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Calorine Twebaze (Author) *Uganda National Oil Company (UNOC)*	**Impact of Artificial Intelligence (Ai) on Predictive Maintenance of Oil and Gas Equipment.**

Abstract

The world of oil and gas operations continue to grapple with the critical intricacies of optimizing maintenance operations to avert Safety related disasters. The influence of Artificial Intelligence (AI) in revolutionizing various sectors is becoming increasingly prominent. This paper focuses on how artificial intelligence can provide a transformative solution to predictive maintenance in oil and gas operations. The research concentrated on oil and gas operations in East Africa.

AI is a relatively novel concept in many fields, including oil and gas engineering, thus the paper focuses on existing literature to understand existing problems in the East African energy context and how this technology can provide transformative solutions. The research compares East African factors with global elements to understand their uniqueness in the oil and gas operations.

The study would enable; 1) Understanding whether the unique geological and operational attributes in East Africa can influence the efficacy of predictive maintenance for oil and gas equipment. 2) How AI powered predictive maintenance can have significant opportunities for East Africa's oil and gas operations, such as early detection of potential failures and remote monitoring capabilities, considering East Africa's hurdles and potential opportunities for advancements, and 3) Effective recommendations that East African nations can consider when seeking to optimize predictive maintenance activities.

The comprehensive research undertaken that involved maintenance practices in oil and gas, innovations in AI for predictive maintenance, enhancement of maintenance through technologies, AI and predictive maintenance versus traditional methods, the following findings were highlighted:

1) Oil and Gas operations in East African countries face particular unique factors of geological complexities such as complex faulting, high pressured reservoirs as well as deep water exploration challenges. 2)The current study identifies unique attributes in limited infrastructure, inadequate technical expertise, political instability, and regulatory uncertainties.

3) Furthermore, the findings based on the literature review indicate that AI algorithms can analyse big data from sensors installed on oil and gas equipment, thus AI-enabled predictive.

This paper thus recommends: (1) investments in advanced technology like AI and Machine Learning (ML) Algorithms, (2) collaboration between Government Agencies, academic institutions, and independent Companies for broader knowledge-sharing on AI's implementation in oil and gas operations, and (3) robust regulatory frameworks that emphasizes, and encourages proactive, predictive maintenance actions by companies involved in oil and gas operations in East Africa.

Keywords: Artificial Intelligence, Innovation, Predictive Maintenance, Machine Learning, Algorithms, Oil and Gas, East Africa.

Roya Geravand (Author) *Pars Oil and Gas Company*	**Application of Deconvolution Analysis in Conjunction with PLT-PTA to Evaluate Stimulation Job Performance: A case study on a Gas Condensate Reservoir located in the Middle East.**

Abstract

Deconvolution is a process in which unit-rate pressure response could be estimated from the observed variable rate and pressure drop data, therefore more data will be available for well testing analysis compared to pressure-derivative, in which only constant rate/ shut-in periods could be interpreted. This study presents application of deconvolution analysis in conjunction with two sets of diagnosing data including pressure transient analysis (PTA), surface well testing and production logging (before and after acidizing job) in a gas condensate carbonate reservoir to evaluate the efficiency of stimulation and well deliverability improvement. This evaluation would help us to optimize the treatment job design and operation in offset wells. In addition, it could be very useful in fully understanding the well test behaviours of individual reservoir layers; and in identifying hydraulic flow units, fluid segregation and possible cross flow between layers. Pressure transient analysis was performed using both pressure derivative and variable-rate deconvolution methods. The deconvolved derivatives were beneficial in identifying infinite acting redial flows and boundary effects detection. The results show the improvement of total productivity index and wellhead flowing pressure after stimulation job. However, the treatment job mostly affects the reservoir layer with higher pressure, hence a non-uniform skin removal.

