Jones**, University of Warwick, Coventry, UK
- **Professor Jon P. Mills**, University of Newcastle, UK
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- **Professor Winston G. Lewis**, UWI, T&T

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
May 2014
Factors affecting Construction Labour Productivity in Trinidad and Tobago

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Abstract: Labour productivity is at the forefront of concerns facing professionals in the construction industry worldwide. Despite the breakthroughs made in technology and an ever-expanding labour market much of the advances in construction are being eroded by inherently poor practices on the job site. This study highlights the factors affecting labour productivity of the Construction industry in Trinidad and Tobago (T&T). A questionnaire was used to gather the relevant data from members of the Trinidad and Tobago Contractors Association. It involved ranking 42 predefined factors divided into 4 categories: Management; Technological; Human/Labour and External. The relative importance of indices (RII) was determined and the factors were ranked. The top ten factors affecting construction labour productivity in T&T are: the lack of labour supervision, unrealistic scheduling and expectation of labour performance, shortage of experienced labour, construction manager's lack of leadership skills, skillset of labourers, delay in responding to requests for information (RFI), payment delay, communication problems between site management and labour, rain and late arrival, early quitting, and frequent unscheduled breaks. Recommendations have been made in the study to address these factors. The research has direct benefits to key stakeholders in the construction industry.

Keywords: Productivity, Construction, Labour, Trinidad and Tobago

1. Introduction

A successful construction project has many important components, a major contributor being labour. In fact, construction labour constitutes the largest unit of human resource on any given project. Human resources represent the most variable, uncontrollable, and important element in production (Kazaz and Ulubeyli, 2007) and labour’s sheer magnitude is the reason why underlying influences (both positive and negative) significantly determine the outcome of projects.

Although Trinidad and Tobago (T&T) has a sizeable labour force and skilled labour exists, poor workmanship and delays as a result of labour issues plague the construction industry. There is limited research into the construction industry in T&T, thus root issues and trends have not been accurately identified or analysed. This paper addresses this void and adopts the methodology used by Jarkas and Bitar (2012) to identify and rank the factors affecting labour productivity in T&T. Each group of professionals targeted within the construction industry may produce differing perspectives on which factors affect labour productivity and to varying degrees. It is not reasonable to amalgamate these differing opinions into one definitive ranking of factors. While the existence of unproductive labour habits is not challenged, the extent of inefficiency and the sources of underperformance have not been addressed. The paper aims to identify the factors affecting labour productivity, rank these factors and to propose solutions to these problems in T&T. Given the limited information available, it explores the labour trends, which in turn can be used to improve management techniques, labour relations, project planning and other related aspects of the construction industry in T&T.

In an effort to create a standard ranking system, any additional factors identified but not included in the questionnaire were not scored. Likewise, the integrity of factors used in the survey has not been tested. It is believed that the factors to be ranked are all predefined, undisputed elements that affect productivity.

2. Literature Review

2.1 What is productivity?

Construction labour productivity is a complex variable to measure, its constituents are vague and are difficult to quantify. A comprehensive understanding of the concept of productivity must be achieved to successfully analyse it. Fundamental concepts provided in previous studies include: “dollars of output per person-hour of labour input” (Adrian, 1987), and “the quantity of work produced per man-hour, equipment-hour, or crew-hour” (Finke, 1998).

Similarly, interpretation of the basic output/input expression can be applied to evaluate labour effectiveness by input use efficiency (partial factor productivity) where
output is assessed with respect to a single factor of production.

\[
\text{Labour Productivity} = \frac{\text{Output}}{\text{Labour Input}}
\]

In this study, as in others, productivity is observed with the work force interpreted as a whole body rather than individual classes of worker (e.g. masons, electricians etc.). Construction projects employ a large number of people, this method does not distinguish productivity among individuals nor does it discern productivity between professions. As a result, the factors documented or recommendations derived may not apply to every class of worker.

### 2.2 Labour productivity, a global dilemma

The construction sector is a strategic part of every society, it is one of the largest employers and attracts a large amount of investment (both public and private), while being responsible for providing necessary infrastructure to nations. Construction employs more than 7% of Europe’s work force and is the largest industrial employer in the continent (Proverbs et al., 1999). Building construction in particular, consumes approximately 70% of construction investment in developing countries (World Bank, 1984).

The battle to complete construction projects on time and within budget is ongoing, being fought when faced with the rising cost of labour and material. Aynur et al. (2008) noted that construction labour accounted for the largest percentage of total project costs in developing countries (i.e., as much as 40% of direct capital cost in large construction projects). Underperformance of this component is detrimental to success.

While improvements have been made in many areas of design and construction technology, addressing the dilemma of productivity has been challenging given the limited data available. Nevertheless, some research has been undertaken to tackle this global problem.

Kuwait, a Middle Eastern territory had undergone a massive state fuelled construction drive initiated in January 2010 but remained plagued by inefficiency and over-budget expenditure. Despite the new technology builders have access to, the excess of construction material, the equipment and financing available, contractors were still faced with rising construction costs, longer project timelines and cost overruns (Jarkas and Bitar, 2012). Much of the leakage had occurred in labour, where weak output had eroded investments made by contractors.

Decreasing productivity has been recognised in the United States (US), witnessed separately in studies by Allen (1985), Business Roundtable (1983) and Stokes (1981) where it was observed that construction output declined between 1968 and 1980 at an annual rate of 2.4 to 2.8%. Teicholtz (2001) showed a continuation of this pattern into the year 1999, with labour productivity measured at an annual compound rate of -0.48%.

The Caribbean is a developing region with impetus provided by a combination of foreign direct investment, state participation and local/regional private sector involvement at varying levels across territories. Construction labour in this region is primarily provided by locals with skills developed either domestically or through information transfer by international firms. In the 2000s a buoyant world economy stimulated investment in new construction within the Caribbean with many territories expanding infrastructure while improving or adding to existing facilities.

While investment may have been positive in the 2000s, publications from the PIOJ (2009) showed Jamaica on a low productivity growth path during this period. It confirmed that overall labour productivity in the region (using international prices) at $9,080 for Jamaica, Barbados $28,302, T&T $33,768, and USA $67,087 for the period 2000-2003. A further decline of Jamaican labour productivity was witnessed in 2008. Moreover, other Caribbean nations garnered similar reviews: “In tourism-based economies such as Barbados, employment growth outstripped GDP growth which is a clear indication of falling labour productivity at the level of the total economy” (ILO 2006).

T&T has an economy based heavily on oil and gas exports, the revenue from which has long fuelled its construction projects. It’s much celebrated expertise in engineering and construction however, has not guarded it from negative industry practices. Shortcomings in engineering projects are well documented and span the entire history of this nation (such inadequacies include weak productive output). ECLAC (2005) actually demonstrates a rise in productivity during the early 1990s but after 1996 there was a noticeable decline.

### 2.3. Outcomes of previous studies

Several labour productivity factors have been identified in research studies. Global productivity trends have been documented and the most popular problems have been identified in the papers. The most prevalent issues include:

a) Unavailability of material
b) Unavailability of tools/equipment
c) Incompetent management
d) Rework
e) Poor communication
f) Lack of incentive program
g) Motivation of workers
h) Schedule of work

These issues (not listed in any order) are reoccurring factors gathered wherever relevant research has been undertaken, have consistently been found to be at the forefront of poor productivity. Table 1 shows a list of some of these factors and their rank in previous studies.
This brief overview of the findings of past research not only outlines the similarity of results achieved, but also illustrates just how widespread these problems are. There has been a lack of progress made and by assembling these studies chronologically one can observe that the same problems have remained atop the list for over 15 years (albeit in different countries).

Multiple studies carefully noted that labour productivity factors were not independent of one another and not all can be controlled. Management must therefore direct the conditions that are manageable and provide a positive environment for labour.

### 2.4 How is this data used?

Understanding labourers is part of the solution to increase efficiency. Construction workers are not machinery and if appraised under identical work conditions different productivity levels might be noticed, furthermore a constant level of productivity is not guaranteed throughout the life of a project (Lam et al., 2001).

Craft workers have been targeted by researchers and their discoveries have offered considerable contribution to management’s outlook. Open and lucid communication among personnel cannot be emphasised enough. It is imperative to achieve harmonious operation of human resource on a construction project. Information must not only be disseminated by a top down approach but gathered from site and conveyed upward. As Jiukun et al. (2009) explain, “a better understanding of the factors influencing labour productivity from the workforce’s perspective can enable site management teams to more effectively allocate their limited resources, provide craft workers with better support, increase craft workers’ motivation, and enhance craft workers’ commitment to productivity improvement.”

Developed countries enjoy much success because they are able to organise production with relatively high levels of productivity. Conversely, low levels of education or poorly trained labour in addition to insufficient infrastructure is prominent in developing countries (Kazaz and Ulubeyli, 2007). This erodes the advantage of cheap labour and leads to over budget and over scheduled projects.

The T&T construction industry embodies this premise, observed in very recent projects during the economic boom as well as past undertakings. A study conducted in T&T by Lewis and Mugishagwe (1997) noted “Construction operations were plagued by low labour productivity…. in addition to these labour related problems there was also a significant lack of sophistication in the managerial skills employed in the industry”.

Despite it comprising a large section of construction cost, the workforce is not seen as important input to a successful project (Kazaz et al., 2008). In T&T, labour always under-performs and management is oblivious of how to change it. Relevant research into the local market must be executed to gather the origins of these deficiencies, so they can be acted upon.

### 3. Study Methodology

Recognising and grading factors of productivity is subjective hence a survey instrument was best suited for data collection in this study. To achieve standard parameters for quantification and analysis, predetermined factors were used in this investigation. The use of labour productivity factors originates from the research findings advocated by Jarkas and Bitar (2012).

Data acquisition targeted the pool of contractors belonging to the T&T Contractors Association (TTCA.). This organisation was chosen to generate feedback as they had a satisfactorily large sample of qualified professionals and this body comprises reputable companies of sufficient financial strength, experience, technical capability and equipment.

For this study, a probabilistic sampling method (Hogg and Tanis, 2009) was used to determine the minimum size of the contractor pool.

\[
n = \frac{m}{1 + \left( \frac{m-1}{N} \right)}
\]

where,

- \(N\) = available population size
- \(m\) = unlimited population size
- \(n\) = limited population size
- \(z\) = statistic value of confidence level used
- \(p\) = value of population proportion that is being estimated
- \(\varepsilon\) = sampling error of the point estimate

From the TTCA pool, the calculated unlimited population size was 384. The available population size was sixty-six (66) and using the above formula the limited population size was calculated to be fifty-seven (57) participants. The survey was able to obtain responses from thirty (30) contractors which represented 52% of the limited population size.
For the purpose of this study, a questionnaire with a combination of close ended and open-ended queries was used as it represents an appropriate tool to draw from the expertise of industry professionals as well as providing timely feedback for the analysis component of this paper. Questionnaires were distributed and each firm was required to score each factor outlined. The factors were derived from previous studies on this subject matter. The questionnaire was administered face-to-face.

Hence, respondents were asked to score each factor using an effect level ranging from 1 to 4 (with 1 representing the least effect and 4, the most effect on productivity). The scores were analysed using the Relative Importance Index (RII).

Relative Importance Index (RII) = \frac{\sum \text{score of factor} \times \text{number of respondents}}{\text{total number of respondents}}

Employee opinion surveys usually end with respondents rating every issue as being important for fear that anything not given high importance ratings would not be addressed (Johnson and LeBreton, 2004).

The RII method is a proven system for analysing employee or customer satisfaction thus making it suitable for this situation. It can expose specific elements that contribute most to management and labour concerns and assist decision makers in allocating organisational resources (Lundby and Fenlason, 2000; Whanger, 2002). The data were compiled and calculations performed utilising spreadsheet software, where the results were ranked and presented in this paper.

4. Results and Discussion

This study examined the factors that affect labour productivity in T&T, and ranked 42 predefined factors divided into four (4) categories, namely 1) Management; 2) Technological; 3) Human/Labour, and 4) External. The RII was used to determine the influence each factor has on construction projects with the highest value attained in the index indicating the highest rank.

4.1 Ranking of Management Factors

Table 2 shows the ranking of the factors and their corresponding RII for the management category. The following is a brief discussion of the top ten factors affecting labour productivity in the management category.

1) **Lack of labour supervision** - Construction workers must be closely monitored to achieve the desired levels of productivity, inadequate supervision as a key reason for idle time on construction projects. Lack of labour supervision was in fact identified as the number one management factor in Jarkas and Bitar (2012), while Soekiman et al. (2011) found that supervision is to be the principal issue affecting productivity.

2) **Unrealistic scheduling and expectation of labour performance** - Practical assessment and scheduling of work is heavily dependent on the skill and experience of management personnel. Scheduling emerged as a pertinent issue, this weakness can fuel deficiencies in other elements such as poor workmanship and labour discontent.

3) **Construction manager's lack of leadership** - Both Henry et al. (2007) and Makulsawatudom and Emsley (2003) found the incompetence of supervisors to be among the chief contributors to poor productivity. Jiukun et al. (2009) ranked it fifth in its list of productivity categories. This factor is also rooted in the expertise of the individual. One must be able to command the respect of both management and labour.

4) **Communication problems between site management and labour** - Relaying information from management to labour and vice versa is challenging for both parties but it is essential on the job-site. Communication was seventh in the productivity categories in Jiukun et al. (2009), sixth in the Makulsawatudom and Emsley (2003) list of critical factors, and sixth in Henry et al. (2007). Inaccurate or ambiguous instruction has been identified as a particular concern for labourers.

5) **Late arrival, early quitting and frequent delays** - Delays may occur as a result of cash flow originating from the client, the contractor, or by poor planning/management of funds on the project. Regardless of the source, labour is only concerned with the bottom line and any disputes could severely hamper progress.

6) **Release of unsuitable storage location** - Storage locations must be accessible and adequate for the workforce in order to maximise output as well as be able to diffuse/resolve problems as they arise.

7) **Lack of incentive scheme** - Incentive schemes are an effective tool in improving productivity. The lack of incentives can lead to decreased morale and productivity among workers.

8) **Lack of suitable rest area offered to labour on site** - A suitable rest area is essential to ensure the well-being of workers and maintain productivity levels.

9) **Unsuitsability of storage location** - Storage locations must be accessible and adequate for the workforce in order to maximise output as well as be able to diffuse/resolve problems as they arise.

10) **Lack of providing labour with transportation** - Providing transportation to workers is crucial in ensuring they are able to attend to their duties promptly and efficiently.

Table 2. Ranking of Management Factors

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<thead>
<tr>
<th>Rank</th>
<th>Factor</th>
<th>RII (%)</th>
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<tr>
<td>1.</td>
<td>Lack of labour supervision</td>
<td>95.00</td>
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<tr>
<td>2.</td>
<td>Unrealistic scheduling and expectation of labour performance</td>
<td>91.67</td>
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<tr>
<td>3.</td>
<td>Construction manager's lack of leadership</td>
<td>88.33</td>
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<tr>
<td>4.</td>
<td>Payment delay</td>
<td>85.83</td>
</tr>
<tr>
<td>5.</td>
<td>Communication problems between site management and labour</td>
<td>85.83</td>
</tr>
<tr>
<td>6.</td>
<td>Late arrival, early quit and frequent unscheduled breaks</td>
<td>84.17</td>
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<td>7.</td>
<td>Shortage of materials</td>
<td>83.33</td>
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<td>8.</td>
<td>Construction method</td>
<td>83.33</td>
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<td>9.</td>
<td>Lack of training offered to operatives</td>
<td>83.33</td>
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<td>10.</td>
<td>Unavailability of suitable tools</td>
<td>81.67</td>
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<td>11.</td>
<td>Lack of periodical meetings with crew leaders</td>
<td>78.33</td>
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<td>12.</td>
<td>Lack of incentive scheme</td>
<td>77.50</td>
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<td>13.</td>
<td>Crow size and composition</td>
<td>75.83</td>
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<td>14.</td>
<td>Sequencing problems</td>
<td>75.83</td>
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<tr>
<td>15.</td>
<td>Inspection delay by site management</td>
<td>74.17</td>
</tr>
<tr>
<td>16.</td>
<td>Accidents as a result of poor site safety program</td>
<td>73.33</td>
</tr>
<tr>
<td>17.</td>
<td>Labour interference and congestion</td>
<td>72.50</td>
</tr>
<tr>
<td>18.</td>
<td>Proportion of work subcontracted</td>
<td>71.67</td>
</tr>
<tr>
<td>19.</td>
<td>Lack of recognition program</td>
<td>70.00</td>
</tr>
<tr>
<td>20.</td>
<td>Working overtime</td>
<td>66.67</td>
</tr>
<tr>
<td>21.</td>
<td>Owner's representative intervention with site management and operatives</td>
<td>60.34</td>
</tr>
<tr>
<td>22.</td>
<td>Lack of providing labour with transportation</td>
<td>60.00</td>
</tr>
<tr>
<td>23.</td>
<td>Lack of suitable rest area offered to labour on site</td>
<td>59.17</td>
</tr>
<tr>
<td>24.</td>
<td>Unsuitsability of storage location</td>
<td>57.50</td>
</tr>
</tbody>
</table>
unscheduled breaks - Respondents revealed that this practice was commonplace in some regions of T&T and disciplining workers was not trouble-free. Reprimanding labour often led to workers resigning their positions thereby depleting the workforce resulting in inevitable schedule setbacks. In T&T, managers described the labour force as having poor work ethic and preferring less physically demanding jobs.

7) Shortage of materials - This was the most significant factor in Makulsawatudom and Emsley (2003) and the second most important productivity category in Jiukun et al. (2009). Lack of materials is due to delinquent project management or as a result of economic constraints on the contractor, this problem could be solved with better planning.

8) Construction method - The construction technique employed is at the discretion of the contractor and depends on the resources available to him. Expertise plays a pivotal role in choosing the construction method and execution of the system. Poor construction methods ranked fifth in the overall importance index found in Henry et al. (2007). Severe disruptions can arise when the workforce is not familiar with the construction technique. Design oversight may provoke this factor as contractor input is not always present in assessing the constructability of a project.

9) Lack of training offered to operatives - Poorly trained workers could severely impact output and diminish the quality of work produced. Contractors in T&T offered limited training opportunities to workers hence their capabilities on-site were limited. External training exists but there is a need for better apprenticeship structures and continuous learning initiatives. Contractors also observed that labourers did not always know current professional standards.

10) Unavailability of suitable tools - This often arose out of poor procurement of equipment or inadequate maintenance of tools. Lack of tools ranked fourth in recent studies conducted by Henry et al. (2007) and Makulsawatudom and Emsley (2003). Management needs to furnish workers with new equipment whenever possible as obsolete tools curtail progress unnecessarily. Attention must also be paid to the number of workers using a specific tool to reduce the competition for resources.

4.2 Ranking of Technological Factors

Table 3 shows the ranking of the factors and their corresponding RII for the technological category. The following is a brief discussion of the top five factors affecting labour productivity in the technological category. These are:

1) Responding to requests for information (RFI) - Workers would regularly ask for instruction/clarification from supervisors and site engineers, responses however are not always prompt. This may lead to idle time thus management must redirect labour whenever possible.

2) Rework - Rework ranked third in Henry et al. (2007) and tenth in Makulsawatudom and Emsley (2003). Rework is the result of poor workmanship or variation to the original design. Respondents emphasised poor methods and inexperienced labour as the main reasons for rework in T&T, they complained of simple tasks that have gone awry. Rework delays the construction schedule and results in undue wastage of materials.

3) The extent of variation/change orders during execution - In T&T, it is common for the project construction phase to begin before the design has been completed, this frequently results in variations due to constructability problems owing to the design or existing in-situ conditions. Thomas and Napolitan (1995) calculated an estimated 30% loss in efficiency when alterations are being performed.

4) Clarity of technical specifications - This may also occur because construction starts before the design has been completed. Makulsawatudom and Emsley (2003) recorded incomplete drawings as a major concern in the study of Thailand’s construction sector, attaining a ranking of the second most critical factor of labour productivity.

5) Coordination level among design disciplines - Architecture and engineering disciplines regularly work together. Major changes must be made as early as possible and failure to attain an accord may result in undesirable variations and subsequent project delays.

4.3 Ranking of Human/Labour Factors

Table 4 shows the ranking of the factors and their corresponding RII for the human/labour category. These are:

Table 3. Ranking of Technological Factors

<table>
<thead>
<tr>
<th>Rank</th>
<th>Factor</th>
<th>RII (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Delay in responding to requests for information</td>
<td>86.67</td>
</tr>
<tr>
<td>2.</td>
<td>Rework</td>
<td>84.17</td>
</tr>
<tr>
<td>3.</td>
<td>The extent of variation/change orders during execution</td>
<td>81.67</td>
</tr>
<tr>
<td>4.</td>
<td>Clarity of technical specifications</td>
<td>81.03</td>
</tr>
<tr>
<td>5.</td>
<td>Coordination level among design disciplines</td>
<td>78.33</td>
</tr>
<tr>
<td>6.</td>
<td>Compatibility and consistency among contract documents</td>
<td>75.83</td>
</tr>
<tr>
<td>7.</td>
<td>Stringent inspection by the engineer</td>
<td>74.17</td>
</tr>
<tr>
<td>8.</td>
<td>Design complexity level</td>
<td>72.50</td>
</tr>
<tr>
<td>9.</td>
<td>Site restricted access</td>
<td>71.67</td>
</tr>
<tr>
<td>10.</td>
<td>Inspection delay by the engineer</td>
<td>68.33</td>
</tr>
<tr>
<td>11.</td>
<td>Confinement of working space</td>
<td>67.50</td>
</tr>
<tr>
<td>12.</td>
<td>Site layout</td>
<td>65.00</td>
</tr>
</tbody>
</table>

Table 4. Ranking Human/Labour Factors

<table>
<thead>
<tr>
<th>Rank</th>
<th>Factor</th>
<th>RII (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Shortage of experienced labour</td>
<td>91.67</td>
</tr>
<tr>
<td>2.</td>
<td>Skill of labour</td>
<td>87.50</td>
</tr>
<tr>
<td>3.</td>
<td>Motivation of labour</td>
<td>82.50</td>
</tr>
<tr>
<td>4.</td>
<td>Physical fatigue</td>
<td>71.67</td>
</tr>
</tbody>
</table>
1) **Shortage of experienced labour** - Contractors in T&T employ most workers temporarily (employment typically lasts the duration of the project), thus they are unable to retain experienced labourers. There are no opportunities for vertical mobility within local construction companies. Workers rather offer their services to competing firms then decide which jobs to pursue, thus the experienced workforce becomes divided.

2) **Skill of labour** - Temporary employment with different contractors develops different methodologies and work habits in labour. Besides, contractors do not anticipate an extended association with workers thus they are unwilling to develop labour as they do not want to train workers for competing businesses.

3) **Motivation of labour** - There are many facets to encouraging labour: management relations, adequate and prompt salary payment, job security in addition to job satisfaction. Most labourers lament the lack of employee benefits available to them and their insecure future in the construction industry. Labourers perceive their jobs to be stagnant rather than a rewarding career and this has a negative effect on their output.

4) **Physical fatigue** - Survey participants noted that labourers do not complain of physical fatigue but would target less strenuous occupations once they were accessible, this trend however, can be attributed to negative local customs. Extended work hours have great effect on fatigue during which workmanship and safety practice begin to wane.

### 4.4 Ranking of External Factors

Table 5 shows the ranking of the factors and their corresponding RII for the external category. These include:

1) **Rain** - T&T is a tropical territory and has a rainy season spanning most of the calendar year. While construction is scheduled to take advantage of the dry season, wet weather is unavoidable and can reduce output on site. Labour usually becomes uncooperative during rainy weather and workers use the occasion to be absent or leave early despite conditions not directly affecting their tasks.

2) **High temperature** - T&T records temperatures in excess of 30°C but locals are accustomed to these conditions and there have been no related injuries or deaths. Complaints of high temperature and their effect on productivity are few.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Factor</th>
<th>RII (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rain</td>
<td>85.83</td>
</tr>
<tr>
<td>2</td>
<td>High Temperature</td>
<td>64.17</td>
</tr>
</tbody>
</table>

### 4.5 Overall Ranking of Productivity Factors

Table 6 ranks all productivity factors and shows their corresponding RII. Survey participants reiterated that these factors are intertwined and their impact must be conceptualised together. For instance, the experience of labour and the skill of labour directly determine the likelihood of rework, the amount of rework necessary and the time to complete such. Likewise, management’s leadership, timely salary disbursement and existing incentive schemes affect labour’s motivation.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lack of labour supervision</td>
</tr>
<tr>
<td>2</td>
<td>Unrealistic scheduling and expectation of labour performance</td>
</tr>
<tr>
<td>3</td>
<td>Shortage of experienced labour</td>
</tr>
<tr>
<td>4</td>
<td>Construction manager's lack of leadership</td>
</tr>
<tr>
<td>5</td>
<td>Skill of labour</td>
</tr>
<tr>
<td>6</td>
<td>Delay in responding to requests for information</td>
</tr>
<tr>
<td>7</td>
<td>Payment delay</td>
</tr>
<tr>
<td>8</td>
<td>Communication problems between site management and labour</td>
</tr>
<tr>
<td>9</td>
<td>Rain</td>
</tr>
<tr>
<td>10</td>
<td>Late arrival, early quit and frequent unscheduled breaks</td>
</tr>
<tr>
<td>11</td>
<td>Rework</td>
</tr>
<tr>
<td>12</td>
<td>Shortage of materials</td>
</tr>
<tr>
<td>13</td>
<td>Construction method</td>
</tr>
<tr>
<td>14</td>
<td>Lack of training offered to operatives</td>
</tr>
<tr>
<td>15</td>
<td>Motivation of labour</td>
</tr>
<tr>
<td>16</td>
<td>Unavailability of suitable tools</td>
</tr>
<tr>
<td>17</td>
<td>The extent of variation/change orders during execution</td>
</tr>
<tr>
<td>18</td>
<td>Clarity of technical specifications</td>
</tr>
<tr>
<td>19</td>
<td>Lack of periodical meetings with crew leaders</td>
</tr>
<tr>
<td>20</td>
<td>Coordination level among design disciplines</td>
</tr>
<tr>
<td>21</td>
<td>Lack of incentive scheme</td>
</tr>
<tr>
<td>22</td>
<td>Crew size and composition</td>
</tr>
<tr>
<td>23</td>
<td>Sequencing problems</td>
</tr>
<tr>
<td>24</td>
<td>Compatibility and consistency among contract documents</td>
</tr>
<tr>
<td>25</td>
<td>Stringent inspection by the engineer</td>
</tr>
<tr>
<td>26</td>
<td>Inspection delay by site management</td>
</tr>
<tr>
<td>27</td>
<td>Accidents as a result of poor site safety program</td>
</tr>
<tr>
<td>28</td>
<td>Labour interference and congestion</td>
</tr>
<tr>
<td>29</td>
<td>Design complexity level</td>
</tr>
<tr>
<td>30</td>
<td>Site restricted access</td>
</tr>
<tr>
<td>31</td>
<td>Physical fatigue</td>
</tr>
<tr>
<td>32</td>
<td>Proportion of work subcontracted</td>
</tr>
<tr>
<td>33</td>
<td>Lack of recognition program</td>
</tr>
<tr>
<td>34</td>
<td>Inspection delay by the engineer</td>
</tr>
<tr>
<td>35</td>
<td>Confinement of working space</td>
</tr>
<tr>
<td>36</td>
<td>Working overtime</td>
</tr>
<tr>
<td>37</td>
<td>Site layout</td>
</tr>
<tr>
<td>38</td>
<td>High Temperature</td>
</tr>
<tr>
<td>39</td>
<td>Owner's representative intervention with site management and operatives</td>
</tr>
<tr>
<td>40</td>
<td>Lack of providing labour with transportation</td>
</tr>
<tr>
<td>41</td>
<td>Lack of suitable rest area offered to labour on site</td>
</tr>
<tr>
<td>42</td>
<td>Unsuitability of storage location</td>
</tr>
</tbody>
</table>

### 4.6 Overview of Productivity Categories

Table 7 shows the ranking of the productivity categories and their corresponding average RII. The Human/Labour group recorded the highest average RII score of 83.33,
this underlined how important the attributes of workers are to productivity. The common perception is that a more skilled and experienced workforce would require less instruction. Management attained the second highest RII score (i.e., 76.47). Management is needed to coordinate execution of projects and provide leadership. Their ability to extract the best out of labour is vital.

Table 7. Ranking of Productivity Categories

<table>
<thead>
<tr>
<th>Rank</th>
<th>Group</th>
<th>Average RII (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Human/Labour</td>
<td>83.33</td>
</tr>
<tr>
<td>2</td>
<td>Management</td>
<td>76.47</td>
</tr>
<tr>
<td>3</td>
<td>Technological</td>
<td>75.57</td>
</tr>
<tr>
<td>4</td>
<td>External</td>
<td>75.00</td>
</tr>
</tbody>
</table>

5. Conclusion and Recommendations
There are low levels of construction labour productivity in T&T. The investigation into the origins of these deficiencies and assessment of their effect could assist in solving the problem. Moreover, an appreciation of the major factors contributing to the shortfalls gives the construction industry impetus to direct its attention.

Survey instruments used in conjunction with the RII have been proven to reduce bias and simplify data for use in analysis. This survey revealed the ten leading factors affecting construction labour productivity in T&T. These are: 1) the lack of labour supervision, 2) unrealistic scheduling and expectation of labour performance, 3) shortage of experienced labour, 4) construction manager's lack of leadership, 5) skill of labour, 6) delay in responding to requests for information, 7) payment delay, 8) communication problems between site management and labour, 9) rain and late arrival, 10) early quit and frequent unscheduled breaks.

Construction firms must pay closer attention to grooming management personnel in order to develop communication with the workforce and minimise cost leakages. Improvement of workforce motivation is twofold, internal (i.e., human resource management) and external (i.e., standardised labour benefits/job security), a concerted effort is needed to address labour concerns. Besides, the labour force must be held accountable for work done while opportunities must be available to improve the skill of labour.

Several recommendations are made. These are, firstly, to provide training/education opportunities for labour in T&T. The training currently available is inadequate, the state must partner with industry to provide facilities and apprenticeship programmes whereby contractors have direct input in developing the skills required at industry standards. This would reduce rework and build labour experience.

Secondly, this is to improve salary structure, incentives and benefits. Adequate and prompt remuneration in addition to appraisal systems embracing quality, schedule milestones and commensurate rewards must be used. Contractors and labour unions must agree, so these measures can be meaningfully pursued.

Moreover, overtime work is the common means of schedule acceleration. This practice is not always beneficial as it is known to increase absenteeism, lower morale and decrease safety (Horner and Talhouni, 1995).

Scheduled overtime, where permanent extension of the work week is adopted must be disbanded and occasional overtime (random increase in work hours) used. Though overtime is not documented to improve productivity, occasional overtime has a lesser negative effect than scheduled overtime (Rifat, 2007). Kazaz and Ulubeyli (2007) demonstrate the importance of insurance and health benefits to labour as security in retirement gives them serenity to continue with their jobs. Offering vertical mobility and permanent employment with a firm sets individual goals for workers, prompting competition and personal development but it may not be available to immigrant labour.

Thirdly, this is to improve supervision/management. Management frequently complains about labour’s inability to operate without instruction and constant monitoring. Conversely, labour is not fond of relentless supervision and begins to loathe observation of their activities. Kazaz and Ulubeyli (2007) explained that delegating duties for specific tasks improves productivity by developing accountability and pride in individuals. Workers and management must be kept abreast of arising issues and involved in the problem solving process one must note however, that too much labour participation has been observed to weaken management’s leadership role.

Management should provide a safe and productive environment, provision of amenities such as personal protective equipment (PPE), modern tools, restroom and canteen facilities lift morale. These items should be standard on the job-site with ample upkeep of services. Poor scheduling and material management can hinder the pace of work as labour exploits insufficient supplies of material and slows output in anticipation of a delivery (Kazaz et al., 2008). Similarly, labour efficiency is reduced by deviations from its normal flow (Kazaz et al., 2008) thus leadership on-site must be suitably skilled to handle these problems as they occur.

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Effect of Bagasse Fibre Reinforcement on the Mechanical Properties of Polyester Composites

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Abstract: The use of natural fibres for the reinforcement of polymers intended for different applications has been on the increase in the recent years due to its advantages. In this study, bagasse/sugarcane (Saccharum officinarum) fibre was used to reinforce unsaturated polyester material in order to assess the viability of the composite materials developed for engineering applications. Sugarcane fibres gotten from the farm plantation were purified by washing thoroughly with water followed by sun drying and pulverizing. The particles were then sieved into 75 µm and added to the polyester in predetermined proportions of 5, 10, 15 and 20 weight percent (wt%) for the production of the composites. Mechanical tests (tensile and hardness) were carried out on the samples from where it was observed that the reinforcement was able to enhance the mechanical properties of the developed composites with a verge point value of 10 wt% reinforcement.