Keywords: Deconvolution, Pressure Transient Analysis, Production Logging, Gas-Condensate

Introduction

Well testing analysis has been used for many years to investigate well condition and obtain reservoir parameters. Well test analysis has become a powerful reservoir characterization tool with the introduction of pressure-derivatives by Bourdet et al. (1983). Recently with the introduction of deconvolution approach and addition of a viable deconvolution algorithm to the well testing analysis tool Kit, a new milestone has been achieved (Gringarten 2008). Deconvolution is a process in which the constant/unit-rate pressure response can be calculated from the observed variable-rate and pressure data, therefore making more data available for analysis compared to the original data set, in which just shut-in periods or periods at constant-rate can be analysed (Gringarten 2008 and Kgogo 2011). Another considerable advantage of deconvolution is that the boundaries can be seen possibly although in conventional analysis, in which boundaries are not seen often and must be inferred (Gringarten 2008).

In this study, the primary objective is to evaluate the matrix acidizing job performance in a gas condensate carbonate reservoir in Iran using two sets of reservoir data including pressure transient analysis (PTA), surface well-testing and production logging tool (PLT), before and after matrix acidizing job. This evaluation would help us to optimize the stimulation job design and operation in

offset wells. Also, it could be very useful in fully understanding the well test behaviour; and in identifying hydraulic flow units, fluid profile of individual layers, fluid segregation, and possible cross flow between reservoir layers.

This paper is organized as following: First, we describe the commercial softwares and methods considered in this work. Then, we provide the PLT-PTA and surface testing interpretation results which have been performed before and after matrix acidizing job in a slanted production well. Finally, we provide the summary of our results and the conclusion.

Methods

In this study we used, Ecrin-Saphir, Emeraude, and Geolog softwares for the interpretation of well-testing, production logging data, and petrophysical logging data, respectively. Pressure transient data were analysed using both pressure-derivative and variable-rate deconvolution methods.

The objective of variable-rate deconvolution method is to calculate the unit-rate reservoir pressure response using the observed pressure drop function and flow rate function data during well-testing, in which the flow rate is variable (ILK 2010). Deconvolution algorithms are quite sensitive to data noise/error. In other word, the small changes in observed data could lead to tremendous changes in the deconvolved output, in this study the constant-rate pressure response (Onur et al. 2008, and Liu et al. 2016). To the best of our knowledge, only three error-tolerant deconvolution algorithms have been developed so far by Von Schroeter et al. (2002, 2004), Levitan (2005), and Ilk et al. (2005). They are stable enough to make the deconvolution a practical tool for well testing and production data analysis. Geravand et al. (2019) provided an integrated reservoir study by combination of well-logging evaluation and well-testing deconvolution analysis. Of the aforementioned algorithms, only the first two have been implemented in Ecrin-Saphir software. The method of these two algorithms for reconstructing the constant-rate pressure response and its logarithmic derivative is based on minimizing a nonlinear weighted least-square objective function. Whereas, ILK's deconvolution algorithm is based on the second-order B-spline functions. The weighted summation of 2nd -order B-Splines is used to reconstruct the unit-rate pressure response and its logarithmic derivative (Onur et al. 2008, Ilk 2010 and Liu et al. 2017). Al-Rbeawi (2018) presented a study in fractured formations, the well test analysis of pressure-rate convolution and deconvolution techniques.

The pressure/rate deconvolution model is given by the well-known convolution integral (van Everdingen and Hurst 1949):

$$p(t) = p_0 - \int_0^t q(\tau)\frac{dp_u(t-\tau)}{dt}d\tau \qquad (1)$$

In the equation above, p(t) and q(t) are the measured pressure and flow rate, and p_0 is the reservoir initial pressure. The deconvolved curve $p_u(t)$ corresponds to the constant/unit rate drawdown pressure response. Instead of calculating directly the $p_u(t)$ curve, we clarify:

$$\{\sigma = \ln ln\,(t) \qquad (2)\; z(\sigma) = \ln ln\left(\frac{dp_u(\sigma)}{d(\sigma)}\right)$$