Keywords: Bagasse fibre; particulate; reinforcement; unsaturated polyester; mechanical properties

1. Introduction

A fibre-reinforced polymer (FRP) is a composite material consisting of a polymer matrix imbedded with high-strength fibres, such as glass, aramid and carbon (Groover, 2004). Generally, polymer can be classified into two classes, thermoplastics and thermosettings. Thermoplastic materials currently dominate, as matrices for bio-fibres; the most commonly used thermoplastics for this purpose are polypropylene (PP), polyethylene, and poly vinyl chloride (PVC); while phenolic, epoxy and polyester resins are the most commonly used thermosetting matrices (Malkapuram, et al., 2008). In the recent decades, natural fibres as an alternative reinforcement in polymer composites have attracted the attention of many researchers and scientists due to their advantages over conventional glass and carbon fibres.

Polyester is classified in the group of general purpose thermoset which are characterised by having average mechanical properties, lower resistance to temperature, higher coefficients of expansion and low cost/commodity-like production and sales. The overall cost can be reduced either by finding a less expensive processing method or by blending the polymer with low cost filler materials. In order to improve the mechanical, physical and other properties, or to tailor a composite for a specific use or to facilitate processing and reducing the cost, natural fibers have been used as reinforcing or filler materials. The advantages of plant fibers are low cost, low density, acceptable specific strength, good thermal insulation properties, reduced tool wear, reduced respiratory irritation, renewable resource and recycling possible without affecting the environment (Husseinsyah and Mostapha, 2011). Fibres of this type, for instance, hemp and flax, are successfully used as packaging material, interior panels in vehicles, and building components, among others.

Moreover, natural fibres like banana, sisal, hemp and flax, jute, coconut, sponges, bamboo, wood dusts and oil palm (Idicula et al., 2005; Jacob et al., 2004; Hautala et al., 2004; Chand and Dwivedi, 2006; Brahmakumar, et al., 2005; Oladele and Adewuyi, 2008) have attracted scientists and technologists for applications in consumer goods, low-cost housing and other civil structures. A number of investigations have also been conducted on several types of natural fibres to study the effect of these fibres on the mechanical properties of polyester matrix composite materials. EL-Tayeb (2008) studied the effect of untreated short baggasse fibre reinforcement on the abrasive wear performance of polyester and the result revealed that wear of SCRP composite was sensitive to variations of load, fibre length and fibre orientation and less sensitive to sliding velocity.

Husseinsyah and Mostapha, (2011) investigated into the effect of filler content on properties of coconut shell filled polyester composites, and the results revealed that increase in coconut shell content led to the increase on tensile strength, Young's modulus and the water absorption. Oladele, (2013) investigated the effect of bone ash and bone particulate reinforced polyester composites for biomedical applications and established that the tensile and flexural properties were enhanced. Fibre-filled commodity thermoplastics were first introduced into the market with the intention of producing a range of new materials for lightly stressed engineering applications (Brahmakumar, et al., 2005).

Recently, natural fibres have proved to be effective
reinforcement as simple fillers in thermoplastic and thermoset matrix composites for automotive sectors (EL-Tayeb, 2008). This work was carried out to investigate the effect of bagasse/sugarcane fibre particle addition on the mechanical properties of unsaturated polyester material. Bagasse fibres are usually regarded as agricultural waste after the extraction of the sugar content. However, they are now being utilised for engineering application in this work so as to turn waste to wealth.

2. Materials and Methods

The main materials that were used for this work are as follows; unsaturated polyester resin procured from Pascal Chemical store in Akure, Ondo State, Nigeria.

The starting material for a thermo set polyester matrix is an unsaturated polyester resin that contains a number of \( \text{C} = \text{C} \) double bonds. Unsaturated polyesters refer to that family of polyesters in which the backbone consists of alkyl thermosetting resins characterised by vinyl instauration as a result of these structure, they are highly reactive. Bagasse/sugarcane (\textit{Saccharum officinarum}) Fibre with its constituent as shown in Table 1, Ethyl Ketone Peroxide (MEKP) was used as the catalyst, Cobalt 2% in solution was used as the accelerator, polyvinyl acetate was used as the mould releasing agent and ethanol as a cleaning/washing agent.

<table>
<thead>
<tr>
<th>Table 1. Constituent of Bagasse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constituent</td>
</tr>
<tr>
<td>Moisture</td>
</tr>
<tr>
<td>Fibre</td>
</tr>
<tr>
<td>Soluble Solids</td>
</tr>
<tr>
<td>Cellulose</td>
</tr>
<tr>
<td>Hemicelluloses</td>
</tr>
<tr>
<td>Lignin</td>
</tr>
</tbody>
</table>

2.1 Material Preparation

Sugarcane plant that was grown for one and half years was used in this work. The bagasse fibre after the extraction of the sugar content was procured from the farm plantation. The fibres were washed with water so as to remove both excess sugar and dirty particle that might have stick to the fibres and sundried for 4 weeks before pulverizing using Denver laboratory ball mill. The particles from the process were sieved with sieve shaker 16155 Model into 75\( \mu \)m sieve size.

2.2 Mould Production

Tensile mould of gauge length 25 mm of a dumb-bell shape was used for the production of tensile samples.

2.3 Production of Composites

To develop the composites, 1g each of catalyst and accelerator was added to 100g of the unsaturated polyester resin. The bagasse in the particulate form was varied in a predetermined proportion of 5, 10, 15 and 20 weight percent (wt%), respectively. The mixture was stirred for about 5-7 minutes until there is proper wetting and soaking of the particles by the polyester resin. The homogenous slurry is poured into the mould and allowed to cure at room temperature before it is removed. The curing rate for each sample was taking and recorded before they are stripped from the mould. The stripped samples were allowed to cure further at room temperature in the laboratory for 28 days before the mechanical tests were carried out.

2.4 Mechanical Testing of Cast Samples

Following the moulding of the composites, samples were prepared for tensile and hardness tests. These tests were carried out as follows:

1) Determination of the tensile properties of the materials - In the present study, tensile tests were performed on INSTRON 1195 at a fixed Crosshead speed of 10 mm min\(^{-1}\). Samples were prepared according to ASTM D412 (ASTM D412 1983), and tensile strength of the standard and conditioned samples were calculated.

2) Determination of the hardness property of the materials - The samples were indented using micro hardness tester following ASTM procedure No.D2240. The reading is noted from the calibrated scale. Five readings were taking for each sample and the average value was used.

3. Results and Discussion

Figure 1 shows the result of the ultimate tensile strength (UTS) property for the various samples produced. It was observed from the results that the UTS increases as the fibre weight content increases up to a threshold point of 10 wt% before experiencing depreciation. This is essentially likely to happen because as the fibre content increases, the tendency for the fibre/matrix bonding strength to decrease is high. As shown, 5-10 wt% reinforcement gave better results than 15-20 wt% because at low fibre content, the bagasse fibres are wetted properly by the polyester and there is little or no fibre touching one another.

![Figure 1. Variation of the Ultimate Tensile Strength against Fibre Weight Content](image-url)
However, at higher fibre content, the reverse was the case, the fibres are touching one another thereby reducing proper fibre wetting and bonding between the bagasse fibre and the polyester matrix. This actually leads to the reduction of the strength of the composites at this higher fibre content. The results show that the unsaturated polyester matrix had a value of 10.01 N/mm$^2$ while sample with 10 wt% had 23.68 N/mm$^2$.

The result of the effect of fibre content on the tensile modulus was shown in Figure 2 where similar trend to that of the UTS was observed. However, there is slight different in the trend as the modulus for the 15 wt% bagasse reinforced sample has higher value than the 5 wt% reinforced sample. The tensile modulus for 10 wt% reinforced sample emerges as the best with a value of 913.73 N/mm$^2$ compared to unreinforced polyester matrix with a value of 318.30 N/mm$^2$.

Figure 3 shows the tensile strain result. It was observed that the unreinforced polyester material has the highest tensile strain property of 3.72 % followed by 5wt% fibre content reinforced sample with a value of 1.39 %. It was observed that the tensile strain property reduces as the fibre content increases from 5-20 wt%. The sugarcane fibres have provide reinforcement effect in polyester matrix because the stiffer the material, the greater the strength and modulus as revealed in Figures 1 and 2, and hence the lower the tensile strain.

Figure 4 shows the variation of hardness property with the samples. It was noticed that the reinforcement leads to the enhancement of hardness property in all the samples produced. The trend was similar to the UTS result. This shows that both the UTS and the hardness were enhanced in the same manner.

The result shows that 5-10 wt% reinforced samples gave the best hardness property where the 10 wt% reinforced sample marginally exceed 5 wt% reinforced sample with values of 75.51 MPa and 72.57 MPa respectively compared to unreinforced polyester matrix with a value of 30.40 MPa. Enhancement of mechanical properties was possible due to adequate wetting and bonding between the sugarcane fibre and the polyester. This was in agreement with the work of El-Tayeb, (2008). It was noticed that microscopic observation evidenced that sugarcane fibre (SCF) has the ability to have a fairly good bonding with polyester matrix. This in turn made the separation of fibre from the composite more difficult, and also contributed to improvement of wear resistance for chopped bagasse/polyester composite.

Figure 5 shows the variation of curing time with the samples. From the results, it was observed that curing rate increases as the fibre content increases. Curing rate is a parameter that can determine and influence the rate of production. The result shows the addition of bagasse fibre brings about rapid curing, and hence save time and resources compared to the unreinforced polyester. While it takes 1 hour for 15-20 wt% fibre content sample to cure, it takes 24 hours for the unreinforced sample. Sample with 10 wt% fibre content displayed best mechanical properties. It takes 2 hours to cure which is also commendable.

4. Conclusion

The use of bagasse/sugarcane fibre particles as reinforcement in unsaturated polyester matrix brings about
improvement in the mechanical properties. Hence, by investigating the effect of bagasse fibre addition on the mechanical properties of unsaturated polyester material, it was interesting to note that the reinforcement yielded several promising results. These are:

1) There is enhancement in the mechanical properties of the reinforced polyester composites up to threshold point of 10 wt% bagasse fibre loading.

2) Bagasse particulate fibre in the range of 5-10 wt% gave the optimum results which show that low fibre weight content is good for better enhancement of properties.

3) Curing rate increases as the bagasse fibre content increases which implies that, curing rate for polyester material is improved by the addition of bagasse fibre thereby leading to increased production rate.

References:


Author’s Biographical Notes:

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Investigating into Automated Filler Solutions in Manufacturing: A Case Study

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Abstract: Automated manufacturing systems are regarded as highly efficient potentially improving the competitiveness of manufacturing companies. However, the extent to which automation is selected for carrying out manufacturing tasks varies with the production conditions. This paper presented main findings of case study that investigated into the need for automating a filler to tackle the problems occurring upstream of the production at a manufacturing plant in Trinidad and Tobago. The manual air blowing and loading of miniature bottles onto the production line created a “pile up” problem at the filler since manual loading was slower than the capacity of the filler. The downtime records showed that manual air blowing and loading were the main reasons. Methods of automating the filler speed to accommodate manual air blowing and loading were analysed, and alternatives of solutions were devised. The recommendation was made for the plant to automate the filler with a Programmable Logic Controller system, comprising of an indicator light, three sensors, a bottle stopper, a variable frequency drive and a manual/automatic selector switch. The system would automate the control of the filler speed on the line, resulting in greater operating efficiencies and lesser wear and tear of the filler.

Keywords: Filler, automation, operating efficiencies, manufacturing, Trinidad

1. Introduction

It is important for factories to find the appropriate level of automation to use for the best system performance and integration in their environments. Some environments lend themselves to fully automatic systems while others do well with semi-automatic systems which involve the use of humans for some of the tasks related to the production. Recent research has shown the importance of integrating humans and technology in manufacturing automation thus supporting sustainable manufacturing systems (Lindstrom and Winroth, 2010). The relationship between humans and technology can be viewed as a continuum from fully manual to fully automatic by approaching the sharing of tasks between the human and technology (Frohm, 2008). This concept is called levels of automation (LoA). It is essential that LoAs be determined within factories for robust production systems.

An urgent need exists in Trinidad and Tobago (T&T) to assess opportunities for development in the manufacturing sector. It is expected to provide a more stable economy and offer sustainable development in the absence of the energy sector (Chowdary, 2009). This paper discusses on manufacturing automation and derives a method to determine the level of automation required for a manufacturer and exporter to use on its production lines. Determining LoAs is especially important in manufacturing industry since budgets and performance are always a concern. In T&T, decisions regarding automation tend to be rather of an ad hoc nature than planned activity and there are no support systems guiding decisions. Thus, there is a need for developing tools to determine the level of automation required in factories.

Two dominant motives for determining the appropriate level of automation are those of achieving a cost-effective manufacturing process and of reducing the negative effects of working environments that can be a danger to health. If the automation level selected is too low, salary costs are high in relation to equipment costs and at the same time the production rate tends to be low, however a low automation level often results in a high degree of flexibility. If the automation level is too high on the other hand, equipment costs are high in relation to salary costs and at the same time the production rate tends to be high as well.

A production system with a high automation level requires that a high production level be achieved in order for it to be particularly profitable (Windmark et al., 2012). It is thus necessary to consider the manufacturing situation at hand to make decisions regarding full or partial automation. In this context, the approach used in this paper involved:

1) Reviewing the literature with respect to automation and manufacturing strategy.
2) Collecting and analysing the data for the case process with respect to line process and production, downtime and reasons for such and the current equipment and
3) Proposing two automated designs and recommending a final choice given the manufacturing situation, and
4) Proposing a method for the choice of the degree of automation for local plants.

2. Literature Review
Automation in the context of manufacturing often refers to the mechanisation and integration of the sensing of environmental variables, which is done through data processing, communication of information, and decision-making (Sheridan, 2002).

The reasons for automating can be viewed from different perspectives, either from a company perspective or from the perspective of the engineering manager or production system designer, who pays special attention to human factors when automating. According to Groover (2001), there are nine reasons for automating from the perspective of a company where productivity is in focus. Besides, Wickens et al. (2004) advocate the human factors view and suggest four reasons for system designers to automate to support or replace human work (see Table 1).

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase labour productivity</td>
<td>Impossible or hazardous work for humans</td>
</tr>
<tr>
<td>Reduce labour costs</td>
<td>Difficult or unpleasant work for humans</td>
</tr>
<tr>
<td>Mitigate the effect of labour shortages</td>
<td>Extension of human capability</td>
</tr>
<tr>
<td>Reduce or eliminate routine manual or clerical tasks</td>
<td>Technical feasibility</td>
</tr>
<tr>
<td>Improve worker safety</td>
<td></td>
</tr>
<tr>
<td>Improve product quality</td>
<td></td>
</tr>
<tr>
<td>Reduce manufacturing lead time</td>
<td></td>
</tr>
<tr>
<td>Accomplish processes that cannot be done manually</td>
<td></td>
</tr>
<tr>
<td>Avoid the high cost of not automating</td>
<td></td>
</tr>
</tbody>
</table>

Sources: Abstracted from Groover (2001) and Wickens et al. (2004)

Today, the resulting requirements for design, setup, and operation of factories become crucial for success. In the past, we often increased the complexity in structures and control systems, resulting in inflexible monolithic production systems. But the future must become “lean” — not only in organisation, but also in planning and technology (Zuehlke, 2010). It is thus important to ensure that the choices made for our systems be appropriate for use.

3. An Automated Filler Solution: A Case
Company TT is a producer of several products ranging from alcoholic and non-alcoholic drinks to sauces in T&T. In the last few years, the company doubled its overall distillation and storage capacity with production levels rising to approximately 20 million litres in 1998. In excess of 95% of the products are exported to consumers worldwide.

There were four (4) packaging lines for the drinks: 1, 2a, 2b and 3 but this work focused on line 2a. Line 2a used rotary vacuum filler which was controlled by both an operator and a mechanic. The operator manually stopped the filler whenever there were insufficient empty bottles on the line upstream of the filler. The mechanic adjusted the filler speed manually depending on how fast the bottles were being loaded. This intermittent stopping of
the filler resulted in increased downtime as well as unhealthy conditions for the filler’s mechanical and electrical components. In addition, the rate of loading of the bottles was dependent on the size of the bottle in production at the start of the day. The case requires a decreased dependency on manual systems and thus provides an opportunity for automating one or more processes on the line.

The data collection and analysis for the case included: 1) Mapping the line process, 2) Identifying the problems associated with the filler, 3) Analysing the reasons for filler downtime, 4) Calculating the line speeds, and 5) Analysing the hourly production.

4.1 Mapping the Line Process

The various line processes practiced on the line were manual air blowing, filling, capping, labelling and packaging. Figure 2 shows a complete process flow chart for the production of miniature (50ml) bottles on Line 2a.

4.2 Identifying Problems with the Filler

Observations on the line showed insufficient bottles upstream to supply the filler. Since this work focused on the upstream end (before and up to the filler) further analysis was then conducted to evaluate the reason for filler downtime.

4.3 Analysing Reasons for Filler Downtime

Downtime was measured for two hours (10 am to 11 am and 1pm to 2pm) every day. It was found that manual loading was a major cause of downtime for the stopping of the filler as seen from Figure 3 since it accounted for nineteen (19) minutes of downtime every hour.

4.4 Calculating the Line Speeds Before the Filler

Speed before the filler was calculated using the following formula:

\[
\text{Speed (bottles/min)} = \frac{\text{Distance (m)}}{\text{Time (s)}} \times \frac{1}{60}
\]

Figures 4 and 5 indicate that the speed before the filler for week 1 was consistent averaging at 94.1 to 94.3 bottles per minute. Week 2 averaged 94 bottles per minute. These are both below the capacity of the filler – 106 bottles per minute.

---

**Figure 2.** Complete Process Flow Chart for the Production of Miniature (50ml) Bottles on Line 2a

**Figure 3.** Frequency of Downtime Causes for Line 2a

**Figure 4.** Speed Values of Week 1
4.5 Analysing the Hourly Production Targets

Hourly production targets were seldom met throughout production runs. Figure 6 shows that the hourly production values for Line 2a recorded for days speed values were calculated. One of the causes for not making these targets was the downtime of the filler.

5. Technical Feasibility of Equipment and Manpower

Prior to designing any new automation system, it was necessary to examine the company’s existing machinery and make decisions as to how many adjustments could be made to the existing equipment in order to automate. For this case, it was necessary to understand the existing system to evaluate the technical feasibility of proposals. Specifically, these included:

1) Whether the filler speed could be adjusted – Tests showed that the USB filler could be adjusted to fill as slowly as eighteen (18) bottles per minute.
2) Whether the filler motor would work with a variable frequency drive (VFD) which is needed for the filler speed adjustment: i) It was found that the filler had an AC motor which could facilitate a VFD (AIC, 1995), and ii) The motor was not directly coupled to the gearbox and there is a crank which changes the distance between the motor pulley and the gearbox pulley which will set the filler speed.
3) Whether the bottles would remain in place on the conveyor with an adjustment of the filler speed (observations indicated that they would).

Additionally, interviews with the staff revealed that they had knowledge of automated systems inclusive of Programmable Logic Controllers (PLCs), sensors and motors. The existing machine and manpower components were satisfactory for recommending automation proposals.

6. Design Proposals for Filler Solution

6.1 Choice of Two Alternative Design Concepts

Having regards the operations at Company TT, two design proposals are explored to solve the problem of the operator having to start and stop the filler which included automation. Two alternatives of design concepts are developed. Alternative 1 deals with the condition where bottles are stopped. Figure 8 shows the control system for the alternative. Its major components are described below:

- 1 Red Light at the loading point.
- 2 Reflective Sensors placed between the loading point and the start of the worm wheel - at 5.45m (171 bottles) and at 3.9m (123 bottles) from the start of the worm wheel.
- 1 Photo Eye Sensor placed at 2.35m (74 bottles) from the start of the worm wheel.
- 1 PLC with eight (8) inputs and eight (8) outputs.
- 1 Variable Frequency Drive with at least two (2) inputs. (It should be noted that VFDs usually come with five inputs).
- 1 Bottle Stopper - This device consists of a directional control valve (DCV) which regulates the air flow to a pneumatic cylinder. The PLC accepts the input of the photo eye sensor (no bottles passing) and sends its output to the directional control valve. Opening the valve will extend the cylinder which in turn will cause an arm to close and tighten around passing bottles preventing them from moving into the worm wheel.

- 1 Manual / Automatic Selector switch. In ‘Manual’ the operator can start the filler, allow the operations to ‘settle’ (for e.g. alcohol strength tests) and then switch to automatic mode with the light as well as the sensors slowing the filler speed if necessary and activating the bottle stopper.

Specifications for this design included efficiency, maintainability, ease of use and automatic capacity. Using Pugh’s matrix, it was found that Alternative 1 should be chosen due to a higher score.

6.2 Choice of Degree of Automation for Filler in Manufacturing

This case used a method to choose the degree of automation that could possibly be used at local plants for similar situations. The method involved:

1) Identification of the specific problem at the level at which it is occurring and its relation to the system as a whole – i.e., the problem within the manufacturing environment. This includes collection of the relevant plant data, and analysis of the data to show that the problem is recurring and causing other issues downstream or upstream of a line.

2) Assessment of the current situation on equipment (i.e., technical feasibility) and staff knowledge.

3) Proposal of automated solutions - i.e., at least two recommendations for evaluation.

4) Evaluation of designs - i.e., to create list of specifications via which to evaluate, and utilise a known design method to evaluate designs, and

5) Evaluation by management – i.e., to determine whether the recommendation fits with their manufacturing strategy.

7. Discussions

The literature states that there are many factors that affect the use of automation in the industry which include the type of product, the production quantity and rate of production required, the particular phase of the manufacturing operation to be automated, the level of skill available in the workforce, the reliability and maintenance problems associated with automated systems and the economics of the process. For this situation, it is clear that one of the major factors influencing the decision is the rate of production required as the automating of the filler would improve the throughput of the line in its current state and even when the air blowing is itself automated.

The analysis shows that an important phase in the manufacturing process is being affected, upstream of the line, as is evident by the downtime chart in Figure 3. The consideration of the level of skill available in the workplace was addressed by interviewing the operators and it was found that they were familiar with PLC systems (the chosen processor) as they occur elsewhere in the plant. They would be able to both operate and maintain any associated equipment for the necessary changeover.

Lastly, the economics of the process was examined and even though there was a considerable cost, the decision would be based on all the factors that were affecting the efficient manufacturing and on time delivery.
From the work done, it was found that decisions regarding manufacturing automation should be made in a more structured manner with the decisions following some known process. The proposed process could be modified for across plant decisions.

8. Conclusion

Based on the findings of this case, it could be concluded that the method for determining the LoA should:

1) review the specific problem in reference to the entire factory, should include data collection and analysis over at least six (6) months,
2) assess the current situation in terms of adapting old equipment and the technical feasibility and using existing staff with the requisite knowledge,
3) consider at least two proposals with a known design method being used to choose the best design, and
4) be evaluated by management to see how it fits in with their manufacturing strategy.

The method relies on data, known design techniques and alignment with the overall manufacturing strategy of the studied plant. It takes into account the evaluation of manufacturing environment, the level of skill and the maintenance required for the new automated systems. The alignment of the manufacturing strategy with the automation decisions is especially important for SMEs in T&T.

References:

AIC (1995), Lowerator for Angostura Limited, Alliance Industrial Corp, Trinidad and Tobago

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Analysis of Gas Expansion Required for Hydrate Formation

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Abstract: Natural gas hydrate technology provides an attractive method to capture and transport natural gas on a small scale utilising a conceptual floating hydrate formation vessel. Expansion of the gas from wellhead conditions is necessary to trigger hydrate formation and this depends on the properties of the gas. Therefore, gas from the well is passed through an expander to lower the temperature and pressure suitable for hydrate formation. Hence, for capturing natural gas from the wellbore, expansion would be used to expand the gas to new pressure and temperature values that represent the inlet conditions to the hydrate formation vessel. The expander is useful to extract energy from gas stream and thereby reducing temperature and pressure of the gas stream to hydrate formation conditions (600 psia and 35°F). The expansion process must also ensure the gas sample remains in the single phase region of the phase diagram, which is important in the design process. If the gas goes into the two-phase region of the envelope, then additional gas separation would be required before formation of natural gas hydrate. This expansion process will be evaluated in the analysis using the selected samples: dry gas sample which is 99% methane and sample 2 which has heavier components up to C6. Results show that the expansion efficiency required to obtain the natural gas at 35°F may vary from sample to sample. In this case, for dry gas sample, 85% efficiency was required, whereas 90% efficiency was needed for sample 2. Some commercial expanders can have up to 90% expansion efficiency.

Keywords: Natural gas hydrate, formation vessel characteristics

1. Introduction

It may be possible that gas hydrate can provide an easier to produce, safer and cheaper to store method of capturing natural gas when compared to other transportation modes such as CNG and LNG (Rajnauth et al., 2008). It is the belief of many researchers that it is possible to form natural gas hydrate from gas as soon as it comes out a well. This is quite different from forming natural gas hydrate from a storage source or pipeline source, simply because the pressure and temperature of the gas is different. Natural gas hydrate has never been formed from a flowing natural gas well. Therefore, since the intention is to form natural gas hydrate directly from the natural gas streams obtained directly from gas wells, one has to consider if the conditions are right for this. The conditions recommended for hydrate formation are 600 psia and 35°F.

Hence, there is the need to expand the gas from the high pressures and temperatures coming from the well to conditions suitable for hydrate formation (as shown in Figure 1) with the hydrate formation vessel at the well site. The intention of this paper is to look at the expansion process required to form natural gas hydrate. The proposed expansion process will be discussed using two representative gas samples (‘Dry gas’ and ‘Sample 2’). The former is basically pure methane, whereas sample 2 has the heavier C₃ and C₆ components (Rajnauth et al., 2013). It is assumed that these gases are produced from a given field, at a given rate which is typical of offshore gas wells. Table 1 shows the natural composition of the gas samples used in this paper (Mole %). Besides, the PVTsim programme (Calsep, 2008) was used for the evaluation of expansion processes in this study.

Table 1. Natural Composition of the gas samples used (Mole %)

<table>
<thead>
<tr>
<th></th>
<th>N₂</th>
<th>H₂S</th>
<th>CO₂</th>
<th>C₁</th>
<th>C₂</th>
<th>C₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Gas</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>99.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Sample 2</td>
<td>0.78</td>
<td>0.00</td>
<td>2.84</td>
<td>92.04</td>
<td>2.82</td>
<td>0.74</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>iC₄</th>
<th>nC₄</th>
<th>iC₅</th>
<th>nC₅</th>
<th>C₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Gas</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Sample 2</td>
<td>0.14</td>
<td>0.21</td>
<td>0.10</td>
<td>0.08</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Figure 1. Design concept showing the need of an Expander
2. Expansion Concept

Turboexpanders (2010) offers the high power level, operating temperature and pressure ratio solutions for energy recovery and refrigeration. The need of the expander in this study is to extract energy from gas stream and hence reduce the pressure and temperature required for hydrate formation. The work the gas performs in the expander is gained from its enthalpy and the gas cools in the expander.

For an ideal case, the isentropic process (no change in entropy and 100% efficient), \( \Delta S = 0 \) and \( W = \Delta H \).

For non ideal case,

\[ W = \Delta H - T \Delta S \]

\[ \Delta S = \frac{1}{\gamma} dH - \left( \frac{T}{\gamma} \right) dp \]

The efficiency of the expander is related to the enthalpy by the following expression:

\[ \Delta H = \frac{S}{T_2} \]

where

- \( T_2 \) - output temperature after expansion
- \( T_1 \) - initial temperature
- \( \eta \) - expansion efficiency

For different expansion efficiencies the output temperatures are different. The Horse Power developed by the expander (Simms, 2009) can be estimated by:

\[ \text{Horse Power} = \Delta H \times w \times \eta \]

where \( w \) is the gas flow rate

The expansion process must also ensure the gas sample remains in the single phase region of the phase diagram, which is important in the design process. From the wellhead, the gas flows through a turbo-expander, which causes the gas temperature to drop to 35 °F, and the pressure to drop to 600 psia, assuming an efficiency of 85% or 90% depending on the sample.

The power developed by the expander and the outlet temperatures are shown in Table 2. The data were obtained from the commercial simulator (Calsep, 2008). An efficiency of at least 85% is required to obtain an outlet temperature of 35 F, required for hydrate formation. This generates 1.01 x 10^7 Btu of energy. Below is a sample calculation of power from the expander:

\[ \text{Power} = \Delta h \times w \times \eta \]

where:

- \( \Delta h \) = change in enthalpy, btu/lbmole,
- \( w \) = flow rate, lbmole/hr
- \( \eta \) = expander efficiency, %.

For an 85% efficiency,

\( \Delta h = 903.1 \text{ btu/lbmole and } w = 550 \text{ lbmole/hr} \)

\[ \text{Power}_{\text{expander}} = 422199.3 \text{ Btu/hr} \]

Some commercial expanders can have up to 90% expansion efficiency (TurboExpander, 2010).

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>100%</th>
<th>95%</th>
<th>90%</th>
<th>85%</th>
<th>80%</th>
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</thead>
<tbody>
<tr>
<td>Inlet, Enthalpy, Btu/lb-mol</td>
<td>574.7</td>
<td>574.7</td>
<td>574.7</td>
<td>574.7</td>
<td>574.7</td>
</tr>
<tr>
<td>Outlet, Enthalpy, Btu/lb-mol</td>
<td>-487.8</td>
<td>-434.6</td>
<td>-381.5</td>
<td>-328.4</td>
<td>-275.3</td>
</tr>
<tr>
<td>Change Enthalpy, Btu/lb-mol</td>
<td>1062.5</td>
<td>1009.3</td>
<td>956.2</td>
<td>903.1</td>
<td>850</td>
</tr>
<tr>
<td>HP, Btu/hr</td>
<td>584375</td>
<td>527359.25</td>
<td>473319</td>
<td>422199.3</td>
<td>374000</td>
</tr>
<tr>
<td>Outlet Pressure, psia</td>
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<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Outlet Temperature, F</td>
<td>19.4</td>
<td>25</td>
<td>30.3</td>
<td>35.5</td>
<td>41.3</td>
</tr>
</tbody>
</table>

3. Gas Expansion Analysis

Below are the steps used in the analysis of gas expansion prior to hydrate formation:

(i) To achieve the hydrate formation conditions (600 psia and 35°F), expansion process was evaluated by the commercial simulator (Calsep, 2008).

(ii) Phase envelopes were obtained for all samples using a commercial simulator (Calsep, 2008).

(iii) The actual wellhead conditions of two selected samples were used in this analysis.

(iv) The simulator was used to determine the temperature of gas after expansion with a fixed hydrate formation pressure (600 psia).

(v) Pressure and Temperature of gas after expansion is plotted on the phase envelope diagram to indicate the phase at this time.

3.1 Dry Gas Sample Analysis

The process flow in Figure 2 illustrates the expansion of dry gas from one producing well to hydrate formation conditions. The wellhead conditions are considered to be 1,750 psia and 168°F. From the wellhead, the gas flows through a turbo-expander, which causes the gas temperature to drop to 35°F, and the pressure to drop to 600 psia, assuming an efficiency of 85% (note that some commercial expanders can exhibit up to 90% efficiency). These new pressure and temperature values represent the inlet conditions to the hydrate reactor vessel.

Figure 3 shows the expansion process with corresponding energy exchange for the ideal process (isentropic and 100% efficient) and for the actual process at various expander efficiencies. On the secondary axis of
the graph is the outlet temperature that corresponds to a given efficiency. The figure presents the variation in enthalpy and entropy for the expansion process considering several expansion efficiencies. At 100% efficiency (Isentropic process), entropy is constant but the value increases as efficiency decreases. The work the gas performs is gained from its enthalpy and the gas cools rapidly in the expander. The key in the expansion process is to ensure the gas remains in the gaseous phase.

Figure 2. Expansion Process Flow for the Dry Gas Sample

The power developed by the expander and the outlet temperatures are shown in Table 3. An efficiency of at least 85% is required to obtain an outlet temperature of 35°F, required for hydrate formation. This generates 1.01 x 10^7 Btu of energy. Below is a sample calculation of power from the expander.

\[ \text{Power} = \Delta h \times w \times \eta_e \]

Where:
\[ \Delta h = \text{change in enthalpy, btu/lbmole}, \]
\[ w = \text{flow rate, lbmole/hr} \]
\[ \eta_e = \text{expander efficiency, %} \]

For an 85% efficiency,
\[ \Delta h = 903.1 \text{ btu/lbmole and } w = 550 \text{ lbmole/hr} \]
\[ \text{Power} = 422199.3 \text{ Btu/hr} \]

Figure 4 shows the phase diagram for Dry Gas sample, with the wellhead and outlet conditions for varying expansion efficiencies. It can be seen that gas remains in the gas phase region during the expansion process. Note that this sample is mainly pure methane and does not exhibit a phase envelope.