Then we seek for the z ($\sigma\sigma$) curve, whose integral pu (t) satisfies Eq.1. Then from Eq.2, the below equation is obtained. Where p_u (t_1) is an arbitrary (early-time) point (Onur et al. 2008, Saphir 4.10, tutorial).

$$p_u(t) = p_u(t_1) + \int_{ln(t)}^{ln(t)} \exp exp\,[z(\sigma)]\, d\sigma \qquad (3)$$

Well 1 (Pre and Post Acidizing Diagnosis)

Well 1 is a slanted well completed with 7" liner in 2006 and has been producing single-phase gas since. It was nominated for diagnosing and stimulation because it had a low productivity index (PI).

Before matrix acidizing job, PLT-PTA and surface testing job were performed in the well. Cross-flow was only detected during static condition. the direction of cross-flow was from bottommost layer and bottom of Layer 2 with higher average pressure into Layer 1 and top of layer 2 with lower average pressure, which based on petrophysical logging they also have different porosity, water saturation and lithology. Pressure derivative identifies fluid segregation and high positive skin factor (average skin for all layers). The Selective Inflow performance (SIP) outputs from production logging interpretation, average pressure and flow rate of individual reservoir layers / flow units, were used for multi-layered PTA. Multiple infinite acting reservoir flow (IARF) were seen after about 50 and 150 min of build-up test that again confirm the system is multi-layer (figure 1).

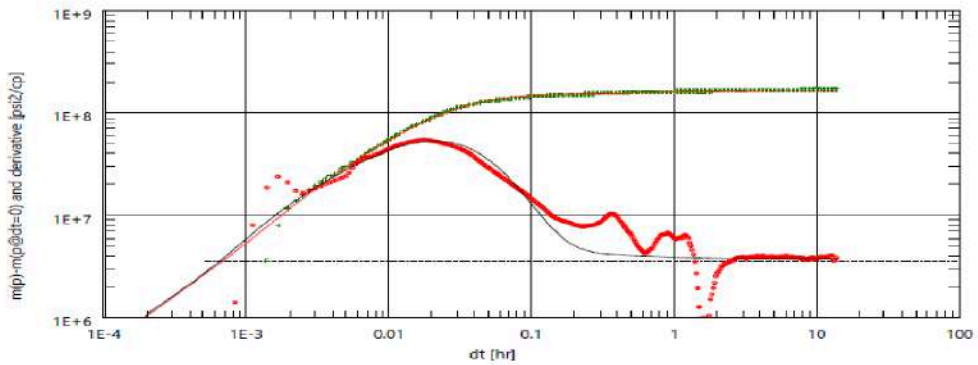
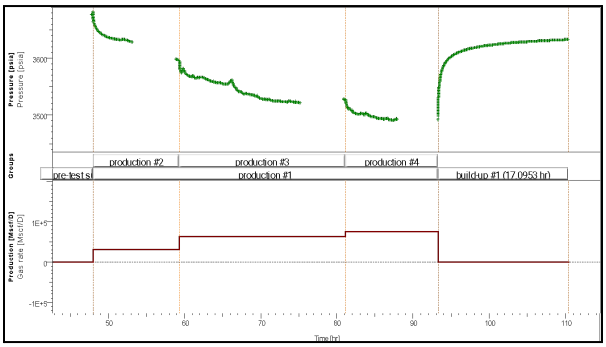


Figure 1 *Log-log plot for Pre-Acid PTA, identifies multi-layer system and positive skin factor.*

After matrix acidizing job, PLT-PTA and surface testing were performed again. Boundary effect cannot be identified from pressure derivative (figure 2). Beside static condition, cross-flow detected during all three flowing surveys. However, the rate of cross-flow was decreasing with choke opening. Similar to before acid PLT, the direction of cross-flow was upward. The main production

contributor was Layer 3, top of Layer 2 and Layer 1 respectively; The middle of Layer 2 has no production contribution either in pre and post acidizing PLT (figure 3). The deconvolution analysis shows two redial composite zones and the boundary effect (figure 4).



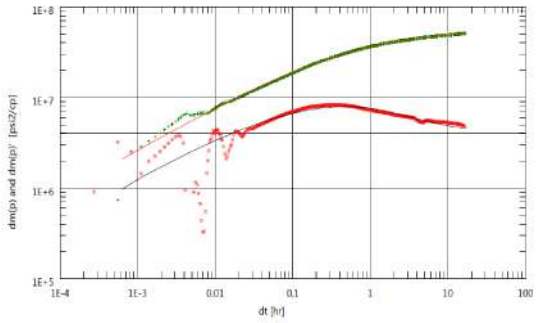


Figure 2 *shows the production history and pressure derivative log-log plot for Post Acid PTA.*

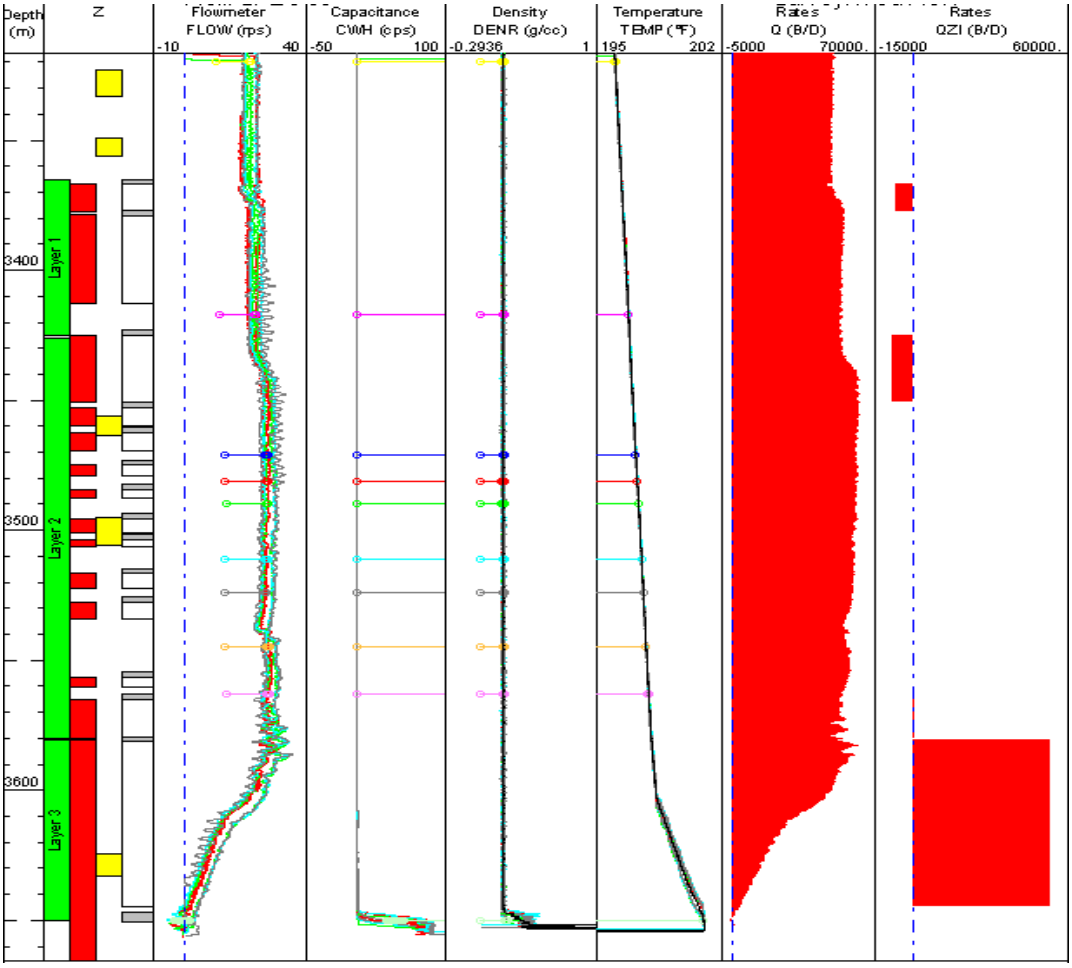


Figure 3 *Rate Contribution of reservoir layers in Moderate Flow shows upward cross flow, Post Acid PLT.*