3.2 Analysis of Sample 2
The process flow in Figure 5 illustrates the expansion of Sample 2 gas to hydrate formation conditions. The actual wellhead conditions in this case are 1,800 psia and 173°F which is slightly different from the Dry Gas Sample. The expansion turbine extracts the potential heat energy from the gas, causing it to cool drastically from 173°F to 35°F. The expansion process is shown in Figure 6.

The power developed by the expander and the outlet temperatures are shown in Table 4. At least 90% efficiency is required to have an outlet temperature of 35°F required for hydrate formation in this case. This generates 1.29 x 10^7 Btu of useful energy. Hence, Figure 7 shows the phase diagram for the Dry Gas sample with wellhead and outlet conditions, and with varying expansion efficiencies. It is to note that at 100% efficiency, the gas is very close to the two-phase region. For 90% efficiency, the gas however remains in the gaseous state.
4. Discussion and Conclusions

Based on the study findings, it is concluded that the expansion process yields useful energy that can be used in many ways, including power generation. Besides, the expansion efficiency required to obtain the natural gas at 35°F may vary from sample to sample. In this case, for dry gas sample, 85% efficiency was required, whereas 90% efficiency was needed for sample 2. Some commercial expanders can have up to 90% expansion efficiency and therefore can be used for expansion of both gas samples prior to formation of a hydrate. If however the efficiency of the expander is below 85%, then this expander may not be applicable for this process. Furthermore, the expansion process ensured that both the dry gas sample and sample 2 remain in the single phase region of the phase diagram, which is important in the design process.

The use of an expander is very important if natural gas hydrate is formed directly from the natural gas streams of gas wells. The expander would extract energy from the gas stream thereby reducing temperature and pressure to hydrate formation conditions. Commercial expanders have up to 90% efficiency. The expansion efficiency required for different samples is different. For sample 2, 90% efficiency was required while the dry gas sample required an efficiency of 85%. Therefore, the selected expander efficiency must allow the expansion of the gas to the required hydrate formation conditions. The power developed by the expander is of the magnitude 4.2 x 10^5 Btu/h.

References:


Author’s Biographical Notes:

Jerome Rajnauth is presently a Reservoir Engineer with the Petroleum Company of Trinidad and Tobago, having received his PhD from Texas A&M University in December 2010 and his MSc and BSc degrees from The University of the West Indies. Dr. Rajnauth has over fifteen years’ experience in various areas of the energy sector having worked in an oil company, a regulatory body of GORTT and a service-oriented company working offshore
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Basic Design Characteristics of a Hydrate Formation Vessel

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Abstract: This paper describes a proposed hydrate formation vessel by exploring some of the basic design characteristics required for an effective and efficient vessel. The purpose of the vessel is to capture and transport natural gas in the form of hydrates. The proposal is to use the same vessel to form the hydrate, being also used for storage and transport to its delivery point. Some important characteristics to consider in the design of “one vessel” concept are the conditions of formation of hydrates, size of the vessel required considering gas production rates of 0.5 to 5 MMscf/d, the level of water and hydrate in the vessel, heat exchange capabilities and insulation needed in the vessel. The “one vessel” concept is very useful in avoiding moving the solid hydrate from vessel to vessel for storage and transportation. This would reduce costs, since no additional facility is needed for dissociation at the final destination, and allow for water re-cycling. Using one vessel for formation, storage, transportation and dissociation of the hydrates gives operational flexibility for temporary storage and transportation. In the absence of pipeline infrastructure, hydrates could be transported in the vessel, by truck, railway or ship.

Keywords: Gas well, hydrate formation, gas expansion

1. Introduction

Natural gas hydrates are ice-like crystalline solids formed from a mixture of water and natural gas subjected to high pressure and suitable low-temperature conditions. The ability of natural gas to form hydrate in combination with water is a very interesting and useful concept (Makagon, 1997). This may be a promising and attractive method of gas transportation. Gas hydrate has a high gas to solid ratio. 1 m³ of hydrate contains 150-180 m³ of gas per m³ of water. To design a vessel used for hydrate formation, storage and transportation, the emphasis would be on upscaling from laboratory experiments. Various aspects of the design of the vessel such as size, heat exchange capabilities and insulation will be discussed. The proposed design of the vessel is for typical production rates from small gas field in the range of 0.5- 5.0 MMscf/d.

Using the ‘one vessel” concept for hydrate formation, storage, transportation and dissociation would provide significant flexibility and cost reduction in capturing and transporting 5 MMscf/d of natural gas to Jamaica (Rajnauth et al., 2013). This vessel concept not only facilitates transportation by sea but also by truck and railway for land transportation.

It is proposed that the same vessel used to form the hydrate be also used for storage and transport to its delivery point. The “one vessel” concept is very useful to avoid moving the solid hydrate from vessel to vessel for storage and transportation, reduce costs, since no additional facility is needed for dissociation at the final destination, and allow water re-cycling. In the absence of pipeline infrastructure, hydrates could be transported in the vessel, by truck, railway or ship. The “one vessel” concept is shown in Figure 1.

The formation of natural gas hydrate yields a high latent heat of formation that must be removed to prevent dissociation. To this aim, the formation vessel could be equipped with heat exchange tubes, extending the full length of the vessel, to facilitate heat transfer from the vessel. The heat exchange tubes not only aid the heat removal process but also: (i) supply heat for later dissociation of hydrate, after formation and storage/transportation, and (ii) provide additional surface area for more effective hydrate formation.

Heat from the surrounding can transfer into the formation vessel and increase its temperature, causing dissociation of the hydrate as it forms. Insulation is therefore necessary to minimize heat transfer with the surroundings.
Some of the reasons for the “one vessel concept” are:
(i) Avoid moving the hydrates to storage and transportation vessel.
(ii) Temporary storage.
(iii) Reduction in facility cost.
(iv) No additional facility cost at the gas destination.
(v) Water can be re-used.
(vi) Reduction in environmental concerns.

It is not the intention here to give further detailed design of vessel since it is out of the scope of this present evaluation. The various design characteristics are discussed below.

2. Upscaling from Laboratory Experiments
This section discusses the condition for upscaling hydrate formation from laboratory experiments which are important in the assumptions of the parameters used in the design of the vessel. Table 1 shows the summary of the comparison between two laboratory experiments and potential upscaling conditions. Experiment 1 used ethane gas with a formation temperature of 38°F and pressure of 366 psia (Zhong and Rogers, 2000).

This experiment had a formation time of 3 hours and a surface area to volume ratio of 0.4. Experiment 2 had hydrate formation conditions of 35°F and 600 psia and used methane gas (Okutani, Kuwabara and Mori, 2008). The formation time in this experiment was 5.75 hours (more conservative) with a 0.4 surface area to volume ratio. In the experiments, the surface area is the internal chamber wall of vessel. The upscaling conditions were assumed to be similar to experiment 2 since the dry gas sample used in this analysis had similar composition (99% methane). Besides, most natural gas samples have significantly more methane than ethane components. It is assumed that in the hydrate process design, the formation conditions will be 35°F and 600 psia, and the surface area to volume ratio of at least 0.4 will be used.

Table 1. Comparison of Hydrate Formation Conditions

<table>
<thead>
<tr>
<th></th>
<th>Experiment 1</th>
<th>Experiment 2</th>
<th>Upscale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td>Ethane</td>
<td>Methane</td>
<td>99% Methane</td>
</tr>
<tr>
<td>Temperature, F</td>
<td>38</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Pressure, psia</td>
<td>366</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Formation Time, hr.</td>
<td>3</td>
<td>5.75</td>
<td>6</td>
</tr>
<tr>
<td>Ratio of Surface Area / Volume</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Figure 2 shows the hydrate PT curve comparison for methane and ethane hydrate used in experiment 1 and 2 and the dry gas sample to be used in the industrial upscaling. It can be seen that both dry gas sample and methane hydrates have very similar PT curves. Also, the formation condition for experiment 1 lies below the PT curves for methane and dry gas sample. Hence these conditions cannot be used for upscaling and thus the hydrate formation conditions of experiment 2 would be used in this analysis for hydrate formation.

In summary, to achieve formation rates similar to laboratory experiment 2, the following was assumed:
(i) A surface area to volume ratio of at least 0.4,
(ii) Similar temperature and pressure (35°F and 600 psia), and
(iii) Similar composition (mostly Methane).

3. Sizing of the Vessel
The rationale for sizing of hydrate vessel is as follows:
(i) Consideration of the expected gas production rates from a well – 0.5 to 5 MMscf/d.
(ii) The size of the vessel must be capable to handle minimum production rate of 0.5 MMscf/d.
(iii) The assumption of length is 3 times diameter that is used for sizing of the vessel. This is typical industry practice.
(iv) To ensure that the surface area to volume ratio of at least 0.4, this ratio is used from the upscaling from laboratory experiments.

For 0.5MMscf natural gas, the total hydrate volume at 600 psia and 35°F is 2,984 ft³. Using the assumption that the length is 3 times diameter, then \( L = 33 \) ft and \( D = 11 \) ft. From \( \frac{nD^2L}{4} = 2984 \)

This vessel gives a surface area to volume ratio of 0.446. Figure 3 shows the side and end views of the proposed hydrate formation vessel. Several possible sizes of vessels were evaluated for various gas production rates to determine the surface area to volume ratio. The only sized vessel that gives the required surface area of at least 0.4 for upscaling is the 11ft x 33 ft cylindrical vessel capable of storing 0.5 MMscf of gas which is commercially available. Therefore, in order to transport 5 MMscf/d, 10 vessel would be required transporting 0.5 MMscf each.
4. Water and Hydrate Levels in Vessel

In the hydrate formation process, gas is pumped into the vessel containing water. It is necessary to estimate the water and hydrate levels in the vessel. It is important that the hydrate does not fill the entire vessel but some space is left at the top (i.e., 3.5%). This would allow gas released during the dissociation process of the hydrate to rise at the top of the vessel and be removed for use at the destination. The water level for hydrate formation and the hydrate level were estimated.

The object is to determine \( x \) which is the height of the water level for hydrate formation (see Figure 4). The following are the steps used to estimate the level in the hydrate vessel as the vessel fills up with water or hydrate (see Figure 5):

(i) Determine the length of the base of the triangle,

\[
\text{base}_t = 2 \sqrt{r^2 - (r - x)^2}
\]

(ii) Area of triangle,

\[
\text{area}_t = \frac{1}{2}bh
\]

\[
\text{area}_t = (r - x)\sqrt{2rx - x^2}
\]

(iii) Use inverse cosine to estimate \( \theta \),

\[
\theta = \cos^{-1}\left(\frac{x}{r}\right)
\]

(iv) Area of sector,

\[
\frac{2\theta}{2\pi} \cdot \text{area}_t = \frac{2\pi}{2\pi} \cdot \text{area}_t = \text{area}_s
\]

\[
\text{area}_s = r^2 \cos^{-1}\left(\frac{x}{r}\right)
\]

(v) Area of hydrate at the end of tank,

\[
\text{area}_h = \text{area}_s
\]

\[
r^2 \cos^{-1}\left(\frac{x}{r}\right) - (r - x)\sqrt{2rx - x^2}
\]

(vi) Volume of hydrate,

\[
1 - \left[r^2 \cos^{-1}\left(\frac{x}{r}\right) - (r - x)\sqrt{2rx - x^2}\right]
\]

Volume of hydrate for varying heights in vessel

\[
1 - \left[r^2 \cos^{-1}\left(\frac{r - X}{r}\right) - (r - x)\sqrt{2rx - x^2}\right]
\]

\( r = \) radius of vessel, 5.5 ft.

\( x = \) height of water or hydrate in vessel, ft.

When \( x = 0.5 \) ft, using above equation

Volume = 50.9 ft\(^3\)

Similar calculations were done for different for \( x \) values up to 11 ft. This is shown in Table 2. The volumes and % of vessel filled for various heights in the hydrate vessel were then plotted in Figure 6. The height and volume water and hydrate in the vessel are also shown. The heights of fluid of about 8 ft and 10 ft correspond to a volume of the water of 2,392 ft\(^3\) and volume of hydrate of 2,997 ft\(^3\).

5. Heat Exchange Design of the Vessel

Considering the purpose of the vessel to form, store and transport natural gas hydrate, then heat exchange must be a factor in the design. The formation vessel should be equipped with heat exchange tubes, extending the full length of the vessel, to facilitate heat transfer from the vessel. As previously mentioned the heat exchange tubes aid the heat removal process, also supply heat for later dissociation of hydrate, after formation and storage/transportation, and provide additional surface area for more effective hydrate formation.
Table 2. Volume and Vessel Filling % as a Function of Height

<table>
<thead>
<tr>
<th>x (ft)</th>
<th>Volume</th>
<th>Vessel Filling (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>50.89</td>
<td>1.62</td>
</tr>
<tr>
<td>1</td>
<td>141.88</td>
<td>4.52</td>
</tr>
<tr>
<td>1.5</td>
<td>256.84</td>
<td>8.19</td>
</tr>
<tr>
<td>2</td>
<td>389.45</td>
<td>12.42</td>
</tr>
<tr>
<td>2.5</td>
<td>535.76</td>
<td>17.08</td>
</tr>
<tr>
<td>3</td>
<td>692.85</td>
<td>22.09</td>
</tr>
<tr>
<td>3.5</td>
<td>858.38</td>
<td>27.37</td>
</tr>
<tr>
<td>4</td>
<td>1030.37</td>
<td>32.86</td>
</tr>
<tr>
<td>4.5</td>
<td>1207.06</td>
<td>38.49</td>
</tr>
<tr>
<td>5</td>
<td>1386.80</td>
<td>44.22</td>
</tr>
<tr>
<td>5.5</td>
<td>1568.05</td>
<td>50.00</td>
</tr>
<tr>
<td>6</td>
<td>1749.30</td>
<td>55.78</td>
</tr>
<tr>
<td>6.5</td>
<td>1929.04</td>
<td>61.51</td>
</tr>
<tr>
<td>7</td>
<td>2105.72</td>
<td>67.14</td>
</tr>
<tr>
<td>7.5</td>
<td>2277.71</td>
<td>72.63</td>
</tr>
<tr>
<td>8</td>
<td>2443.25</td>
<td>77.91</td>
</tr>
<tr>
<td>8.5</td>
<td>2600.34</td>
<td>82.92</td>
</tr>
<tr>
<td>9</td>
<td>2746.64</td>
<td>87.58</td>
</tr>
<tr>
<td>9.5</td>
<td>2879.25</td>
<td>91.81</td>
</tr>
<tr>
<td>10</td>
<td>2994.21</td>
<td>95.48</td>
</tr>
<tr>
<td>10.5</td>
<td>3085.21</td>
<td>98.38</td>
</tr>
<tr>
<td>11</td>
<td>3136.09</td>
<td>100.00</td>
</tr>
</tbody>
</table>

(i) Estimate the overall flow rate of water required to absorb the latent heat of formation using the following equation

\[ Q = mC_p(T_2 - T_1) \]

where,

- \( m \) is the mass flow rate/cycle,
- \( Q \) is the heat to be removed,
- \( C_p \) is the heat capacity of the fluid,
- \( T_2 \) - \( T_1 \) Change in temperature is the difference between the hydrate formation temperature and the temperature of the flowing fluid.

\[ \begin{align*}
Q & = 3.15 \times 10^7 \text{ Btu} \\
C_p & = 0.7643 \text{ Btu/lb-F} \\
T_2 & = 35^\circ \text{F} \\
T_1 & = 30^\circ \text{F} \\
m & = 987166 \text{ gal/cycle}
\end{align*} \]

(ii) Estimate the flow rate for different tube sizes using standard recommended velocities for each tube size. These tubes velocities range from 2-8 ft./s.