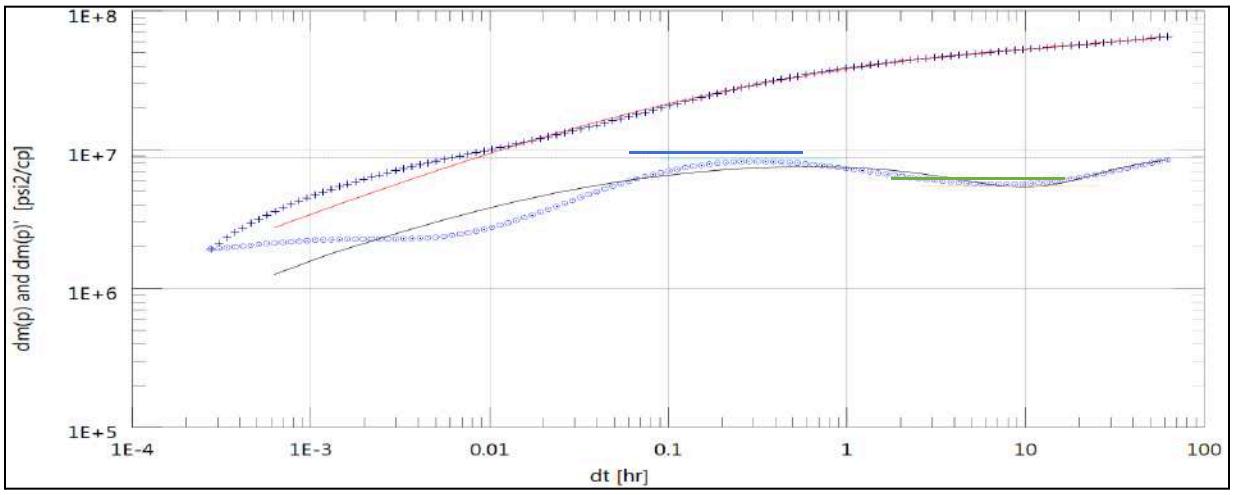


Figure 4 *Deconvolution provides more data for interpretation, Post-Acid PTA.*

Conclusions

Before treatment job, the cross flow was detected only in static condition whereas, in post-acidizing PLT, it could be seen in all three flow after flow surveys as well (minimum, moderate and maximum flow rates). Layer 3 was the main contributor. This phenomenon implies that the treatment job affects the reservoir layer with higher pressure much more compared to other reservoir layers.

The PTA results are the function of the range of pressure response and flow rate data during well testing. Among other benefits of deconvolution method, the deconvolved derivative provided us with more data range for interpretation (around 70 hours in post acid PTA). For example, two infinite acting radial flow (IARF) with different kh products and skin effects as well as boundary effect was detected in post acidizing PTA analysis. Whereas, the boundary effect cannot be seen on pressure-derivative curves; and after about 17 hours of build-up the derivative is still showing IARF. Also, the drawdown periods cannot be analysed because of fluid segregation in gas condensate reservoir.

Surface well-testing results shows the total productivity index and wellhead flowing pressure improved very well after treatment job. However, based on PLT-PTA, the skin factors of individual reservoir layers have not been removed evenly.

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Bonsu Franklina Boakyewaa (Author) *Kwame Nkrumah University of Science and Technology*	**Hindrances to the Adoption of Prefabrication in the Ghanaian Construction Industry**

Abstract

Purpose: The construction sector suffers significant challenges which are intertwined with processes and products of the traditional onsite construction approach. The quest for a lasting solution to these problems is heralding the change towards offsite construction. The primary success parameters of every project are time, cost and quality. The need to control large quantities of waste is also an issue of great concern in the construction industry. The adoption of new technological advancement in the construction sector is seen as the way forward to achieving project success. Prefabrication has been adopted for construction project by many countries across the world. The aim of this study was to investigate the hindrances faced by the Ghanaian construction industry in adopting prefabricated construction.

Methodology: This was achieved by meeting the following objectives: To examine the state and extent to which prefabrication is used in Ghana; To identify the strategies to enhance the adoption of prefabricated construction in Ghana; To explore the barriers to adopting prefabricated construction in the Ghanaian construction industry. The research made use of literature review of existing work. One hundred and twenty (120) questionnaires were designed and administered to respondents as a quantitative research method. The purposive and the snow ball techniques were employed in attaining our sample size and the data gathered were analyzed using the Statistical Packages for Social Science (SPSS) software. Mean score ranking was the statistical tool used in the analysis.

Findings: Findings of the study indicated that the current level of prefabricated construction in Ghana is low. Some of the barriers identified were disapproval by the market, lack of skilled personnel to carry on with prefabricated components on site, difficulty in transporting prefabricated components to site, low investment into prefabrication, high employee training cost, monotone aesthetics issues, lack of necessary technical expertise, high cost due to discordant scale, lack of relative policies, laws and standards, high initial construction cost, inflexible changes in design, personal interest (Familiarity and personal preference), lack of governmental incentives. The results also indicated that, in spite of the difficulties in the adoption of prefabrication, stakeholders in the Ghanaian construction industry believe that Government, Contractors, Developers and Users can help in the adoption of prefabrication if the following measures are successfully observed; Train workers by offering appropriate technical guidance, Encourage stakeholders to adopt prefabrication, Filling gaps in industry standards, Effectively reduce upfront cost, Government to vigorously cultivate professional talents, Government incentives, Increase research input and Government to implement policies to remove the economic barriers

Implications: The adoption of prefabrication will contribute to reducing the huge housing deficit and facilitate the industrialization of the construction industry. Prefabrication has the capacity to

offer alternative choice of solutions and to further improve quality and value for money for construction projects. The findings will contribute to the adoption of prefabrication for construction projects and has provided a broad view of the essence for the use of prefabrication in construction.

Originality: This study provides valid points on the state of prefabrication in Ghana and the hindrances to its adoption in the Ghanaian construction industry.

Keywords: Prefabrication, Construction industry, Ghana, Hindrances

1.0 INTRODUCTION

The construction industry provides numerous job opportunities and economic contributions and is a basis for other businesses (Venugopal et al., 2020). Its role in socioeconomic development goes beyond its share of national output (Tafesse, 2020). However, its rapid growth has negative consequences for the environment. According to the International Energy Agency, the building industry consumes the most energy and emits the most CO2. Recently, the construction industry has evolved from conventional site-based methods to industrialized systems and offsite production techniques (Pan et al., 2012). Offsite building technologies like prefabrication and modularization have been introduced to tackle the problem of productivity restrictions in traditional onsite construction, aiming to increase efficiency and standardize quality management (Alazzaz and Whyte, 2012). Prefabrication is generally a composition of construction components made in the factory after they are designed, then delivered to construction sites, and simply assembled there to complete the desired structure (Tam, 2007). In recent years, there has been a growing interest in prefabricated construction from both investors and buyers, and it is quickly becoming a new standard in home building (Timber, 2015). In some countries, prefabricated or industrialized building systems (IBS) have often been described as a potential sustainable construction process, integrating a circular economy into the policy (Luo et al., 2021). The construction industry attracts the most attention in the CE transition among different industries because of its significant resource intensity (WEF, 2015). Prefabrication application has been widely identified as a prospective way to contribute to the construction industry's sustainable development (Wu et al., 2021).