Using 1” heat transfer tubes, the total flow rate through the 1” tubes is

\[ q = \frac{2443.25 \pi \times 8}{60} \]

where,

- \( D \) internal diameter of tube, ft.
- \( v \) velocity, ft/s

For \( v = 8 \text{ ft/s} \) and \( D = 0.834 \text{ ft} \),

\[ q = 817.3 \text{ gal/hr} \]

(iii) Assuming a time of hydrate formation of 6 hours, the amount of fluid (gals) for each tube size is then estimated. For 6 hrs,

\[ q = 817.36 \times 6 = 4903.8 \text{ gal/cycle} \]

(iv) The amount of tubes is then estimated from the overall flow divided by the individual tube flow.

Number of 1” tubes required to remove latent heat is,

\[ n = \frac{987166}{4903.8} = 202 \]

Similar calculations were done for other tube sizes and are shown in Table 3. Also shown in the table are the volumes of the various tubes. This indicates the amount of physical space the tubes take up in the vessel.

For this study, the 1” tubes were selected for the following reasons:

(i) The least amount of tubes to remove the latent heat of formation.

(ii) The least space taken up in the vessel with an overall volume of 36.2 ft³.

For geometry purposes, 240 tubes would be used in the hydrate formation vessel. The surface area to volume ratio increases using the heat transfer tubes in the vessel (i.e., from 0.446 to 0.58). This can impact the analysis of the formation time and as a result is a limitation using the upscaling formation time. The actual volume available for gas and water to come into contact is the volume of the vessel less the volume of the tubes is 3,107 ft³ (i.e., 3,143 ft³ - 36 ft³).

5.1 Size and Number of Tubes Required for Heat Removal

This section evaluates the possible sizes and amounts of heat exchange tubes required for the removal of heat in the hydrate vessel. Several sizes of tubes were evaluated to determine the most appropriate size for the vessel. The following are the steps used in the estimation of the number of tubes required for different tube sizes (TEMA, 1999) and in this example brine is used as the heat removal fluids, however many refrigerants can be used:

Figure 6. Plot of Volume and % Filled vs. Height in Hydrate Vessel for 0.5 MMscf
Table 3. Number and Volume of Tubes for Different Tube Sizes

<table>
<thead>
<tr>
<th>OD, in</th>
<th>Velocity (ft/sec)</th>
<th>Water Flow rate, q (gal/hr)</th>
<th>Number of tubes</th>
<th>Volume of tubes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>2</td>
<td>2.1</td>
<td>79375.7</td>
<td>892.9</td>
</tr>
<tr>
<td>0.375</td>
<td>3</td>
<td>19.2</td>
<td>8548.0</td>
<td>216.4</td>
</tr>
<tr>
<td>0.5</td>
<td>4</td>
<td>65.5</td>
<td>2510.3</td>
<td>113.0</td>
</tr>
<tr>
<td>0.625</td>
<td>5</td>
<td>154.7</td>
<td>1063.4</td>
<td>74.8</td>
</tr>
<tr>
<td>0.75</td>
<td>6</td>
<td>300.6</td>
<td>547.4</td>
<td>55.4</td>
</tr>
<tr>
<td>0.875</td>
<td>7</td>
<td>516.8</td>
<td>318.3</td>
<td>43.9</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>817.3</td>
<td>201.3</td>
<td>36.2</td>
</tr>
</tbody>
</table>

5.2 Tubes Spacing in the Vessel

Another important consideration is spacing of these heat exchange tubes in the vessel. Figure 7 shows the end view of the vessel with a section of tube spacing. The tube spacing in the vessel was then estimated. The object of this exercise is to determine \( x \) which is the distance between two heat exchange tubes in the hydrate vessel.

![Figure 7. Section of the Tube Spacing within the Vessel](image)

The following method is used to estimate the value of \( x \). Given that:

- \( r_{tube} \) – radius of tube = 0.5 in
- \( r_{circle} \) – radius of circle = 66 in
- \( n \) – no of tubes = 240

(i) Determine the Area of \( \frac{1}{4} \) circle,

\[ \frac{\pi r_{circle}^2}{4} \]

(ii) Calculate the Area of square,

\[ (2r + x)^2 \]

(iii) Evaluate the Area of shaded region,

\[ (2r + x)^2 - \left( \frac{\pi r_{circle}^2}{4} \times 4 \right) \]

(iv) Determine the Area of tubes,

\[ \pi r_{tube}^2 \]

(v) Calculate the Area of circle,

\[ \pi r_{circle}^2 = 16286 \]

(vi) Estimate the value of \( x \) using the following ratio,

\[ \frac{\pi r_{circle}^2}{(2r + x)^2 - \pi r_{tube}^2} \]

This is important in modelling the time of dissociation of the hydrate. The distance \( x \) between two tubes was estimated, and the value of \( x \) was found to be 6.55 inches.

5.3 Vessel Insulation

Heat from the surrounding can transfer into the formation vessel and increase the temperature of hydrate, causing dissociation of the hydrate as it forms. Insulation is therefore required to minimize heat transfer with the surroundings during formation, storage and transportation of the hydrates. NanoPore thermal insulation provides exceptional performance with a very low overall thermal conductivity of 0.004 Btu.in./ft.\(^2\).h.F. Because of its unique pore structure, NanoPore thermal insulation can provide thermal performance greater than conventional insulation materials (NanoPore, 2010). Fiber glass has a thermal conductivity of 0.347 Btu.in./ft.\(^2\).h.F, expanded polystyrene 0.208 Btu.in./ft.\(^2\).h.F and polyurethane a value of 0.173 Btu.in./ft.\(^2\).h.F. About 240 btu/h of heat gained from the surroundings must be removed when using 1” thickness NanoPore material, compared to 4.35 x 10\(^7\) btu/hr without any insulation.

Using

\[ Q = \frac{K \cdot dt}{A} \]

where,

- \( K \) = thermal conductivity (0.004 Btu.in./ft.\(^2\).h.F)
- \( A \) = surface area (1330.5 ft\(^2\))
- \( dt \) = temperature change (80-35=45 F)
- \( S \) = Insulation thickness (in)

For \( S = 1 \) (i.e. 1” NanoPore insulation),

\[ Q = \frac{0.004 \times 1330.5 \times 45}{1} = 239.5 \text{ Btu/hr} \]

In Table 4, various NanoPore thicknesses with corresponding heat transfer are shown. When one considers economics, the 1” NanoPore insulation will be quite adequate.

Table 4. Heat Gain using NanoPore Insulation

<table>
<thead>
<tr>
<th>NanoPore Thickness (in)</th>
<th>Heat Gain (btu/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>190260.2</td>
</tr>
<tr>
<td>1</td>
<td>239.5</td>
</tr>
<tr>
<td>2</td>
<td>119.7</td>
</tr>
<tr>
<td>3</td>
<td>79.8</td>
</tr>
<tr>
<td>4</td>
<td>59.9</td>
</tr>
<tr>
<td>5</td>
<td>47.9</td>
</tr>
</tbody>
</table>

The low heat transfer (i.e., 240 btu/hr) into the hydrate vessel is not significant enough to cause any significant increase in temperature of the hydrate. The overall temperature rise in 24 hrs in the hydrate vessel is only 0.055°F. This was calculated as follows:

For 1 hr, \( \Delta T = \frac{Q}{\text{heat capacity}} \)

where,

- \( CP \) = heat capacity of hydrate (10.82 Btu/lbmole. F)
- \( n \) = no of moles (9602)
- \( Q \) = heat transfer (239.5 Btu/hr)
- \( \Delta T = 0.002 \text{ F in 1 hr} \)
5.4 Description of Insulation Material

It is proposed that NanoPore insulation material be used on the hydrate vessel. This is a porous solid that is prepared by one of several processes which yield both low density and small pores (NanoPore, 2010). Because of its unique pore structure, NanoPore thermal insulation can provide thermal performance unequalled by conventional insulation materials. In the form of a vacuum insulation panel (VIP), it can have thermal resistance values as high as R40/inch which is 7-8 times greater than conventional foam insulation materials.

Due to unique structure, its conductivity can actually be lower than air at the same pressure. Its superior insulation characteristics are due to the unique shape and small size of its large number of pores. Gas molecules within the matrix experience the Knudsen effect, which virtually eliminates exchange of energy in the gas, effectively eliminating convection and lowering overall thermal conductivity. NanoPore Insulation may be used over a wide temperature range from below cryogenic (<=-196°C) to high temperatures (>800°C).

6. Environmental Considerations

If during shipping the hydrate vessel falls into the ocean, it is expected that once the vessel remains sealed and intact there would not be any significant effect on the hydrate in the vessel. While the temperature of ocean water changes and would be expected to be lower than the atmospheric temperature, the heat transfer into the vessel is expected to be lower when the transportation was at atmospheric temperature. So in this case, there would be no effect on the hydrate in the vessel. Similar case is expected for land transportation of hydrate.

It must be remembered that pressure vessels are designed to operate safely at a specific pressure and temperature technically referred to as the "Design Pressure" and "Design Temperature". A vessel that is inadequately designed to handle a high pressure constitutes a very significant safety hazard. Because of that, the design and certification of pressure vessels is governed by design codes, such as the ASME Boiler and Pressure Vessel Code in North America. The safe design, installation, operation, and maintenance of pressure vessels in accordance with the appropriate codes and standards are essential to safety and health.

7. Conclusions

In this study, the pressure and temperature to form the hydrate is assumed to be similar to the conditions used from previous laboratory experimental studies. The size of the hydrate formation vessel was chosen to be 11 ft x 33 ft cylinder for 0.5 MMscf/d. This was most appropriate size based on the required surface area to volume ratio of at least 0.4.

The vessel would be 75% filled with water required to form 0.5MMscf natural gas hydrate. When hydrate formation is complete the vessel will be 96.5% filled leaving 3.5% space free. This free space helps when the hydrate is dissociated and the gas rises and is removed. Besides, the size of the heat transfer tube proposed is 1” and the amount of 1” heat exchange tubes required is estimated at approximately 240 for the 11 ft x 33 ft cylindrical vessel.

The spacing of the heat exchange tubes in the vessel is estimated to be 6.55 inches between each tube. NanoPore (2010) provides superior insulation characteristics to other insulation materials. This thermal insulation provides exceptional performance with a very low overall thermal conductivity of 0.004 btu/in²·h·F.

References:


Author’s Biographical Notes:

Jerome Rajnauth is presently a Reservoir Engineer with the Petroleum Company of Trinidad and Tobago, having received his PhD from Texas A&M University in December 2010 and his MSc and BSc degrees from The University of the West Indies. Dr. Rajnauth has over fifteen years’ experience in various areas of the energy sector having worked in an oil company, a regulatory body of GORTT and a service-oriented company working offshore Trinidad, Gulf of Mexico and Venezuela. He has authored and presented over fifteen SPE papers as well as other technical and journal publications on the Oil and Gas Industry. His research interests include unconventional oil and gas, reserves estimation and gas transportation methods. He was the recipient of the SPE Young Engineer award in 2004, and served as Director of Continuing Education on the Trinidad Chapter from 2003-2005. Dr. Rajnauth has been a committee member on several committees such as the Joint Steering Committee to the Unitisation Agreement 2012, the LACPEC Petroleum Conference 2003 and the Fifth Gas Exporting Countries Ministerial Forum 2005 in Trinidad.
Effect of Storage Condition and Duration on Selected Physical and Mechanical Properties of Star Apple Fruit (*Chrysophyllum* spp)

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Abstract: Effect of storage condition and duration on some physical and mechanical properties of star apple fruit kept in ambient (27.8°C and 52% RH) and refrigerated (5°C and 70% RH) conditions for 25 days was determined. The properties were determined at five day intervals (1, 5, 10, 15, 20 and 25 days) using standard methods. Moisture loss under ambient was higher (36%) than 7.6% recorded for refrigerated sample. Unit mass of star apple decreased from 67.38 to 47.09g and 71.72 to 55.75% in ambient and refrigerated condition respectively with increase in storage duration from one to twenty days. Size and shape of star apple stored under ambient condition were significantly influenced (p<0.05) while refrigerated condition has no significant (p>0.05) effect after 25 days of storage. True and bulk densities of the samples ranged from 1.35 to 0.94 g/cm 3 and 0.547 and 0.3 g/cm 3 respectively. Static angles of repose and coefficient of friction increased with storage duration. Stress at break, yield and peak were not significantly different (p>0.05). Storage conditions and duration did not significantly (p>0.05) influence recorded strain and deformation. Force at break, yield and peak decreased from 59.22 to 38.14 N, 67.05 to 34.18 N and 68.53 to 34.13 N respectively. Generally, energy demand to compress the fruit decreased with storage duration. Using physical and mechanical properties as criteria, refrigeration at 5°C and 70% RH is recommended for short-term storage of star apple fruit.

Keywords: Star apple, physical properties, mechanical properties, storage, temperature, humidity

1. Introduction

In solving problems associated with development of agricultural machine and equipment, data on post-harvest operations of some engineering properties of agricultural materials are important. These include optical, electrical, thermal, physical and mechanical properties. Information on these properties is useful in development of handling, processing, packaging and storage equipment for crops. Published works on engineering properties of agricultural products include Altuntas and Sekeroglu (2008) on chicken egg, Ogunsina, Koya, and Adeosun (2008) on dika nut, Kibar and Ozturk (2008) on soybean, Tavakoli, Mohtasebi and Jafari (2009) on wheat straw, Davies (2010) on melon seed, Akinoso and Raji (2011) on palm kernel, Olapade, Akinoso and Oduwaye (2012) on *Cassia sieberiana* seed, Akinoso and El-alawa (2013) on locust bean seed and Akinoso and Lasisi (2013) on pigeon pea. Findings from these researches clearly showed that engineering properties of biome mater significantly depend on treatments such as crop variety, moisture content, temperature, storage duration and cooking duration.

Star apple (*Chrysophyllum* spp) is found in Africa, Central America and the West Indies. Species of *Chrysophyllum* are *Chrysophyllum albidum*, *Chrysophyllum cainito* and *Chrysophyllum africanum*. The fruit belongs to the *Sapotaceae* family with four succulent components of peel, pulp, juice and pericarp. The fruit was reported by Oyelade et al. (2005) to be sub-spherical in shape of about 3 to 5cm in diameter and 6cm long pointed at apex. Each fruit consists of five cells of seed. It is an under-utilised fruit that is rich in vitamins and micro nutrient (Ige and Gbadamosi, 2007). Edem, Eka and Ifon (1984) reported that the fruit contains hundred times more vitamin C than oranges and 10 times than vitamin C content in guava or cashew. Adepoju and Adeniyi (2012) report on species of star apple showed that the pulp contains high potassium, calcium, magnesium, phosphorus, zinc, copper and manganese but low in sodium and iron. The study further revealed that ascorbic acid (vitamin C) and α-tocopherol of the crop are higher than recommended dietary allowances of 75 and 90mg/day of vitamin for female and male respectively, and 15mg/day of α-tocopherol. In addition, the pulp contains protein (8.2%), fat (14.3%), carbohydrate (68.2%) and crude fibre (5.0%) (Ige and Gbadamosi, 2007).

Crops are preserved for short, medium and long term depending on the target. Suitable storage condition must be chosen to retain the quality and quantity of the products. Physiological properties of a product determine
the kind of storage condition to be adopted. Deterioration of fruits and vegetables during storage depends largely on temperature and humidity. Refrigeration and open-air storage at ambient temperature are common practice used for short-term storage of fruits including star apple (Mijinyawa, 2010). Therefore, the study was designed to determine the effect of storage condition and duration on physical and mechanical properties of star apple.

2. Materials and Methods

2.1 Sample collection

Star apples sourced from a local market in Ibadan Oyo state, Nigeria was used for the study. The fruit was identified in Department of Botany, University of Ibadan as Chrysophyllum albidum G. Don. They were sorted to remove defected and ensure consistency based on appearance using visual judgement. A portion (300 pieces) of the fruit was stored in ventilated room inside a fibreboard box and thinly spread without layers at ambient conditions (27.8°C and 52% RH). Each box (70 x 70 x 5 cm) contained 60 pieces of star apple. The other portion (300 pieces) was stored inside Newclime refrigerator (model 9230, China) at (5°C and 70% RH) as recommended by Cornell cooperative extension (2014). For each experiment, refrigerated sample was left for 2 hours to equilibrate with room temperature before each determination (Coskun, Yalcin and Ozarslan, 2005). Physical and mechanical properties of the fruits were determined at the five-day intervals (1, 5, 10, 15, 20 and 25 days).