2.0 LITERATURE REVIEW

2.1 The state of prefabricated construction in Ghana

Historically, two significant attempts have been used to deploy prefabricated construction techniques in delivering mass housing in Ghana (Ofori, 1989). However, though not documented, after the two unique attempts, there was a renaissance of informal offsite construction in the Ghanaian construction industry in the early 90s when as a result of population and economic growth, developers and squatters started converting and utilizing prefabricated shipping containers into stores and for housing development (Guribie and Sule, 2022). This resulted in local offsite construction industry and market, with local artisans developing locally made prefabricated steel

modules (Guribie and Sule, 2022). In recent times, though there are no official accounts of a formal prefabricated construction market in Ghana, anecdotal evidence suggests that there are increasing numbers of prefabricated building construction companies (PBCCs) in the country (Wuni and Shen, 2019a). Given that these companies exist even though offsite construction is not explicitly recognized in the national housing policy suggests that there is a growing offsite construction supply market in Ghana, which can be improved (Wuni and Shen, 2019a). There is a low familiarity among stakeholders with the concept of its Production and the low level of mechanization of construction technology development in Ghana (Amankwah et al, 2015)

2.2 Barriers to the adoption of prefabricated construction in Ghana

The hindrances to the adoption of prefabrication have been investigated. Nine hindrances identified by earlier researchers were assessed; i) inflexible for changes of design; ii) higher initial construction cost; iii) time-consuming in the initial design development; iv) limited site space for placing prefabricated building components; v) lack of experience on the contractors; vi) monotone in aesthetics issues vii) leakage problems at joints of prefabricated components; viii) inadequate background research information; ix) lack of demand for offsite produced (prefabricated) components (Zhai, et al., 2013and Tam et al., 2007). Other researchers focused on other aspects, including cultural, practical, and technical aspects (Navaratnam et al., 2022). In this study, we will consider four hindrances.

2.2.1 Inflexible Changes in Design

It is an excellent challenge for prefabricated projects to easily change or modify the designs post the initial design phase (Blismas et al.,2005). It reduces flexibility and efficiency during the construction phase, subsequently decreasing the attractiveness of promoting prefabrication (Blismas et al., 2005). The components, modules, and assembly process are determined in the design stage and are nearly impossible to change at the construction stage (Jaillon and Poon, 2010)

2.2.2 Higher Initial Construction Cost

High initial funds are required to set up the factory to manufacture the required prefabricated components (Moradibistouni et al.,2019). Higher initial and transportation costs are the main economic hurdles of prefabrication (Jaillon and Poon, 22008). Higher initial investment and capital costs are highly unfavorable for the long-term development of prefabricated construction (Pan et al., 2007; Blismas et al.,2009 & Tam et al.,2007)

2.2.3 Lack of Expertise

It is generally agreed upon that lack of experience prevents the further development of prefabricated construction (Blismas et al.,2005). This is due to the lack of experience and knowledge about the design, logistics, and installation of prefabrication components (Boafo et al., 2016). The lack of competence in prefabrication can cause mistakes in the production of components and modules and delay the schedule. Lack of competence in the assembly may result in quality problems and schedule delays as well as more significant cost expenditures (Arditi et al.,2000)

2.2.4 Monotone in Aesthetics Issues

The standardization may lead to monotonous and repetitive building designs, thus constraining architectural creativity and design freedom (Polat, 2008). This will also hinder the adoption of prefabrication in the construction industry since the aesthetic character of structures has high importance to clients and related stakeholders (Zhang et al.,2018)

2.3 Strategies to Enhance the Adoption of Prefabrication in Ghana

Steinhardt and Manley (2016), analyzed the use of prefabricated components in the housing industries of Australia, Japan, Sweden, Germany and other countries. It was found that under certain conditions, market demands, public preferences, and national policy support can drive the use of prefabricated components. The cost-effectiveness of prefabricated components in Ghana is a vital issue for all stakeholders. Therefore, the Government should implement policies to remove the economic barriers, encourage stakeholders to adopt PC, and train workers by offering appropriate technical guidance, effectively reducing the upfront cost (Hong et al, 2018).