2.2 Moisture content

Moisture content of the fruit was determined using ASAE standard S352.2 (ASAE, 1998). Randomly selected fruits were cut into pieces and weighed using electronic digital balance (Scout™ Pro OHaus model SPU401, Germany) with accuracy of 0.001g. Length and thickness were measured using digital vernier calliper (Capper precision, China) with 0.01mm accuracy. The mean values of the length and diameter for the samples of 25 fruits were determined. Equations 2, 3 and 4 were used for computation of geometric mean (Razavi et al., 2009), surface area and sphericity of the fruit (Mohsenin, 1986), respectively.

\[ D_g = (LD)^{1/3} \quad (2) \]

\[ SA = \pi D_g^2 \quad (3) \]

\[ \phi = \left( \frac{L}{D} \right)^{1.333} \quad (4) \]

Where,

- \( L \) is length (mm)
- \( D \) is diameter (mm)
- \( D_g \) is geometric mean diameter (mm)
- \( \phi \) is sphericity (%)
- \( S_A \) is surface area (cm²)

2.4 Density and porosity

Bulk density of the fruit was obtained by filling a container of 129.40 mm height and 98.03 mm diameter with fruits (Aremu and Fadele, 2011). Ratio of mass to volume was recorded as density. True density was determined by water displacement of a unit star apple. The ratio of the weight of fruits to volume of the displaced water gave the true density (i.e., Equation 5). The porosity is the ratio of bulk density and true density (i.e., Equation 6) (Mohsenin, 1986).

\[ \text{True density} = \frac{\text{Mass of the fruit submerged in g}}{\text{Volume of water displaced in cm}^3} \quad (5) \]

\[ \text{Porosity} = \frac{\text{true density} – \text{bulk density}}{\text{true density}} \times 100 \quad (6) \]

2.5 Coefficient of static friction

Static coefficient of friction was determined for plywood, glass, rubber, plastic, galvanised mild and stainless steels. The fruit was placed on the surface at vertex, the inclination of the surface was increased gradually with a screw device until the fruit just started to slide down and the angle of tilt (α) was read from a graduated scale. Static coefficient of friction (µ) was calculated using Equation 7 (Milani et al., 2007).

\[ \mu = \tan \alpha \quad (7) \]

2.6 Static angle of repose

Static angle of repose was determined using Sadiku (2012) reported method. A wooden box (25 x 25 x 20 cm) filled with star apple fruits was mounted on a tilting surface that was gradually tilted until the fruits slide. The angle at which sliding occur was recorded as static angle of repose.

2.7 Determination of mechanical properties

Mechanical properties viz: stress at break, strain at break, force at break, deformation at break, energy to break, stress at peak, strain at peak, force at peak, deformation at peak, energy to peak, stress at yield, strain at yield, deformation to yield, force at yield and energy to yield were determined using Testometric AX Type DBBMTCL 2500 kg (Rochdale, England). These tests were carried out using Akinoso and Raji (2011) reported method. A unit of star apple from the samples was placed between the compressions plates of the testing equipment. Each fruit was compressed at a constant deformation rate 10.00 mm/min., and readings were made using data logger. The
procedures were repeated in 50 replicates.

2.8 Statistical analysis
Mean values of replicates were recorded as data. This was subjected to ANOVA, and means were separated using Duncan multiple range rest. In addition, regression analysis of the models generated was done. For all the analysis, level of significant was accepted at 5%. SPSS 16.0 version software was used to run statistical analysis and developed mathematical models.

3. Results and Discussion

3.1. Moisture content
Moisture content of samples stored at ambient condition (27.8°C and R.H. 52%) for 25 days ranged from 71.49 to 45.64% while refrigerated (5°C and 70% RH) samples moisture content were 70.25 to 64.91% (see Table 1). For both storage conditions, moisture contents significantly (p<0.05) decreased with storage duration. However, rate of moisture loss under ambient was higher (36%) than 7.6% recorded for refrigerated sample. This was expected because transpiration takes place under ambient condition while at refrigerated condition, water molecule in the sample crystallizes, thus hinders moisture lost. Moisture content determines the quality, the worth and shelf life of agricultural produce.

3.2. Mass
The mass of biomaterial has practical application in cleaning and conveying operations. The mass in ambient and refrigerated condition decreased from 67.38 to 47.09g and 71.72 to 55.75% respectively with increase in storage duration (see Table 1). Star apple mass was heavier than mass of tenera (22g) and dura (18g) varieties of palm fruit (Akinoso and Raji, 2011). As stated above, moisture was about 70% of the chemical composition of star apple, thus significant loss of moisture reduced the mass. Equations 8 and 9 present the effect of storage duration (y) on mass (M) of the samples kept under ambient and refrigerated conditions respectively.

\[
M_{\text{amb}} = -0.8188y + 64.749 \quad (8)
\]

\[
R^2 = 0.891
\]

\[
M_{\text{ref}} = -0.0095y^2 + 0.0381y + 0.84y^3 + 7.6744y^2 - 25.427y + 78.365 \quad (9)
\]

\[
R^2 = 1
\]

3.3. Static angles of repose
The static angle of repose is the angle made with horizontal at which the material will stand when filled. Static angles of repose increased from 20° to 30° under ambient condition while for refrigerated condition, the angles ranged from 20° to 24° (see Table 1). From the results, the ability of the fruits to roll over one another was reduced with increase in storage duration and reduction in moisture content. Forces of solid friction at the material interface of canola seeds decreased with increase in moisture content (Razavi et al., 2009). Shrinkage of the fruit was noticed with increase in storage duration, this hinders rolling and increase angle of repose. Equations 10 and 11 model static angles of repose (θ) for ambient and refrigerated storage conditions respectively.

\[
\theta_{\text{amb}} = 0.4532y + 20.676 \quad \text{and} \quad R^2 = 0.935 \quad (10)
\]

\[
\theta_{\text{ref}} = 0.1371y + 21.597 \quad \text{and} \quad R^2 = 0.507 \quad (11)
\]

3.4. Size and shape
The size (geometric mean diameter and area) and shape (sphericity) of star apple stored under ambient condition were significantly influenced (p<0.05) by storage duration while refrigerated condition has no significant (p>0.05) effect after 25 days of storage (see Table 2). The fruit size is one of the major factors in the design and selection of equipment for primary processing such as separation (Akinosho and Raji, 2011). In addition, the information is useful in determining the clearance between beater blades and screens in fruit juice extractor. The largest geometric mean diameter of star apple (47.99 mm) was lower than 64.05 mm reported for apple by Meisami-asl et al. (2009). Equations 12 and 13, respectively model storage duration (y) and geometric mean diameter (Gd) of samples stored under ambient and refrigerated conditions.

\[
G_{d\text{amb}} = 0.0154y^2 - 0.8765y + 49.764 \quad \text{and} \quad R^2 = 0.9443 \quad (12)
\]

\[
G_{d\text{ref}} = 0.0052y^2 - 0.112y + 47.7 \quad \text{and} \quad R^2 = 0.9602 \quad (13)
\]

Sadiku (2012) stated that surface area depends on geometric diameter, which also depends on axial dimension of biomaterial. In addition, surface area of fruit gives indication of its behavioural pattern when it subjected to flowing fluid such as water and ease of separating extraneous materials during cleaning operation. Surface area of the star apple ranged between 72.73 and 45.20 cm². This was lower than 102.05 mm² reported for an apple fruit (Kheiraliipour et al., 2008) and 122.65 cm² for a doum palm fruit (Aremu and Fadele, 2011). However, it was higher than 19.68 cm² reported by Karamat et al. (2008) for a date fruit.

Fruits sphericity ranged from 0.32 to 1.00 (Mohsenin, 1986). The sphericity of star apple kept under ambient condition decreased from 1.0 to 0.89 as storage period increased from 1 to 25 days while refrigerated sample sphericity varied from 0.96 to 0.93 (see Table 2). Sphericity values of 1.00 support high tendency to roll about any of the axis. Kheiraliipour et al. (2008) reported 0.99 and 1.07 as sphericity for two varieties of apple while Arman et al. (2013) recorded 0.96 and 0.90 for Kowse and Atirli varieties of apple.
Hence, star apple will roll easily on any of its axis because it has high sphericity but the ability will be reduced as storage period increases under ambient condition. Sphericity is used in the design of holes on screens for the separation and cleaning of agricultural materials during post-harvest operation.

### 3.5. Density and porosity

True and bulk densities of the samples ranged from 1.35 to 0.94 g/cm³ and 0.547 and 0.3 g/cm³ respectively (see Table 3). They both decreased significantly (p<0.05) with storage duration at ambient condition. Similar observations were reported by Aremu and Fadele (2011) on doum palm fruit, Fathollahzadeh et al. (2008a) on Apricot kernels, and Balasubramanian (2001) on cashew nut. Storage duration was not significant (p>0.05) on density of refrigerated samples.

Porosity (ε) of the star apple as affected by storage duration and condition is presented in Table 3. It shows similar trend with effect on densities. Porosity depends on magnitude of variation in true and bulk densities (Milani et al., 2007). This explains the results. Increase or decrease in porosity will determine the magnitude of pore spaces in fruit mass or grain mass (Sadiku, 2012). Results of this experiment suggest that porosity of fruit in ambient condition will be high when stacked up for storage. The relationship is presented as Equations 14 and 15.

\[
\varepsilon_{\text{amb}} = -8E-05y^4 + 0.0131y^3 -0.4694y^2 + 5.2577y + 54.748 \\
R^2 = 0.759
\]

\[
\varepsilon_{\text{ref}} = -0.0025y^4 + 0.1247y^3 - 2.0548y^2 + 12.1565y + 39.267 \\
R^2 = 0.6465
\]

### 3.6. Static coefficient of friction

Static friction (µ) is force parallel to two opposing surfaces that are stationary. For movement to be initiated in an object that is in a state of rest, enough energy must supply to overcome the frictional force holding the object. Static coefficient of friction is required in the appropriate selection of structural material in the design of machine components that involve the flow of biomaterial. Static coefficient of frictions of star apple on all the materials ranged from 0.2 to 0.3 (see Table 4).

Low static coefficient of friction may be associated with shape of the fruit, which is spherical. For ambient condition, linear increase of static coefficient of friction with storage duration was observed on plywood surface only while other materials and refrigerated samples display polynomial trend. Effect of storage duration on static coefficient of friction was significant (p<0.05) on
Table 4. Static coefficient of friction of the star apple

<table>
<thead>
<tr>
<th>Storage period</th>
<th>Plywood</th>
<th>Glass</th>
<th>Rubber</th>
<th>Galvanised steel</th>
<th>Mild steel</th>
<th>Stainless steel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A&lt;sub&gt;NS&lt;/sub&gt;</td>
<td>R&lt;sub&gt;s&lt;/sub&gt;</td>
<td>A&lt;sub&gt;NS&lt;/sub&gt;</td>
<td>R&lt;sub&gt;s&lt;/sub&gt;</td>
<td>A&lt;sub&gt;NS&lt;/sub&gt;</td>
<td>R&lt;sub&gt;s&lt;/sub&gt;</td>
</tr>
<tr>
<td>1</td>
<td>0.32</td>
<td>0.14</td>
<td>0.25</td>
<td>0.23</td>
<td>0.18</td>
<td>0.23</td>
</tr>
<tr>
<td>5</td>
<td>0.22</td>
<td>0.30</td>
<td>0.18</td>
<td>0.18</td>
<td>0.15</td>
<td>0.19</td>
</tr>
<tr>
<td>10</td>
<td>0.19</td>
<td>0.16</td>
<td>0.27</td>
<td>0.21</td>
<td>0.22</td>
<td>0.19</td>
</tr>
<tr>
<td>15</td>
<td>0.21</td>
<td>0.28</td>
<td>0.19</td>
<td>0.19</td>
<td>0.20</td>
<td>0.27</td>
</tr>
<tr>
<td>20</td>
<td>0.19</td>
<td>0.18</td>
<td>0.20</td>
<td>0.25</td>
<td>0.26</td>
<td>0.20</td>
</tr>
<tr>
<td>25</td>
<td>0.25</td>
<td>0.36</td>
<td>0.17</td>
<td>0.27</td>
<td>0.29</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Remarks: A is ambient; R is refrigerated; S means significant effect at p<0.05; NS means not significant p>0.05

3.7. Stress

Stress at break, yield and peak of samples stored at ambient condition ranged from 0.03 to 0.05 MPa, 0.00 to 0.05 MPa and 0.03 to 0.05 MPa respectively (see Table 5). For refrigerated samples, stress at break, yield and peak ranged from 0.02 to 0.05 MPa, 0.22 to 0.05 MPa and 0.02 to 0.05 Mpa, respectively (see Table 6). For both storage conditions, the break, yield and peak points were not significantly different (p>0.05) from each other. This suggests that the fruit is ductile, thus machine operating on compression mechanism will be appropriate for size reduction. Similar observations were reported for sweet orange and barberry fruits by Singh and Reddy (2006) and Fathollahzadeh and Rajabipour (2008b) respectively.

3.8. Strain and deformation

Storage conditions and duration did not significantly (p>0.05) influence the recorded strain and deformation at break, yield and peak. Strain at yield was zero for all samples (see Table 5 and 6). Least deformation (7.19 mm) was recorded when the sample was refrigerated for 20 days.

3.9. Force

Force at break, yield and peak decreased from 59.22 to 38.14 N, 67.05 to 34.18 N and 68.55 to 39.79 N respectively for ambient stored samples (see Table 5). For refrigerated samples, force at break, yield and peak decreased from 59.22 to 24.01 N, 67.05 to 30.92 N and 68.53 to 34.13 N respectively (see Table 6). The values significantly (p<0.05) decreased with storage duration. The data obtained were lower than values (135 to 65 N) reported for sweet orange by Singh and Reddy (2006). Ambient samples required higher force to break than the refrigerated samples. Masoudi, Tabatabacefa and Borghae (2007) reported that storage period has significant effect on mechanical properties of apple. This may be attributed to difference in rate of moisture loss.

3.10. Energy

Energy needed to break and yield star apple fruit stored in ambient condition varied between 0.36 and 0.19 J, and 0.03 to 0.17 J respectively (see Table 5). While energy needed to break and yield refrigerated samples of star apple fruit varied from 0.36 and 0.19 J, and 0.03 and 0.10 J, respectively (see Table 6). Singh and Reddy (2006) reported 3.79 to 4.83 J as range of cutting energy for sweet orange stored in ambient and refrigerated conditions. Generally, energy demand to compress the fruit decreased with storage duration from 1 to 25 days. Noticeable differences between energy at yield and break showed high ductility of the fruit.
Similar observation was reported for cooked locust beans by Akinoso and El-alawa (2012). Data on energy is useful in selection of power drive for processing machine.

### 4. Conclusions

Refrigeration of star apple for 25 days reduced moisture loss. At ambient condition, 36% of moisture content in star apple stored for 25 days was lost. Keeping star apple in ambient environment significantly changed the mass, size, shape and density of the fruit. Refrigeration retains mass, size, shape and density of star apple. Static angles of repose increased with storage duration while coefficient of friction reduced. Storage conditions and duration did not significantly influence the recorded strain and deformation at break, yield and peak.

Star apple is a ductile material, for both storage conditions, stress at break, yield and peak points were not significantly different (p>0.05) from each other. Generally, force and energy demand to compress the fruit decreased with storage duration. Using physical and mechanical properties as criteria, refrigeration at 5°C and 70% RH is recommended for short-term storage of star apple fruit.

### Table 5. Mechanical properties of star apple stored at ambient condition

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Storage period (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Stress at peak (Mpa)</td>
<td>0.05±0.01</td>
</tr>
<tr>
<td>Stress at yield (Mpa)</td>
<td>0.05±0.00</td>
</tr>
<tr>
<td>Stress at break (Mpa)</td>
<td>0.05±0.00</td>
</tr>
<tr>
<td>Strain at peak (mm/mm)</td>
<td>0.17±0.01</td>
</tr>
<tr>
<td>Strain at yield (mm/mm)</td>
<td>0.00±0.00</td>
</tr>
<tr>
<td>Strain at break (mm/mm)</td>
<td>0.17±0.01</td>
</tr>
<tr>
<td>Deformation at peak (mm)</td>
<td>9.13±0.64</td>
</tr>
<tr>
<td>Deformation at yield (mm)</td>
<td>9.13±0.64</td>
</tr>
<tr>
<td>Deformation at break (mm)</td>
<td>9.73±0.35</td>
</tr>
<tr>
<td>Force at yield (N)</td>
<td>67.05±10.03</td>
</tr>
<tr>
<td>Force at peak (N)</td>
<td>59.22±14.64</td>
</tr>
<tr>
<td>Energy to break (J)</td>
<td>0.36±0.06</td>
</tr>
<tr>
<td>Energy to yield (J)</td>
<td>0.03±0.06</td>
</tr>
<tr>
<td>Energy to peak (J)</td>
<td>0.00±0.00</td>
</tr>
</tbody>
</table>

### Table 6. Mechanical properties of star apple stored at refrigerated condition

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Storage period (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Stress at peak (Mpa)</td>
<td>0.05±0.01</td>
</tr>
<tr>
<td>Stress at yield (Mpa)</td>
<td>0.05±0.00</td>
</tr>
<tr>
<td>Stress at break (Mpa)</td>
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</tr>
<tr>
<td>Strain at peak (mm/mm)</td>
<td>0.17±0.01</td>
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<tr>
<td>Strain at yield (mm/mm)</td>
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<tr>
<td>Strain at break (mm/mm)</td>
<td>0.19±0.01</td>
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<tr>
<td>Deformation at peak (mm)</td>
<td>9.13±0.64</td>
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<tr>
<td>Deformation at yield (mm)</td>
<td>8.85±0.35</td>
</tr>
<tr>
<td>Deformation at break (mm)</td>
<td>9.73±0.35</td>
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<tr>
<td>Force at yield (N)</td>
<td>68.53±8.90</td>
</tr>
<tr>
<td>Force at peak (N)</td>
<td>67.05±10.03</td>
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<tr>
<td>Energy to break (J)</td>
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<tr>
<td>Energy to yield (J)</td>
<td>0.03±0.06</td>
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<tr>
<td>Energy to peak (J)</td>
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</tbody>
</table>

### References:


Mohsenin, N. N. (1986), A.K. Aremu et al.: Effect of Storage Condition and Duration on Selected Physical and Mechanical Properties of Star Apple Fruit


Authors’ Biographical Notes:

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A Five-Stage Approach for Improving the Processes of Student Admissions Application for Postgraduate Programmes at UWI

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Abstract: Business Process Modelling (BPM) in systems engineering is the activity of representing processes of an enterprise, so that the current process could be analysed and improved. The adoption of BPM would assist organisations in visualising the processes that should be aligned with their values and capabilities. This paper explores the concepts associated with process mapping, business process re-engineering, total quality management, and lean thinking into process improvement in an academic setting of the School for Graduate Studies and Research (SGSR) at The University of the West Indies (UWI). With respect to the nature of SGSR operations, an attempt was made to derive a 5-stage BPM approach for mapping process improvements. This paper presents the process improvement initiatives using the selected processes associated with student admissions application into postgraduate programmes of UWI. Problems and factors affecting these processes are identified and the process maps are redesigned. It is recommended for the SGSR to implement the re-designed processes and test the effectiveness and efficiency of the new processes in handling student admissions application. Future research could validate the adoption of 5-stage approach on mapping core processes in other operational groups at SGSR. The lessons accomplished would provide insights for other academic units and institutes in an attempt to improve the design and delivery of their processes with the BPM initiative.

Keywords: Process mapping, BPM approach, student admissions, the SGSR, OSGR, UWI

1. Introduction

At St Augustine Campus of The University of the West Indies (UWI), the School for Graduate Studies and Research (SGSR) has been working with the Office of the Graduate Studies and Research (OSGR) towards aligning the core activities with the university’s strategic initiatives, as related specifically to the responsibilities of the unit, with recruitment, enrolment and throughput being prime targets (Pun, 2013). The SGSR is regarded as an operational entity within the university context. It has been providing administrative services to various faculties, departments and teaching units on graduate studies and research. ISO 9001 requires such an entity to follow a process approach when managing its business (ISO, 2010), and to this end creating business process maps would assist (Wikipedia, 2014). The entity can then work towards ensuring its processes are effective (the right process is followed the first time), and efficient (continually improved to ensure processes use the smallest amount of resources).

Business Process Modeling (BPM) in systems engineering is the activity of representing processes of an enterprise, so that the current process may be analysed and improved (Jacka and Keller 2011; Wikipedia, 2014). The OSGR had since January 2013 been piloting a new structure with eight (8) operational groups, namely 1) Application; 2) Examination and Research Projects; 3) Student Matters; 4) Research – MPhil and PhD Programmes; 5) Graduation; 6) Appointment of External Examiners and Scripts; 7) Secretary; and 8) Research and Publication and Scholarships (Pun, 2013). These groups are manned with current staff members and each has its core responsibilities and led by a delegated group leader.

There has been a need for the SGSR via the OSGR to diagnose and design/re-design its core processes and improve its operational efficiency and effectiveness in line with the re-structuring goals. The paper aims to identify the problems and factors affecting the selected processes under the Application group. This operational group is responsible for handling student admissions application into postgraduate programmes that represents the beginning of the students’ interaction with the SGSR. A generic 5-stage approach was derived and used to guide this BPM initiative.

2. Literature Review

2.1 Business Process Modelling and Mapping

A business process is a collection of related, structured activities or tasks that produce a specific service or product (serve a particular goal) for a particular customer or customers. According to Wikipedia (2014), there are three (3) main types of business processes:

1) Management processes that govern the operation of a system. Typical management processes include corporate governance and strategic management.
2) Operational processes that constitute the core business and create the primary value stream. Typical operational processes are purchasing, manufacturing, marketing, and sales.
3) Supporting processes that support the core processes. Examples include accounting, recruitment, and technical support.

A business process can be decomposed into several sub-processes, which have their own attributes, but also contribute to achieving the goal of the super-process. The analysis of business processes typically includes the mapping of processes and sub-processes down to activity level. A business process model is a model of one or more business processes, and defines the ways in which operations are carried out to accomplish the intended objectives of an organisation. Such a model remains an abstraction and depends on the intended use of the model. It can describe the workflow or the integration between business processes. It can be constructed in multiple levels.

BPM is typically performed by business analysts and managers who are seeking to improve process efficiency and quality. Process maps serve as a visual aid and graphical descriptions (such as flow-charts, work flow diagrams and value stream maps) for representing work processes, and help align system rudiments in the same direction to foster an atmosphere for improvements (Wikipedia, 2014). Process mapping has in recent years developed due to software tools that can attach metadata to activities, drivers and triggers to provide a complete understanding of processes. Process mapping is no longer two-dimensional but multi-dimensional, and is capable of supporting various business goals (Cooper, 2014). Hence, the process improvements identified by BPM may or may not require Information Technology involvement, although that is a common driver for the need to model a business process.

Jacka and Keller (2011) contended that the BPM approach would help develop the customer focus of a process, lend a hand in eliminating unnecessary actions and reduce the complexity of the process thus adding to process improvement. According to Wikipedia (2014), four (4) major steps of process mapping are identified. These are:
1) Process identification - attaining a full understanding of all the steps of a process.
2) Information gathering - identifying objectives, risks, and key controls in a process.
3) Interviewing and mapping - understanding the point of view of individuals in the process and designing actual maps.
4) Analysis - utilising tools and approaches to make the process run more effectively and efficiently.

2.2 Common Approaches of Process Improvements
Business process re-engineering (BPR), total quality management (TQM), and lean thinking are among three common approaches utilised to gain and sustain process improvements (Pun and Deonarine, 2008; Cooper, 2014). Hammer and Champy (1993) expressed BPR as the fundamental rethinking and radical redesign of present processes in an effort to attain improvement in key areas of performance such as cost, quality of service and timeliness. BPR is centred on the customer’s value experience and seeks out ways to eradicate all actions that do not add value for the customer. One main purpose for implementing BPR is to produce major improvements in customer experience through “radical redesign” and “fundamental rethinking”.

Unlike BPR, TQM places prominence on changing the mindset and culture of people. TQM focuses on incremental, unremitting improvement, and is described as corporate culture exemplified by an increase in satisfied customers as a consequence of active employee participation (Pun and Lau, 2003).

Lean thinking is similar to TQM with regards to the incremental approach to process improvement (Womack and Jones 1996). Over the years, Lean concept has spread from production processes to other non-production processes including administrative operations (Alpel et al., 2007). It is stated that activities that do not provide value are a waste and should be eliminated. Therefore, a crucial element of Lean is the removal and/or the elimination of non-value added steps contributing to the streamlining processes, taking into account the customer’s point of view (LERC, 2014). Table 1 depicts the focal concepts among BPR, TQM and lean thinking.

3. A 5-Stage Approach of BPM for Mapping Process Improvement
Built upon the four common steps of process mapping (see Section 2.1), a generic approach of BPM is derived, incorporating the concepts of process understanding via BPR (Hammer and Champy, 1993), and identifying non-value added steps in the process, non-process and process-

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Descriptions</th>
<th>Where used?</th>
<th>Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPR</td>
<td>Radical redesign of business processes.</td>
<td>Where IT is the main driver of change</td>
<td>Process</td>
</tr>
<tr>
<td>TQM</td>
<td>Continuous, incremental improvement</td>
<td>Where formal management systems are already set-up</td>
<td>Process, customer and defects reduction</td>
</tr>
<tr>
<td>Lean Thinking</td>
<td>Identification and reduction of wastes</td>
<td>Where fast results are needed and limited performance data is available</td>
<td>Process, Customer, defects reduction and waste reduction</td>
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based problems through TQM and Lean thinking (Womack and Jones 1996; Pun and Lau, 2003). The proposed approach has five (5) stages. These are:

Stage 1: Understand the steps of the process - to understand the steps involved in a process through observation, interviews, questionnaires, archival records and documentation. Process understanding is a crucial part of process development. Understanding the process from the perspective of the stakeholders (such as users, customers, and employees) is important to this step.

Stage 2: Determine non-value added steps – i.e., to determine the non-value added steps in the process and identify the problems and factors that affect the process indirectly. Although some steps may not add value directly, they may contribute indirectly to the process. A thorough cause and effects analysis could confirm the non-value added steps to be eliminated. Besides, a step is irrelevant to one process but might be relevant to another process. In such instance, the steps to be eliminated in one process could be incorporated into another process.

Stage 3: Identify process- and non-process based problems – i.e., to determine process- and non-process based problems and identify the causes. These problems are to be analysed, and suggestions of corrective and/or improvement actions be sought to eliminate/reduce them.

Stage 4: Rectify problems and redesign the steps – i.e., to rectify the problematic steps in the process and justify for redesign of steps. The employees involved should be questioned about the steps that take too much time or too much work. They should also be questioned about steps in the process that hinder the progress of other steps. Once the problems are identified they should be analysed and steps should be taken to rectify the problems. The steps could be re-adjusted or changed completely from the process.

Stage 5: Develop the to-be process maps – i.e., to combine and redesign to-be process incorporating the results from the previous stages. It is crucial for the success of the redesigned processes and all the explanations for the changes made for the user evaluation and management approval.

4. A Case Study: The Student Admissions Application of Postgraduate Programmes at UWI

The SGSR has since 2011 embarked on an initiative to restructuring the processes of the OGSR at UWI, St Augustine Campus. This case is concerned with identifying the factors affecting the efficiency and effectiveness of the work alongside the processes and hence adopting the 5-stage BPM approach for mapping process improvements. The focuses have been put on re-designing and streamlining the core processes of the student admissions application of both taught and research postgraduate programmes.

4.1 Understand the Steps of the Process

Process understanding was done through the use of several data acquisition techniques. Documentation and archival data was used to develop preliminary process maps and interviews and questionnaires were used to gain understanding of the processes of student admissions application of postgraduate programmes. The current status (‘As-is’) process maps were then developed. Personal interviews with employees were made to acquire views on the steps and issues of student admissions application. These maps were then modified based on their perception of the ‘As-is’ processes. Focus on the customer/student issues would also be incorporated in the improvement process.

Based on the diagnosis of the process on student admissions application, several issues, affecting both the effectiveness and efficiency of the process, are identified. These included network disturbances, transfer of documents to and from departments, searching for loose documents, matching and placing loose documents together with stacked documents and staff performing multiple duties.

From the student perspective, one common issue would be the tracking of application. Having regards the increasing numbers of applications per course in a large amount, these applications need to be sorted, wait for outstanding documents, attach loose documents and then be pushed into the system for tracking. Hence, the tracking process for students has always been lagging. Another issue with the Application process would be the online display of courses and documents that should be submitted when applying for the distinguished course. Although the information has been posted on the web site, some students (mainly mature students) might not be versed with the online system and prefer printed copy documentation (e.g., booklets, pamphlets, etc.).

4.2 Determine Non-Value Added Steps

After identifying the current process, the second stage began with the determination of non-value added steps. Questionnaires and interviews were conducted and the problems identified were split into three categories; Non-value adding steps, non-process based or external problems and process based problems. The applications process was understood, and the non-valued added steps were identified and then either eliminated or modified. Figure 1 illustrates some of non-value added steps identified and the changes made, respectively. For instance, while some steps do not add value to the applications process, they might be important to other departments. These steps should therefore be included in the departmental process. As illustrated, the first step does not add value to the process directly. However, it is important because it ensures that the other crucial steps in the process are completed on time. The second and third steps are modified to exclude the preparation and distribution of the advertisements.
4.3 Identify Process- and Non-Process Based Problems

The third stage was to determine process-based and non-process based problems, and identify factors affecting the time and effectiveness of the process. The common problems identified were 1) network disturbances, 2) students not being aware of the documents that they need to submit, and 3) the storage of loose documents. To tackle these problems, for instance, the Campus IT department could ensure that student must print a file containing all the required documents before they complete the application process online. This would assist the Admissions Team at OSGR in storing the documents for respective students. A proper document management system (DMS) would improve the process flow because files could be accessed readily.

4.4 Rectify the Problems and Redesign the Steps

This was to rectify the problems by eliminating and/or minimising them. An analysis of process redesign was conducted, and steps were adjusted for non-value added and process-based problems. One major problem rectified was to search for loose documents from student files at OSGR. Instead of storing loose documents in a folder, the documents could be scanned and made available on the DMS. The hard copies could be filed for later use. To ensure that student files are stored in the correct place, the student’s name would be indexed and their files be uploaded in a specific location using the file type. The transcripts and referee reports (which would usually be sent via mail) would be scanned and added to DMS. The clerks could then access the scanned documents from the system directly (see Figure 2).

4.5 Development and Evaluation of the ‘To-Be’ Process Maps

The current processes were analysed, the non-value added steps were either modified or eliminated. The process-based problems were rectified through the re-design of the process steps. Suggestions on the reduction and/or elimination of the non-process based problems would be made. The implementation of re-designed processes for student admissions application would rely on the IT supports. Figure 3 illustrates the ‘To-be’ process.
With respect to the redesign of processes, for instance, the clerk could then access students’ documents (e.g., transcripts) that are available via the DMC. Adding this system automatically would also reduce the likelihood of documents being lost. Once the clerk checks the system and notes that documents are outstanding an email is sent to the student. The changes would reduce the time taken by the faculty clerks searching for loose documents. This would then reduce the likelihood of documents being replaced in transit from one person to another.

Hence, the development of ‘To-be’ process maps would be subject to objective evaluation by senior management. This would determine whether the re-design of processes and the ‘to-be’ process maps could fit for purposes. The management feedback on monitoring the process from the internal and external views would promote the BPM initiative. Moreover, presenting the re-design of processes and explaining the ‘To-be’ process maps.
maps to the stakeholders (such as users, staff and customers, etc.) and getting their views could improve on the process.

5. Conclusion
The pursuit of performance excellence as a way of managing businesses has been increasingly recognisable (EFQM, 2013). The main purpose behind BPM is to assist organisations like the SGSR in becoming more efficient and aligning with their corporate values and capabilities (Jacka and Keller, 2011). There would be a research venue for investigating and integrating the BPM initiative into fostering process improvements with concentration on the human-organisation interface.

This paper presents the BPM initiative of improving the processes of student admissions application to postgraduate programmes at UWI. This paper demonstrates the use of the 5-stage BPM approach derived for mapping process improvement. It verifies the use of BPM that could help drive the increase in the efficiency and effectiveness of the processes. It is recommended for the SGSR to implement the re-designed processes and test the effectiveness and efficiency of the new processes in handling student admissions application.

Future research could validate the adoption of 5-stage approach on mapping core processes in other operational groups within the SGSR/OGSR. Comparative evaluations and case studies are suggested to examine the determinants of process improvement among these processes. Moreover, there is a need to investigate the extent to which the employment of the proposed BPM model would contribute towards achieving sustainable performance at SGSR/OGSR. The adoption of the approach could be extended to other academic units at UWI as well as other institutes and departments.

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References:

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