3.0 METHODOLOGY

The sole aim of this study is to investigate the hindrances to the adoption of prefabrication in the Ghanaian construction industry. Taking into account the aim of the research, the quantitative method was used. The quantitative method gives an overall view of the hindrances impeding the growth of prefabrication in Ghana. It employed the use of a questionnaire to adequately gather a standardized data from samples that represented the whole population. The study employed the deductive approach as ta critical study of what others have done, was looked at, read existing theories of this particular phenomena and tested hypotheses that have emerged from those theories. The survey research strategy was used because questionnaires were the primary tool used to obtain data. Again, adopting to survey allowed the acquisition of data from a wider population size as our geographical scope covers two major cities in the country. For research design, the study adopted the descriptive research design because it has specific aims and research questions.

A comprehensive, closed-ended questionnaires were designed based on the proposed hindrances modelled from reliable prior publications. Each variable was scored on a Likert scale of 1 to 5. This was done mainly to pinpoint the major hindrances to the adoption of prefabricated construction in Ghana. A pilot test on 5% of the sample size was conducted to gather feedback on the questions and identify any changes that need to be made to questionnaire's framework. This percentage amounted to 12 copies of the questionnaire. Respondents gave feedback either virtually through google forms or hardcopy forms. 120 target population required 120 questionnaires to be administered and out of this number, a total of 118 questionnaires received responses from respondents. The questionnaire was administered majorly through an electronic medium using Google Forms and a few hard copy responses were recorded. Out of 120 questionnaire distributed, a total of 118 questionnaires representing 98. 33% received responses from respondents and deemed valid for analysis. The statistical tools employed in the analysis included the mean score ranking and the one-sample t-test. The mean score ranking was used to determine the central tendency of the various barriers and

strategies to enhance the adoption of prefabricated construction. The Statistical Package for Social Sciences, version 23.0, was used for the analysis of the data.

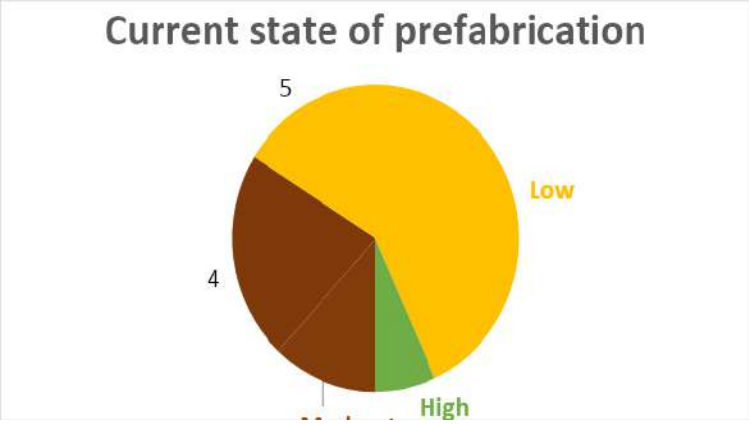
4.1 Demographic Data

4.0 Results and discussion

In the section where respondents were required to indicate the type of organization in which they worked, it is observed that all respondents worked under at least one of the organizations listed. Table 1 contains concise data of the demographic information requested from respondents. In the table, it is seen that other information concerning the respondents' employment status, highest level of education, type of construction firm and the years of experience. The results below suggest that the respondents were well-educated and had the necessary knowledge to partake in the study.

4.2 Current State of Prefabrication.

This specific objective was set to access the level of prefabrication adoption in Ghana among the respondents. It was rated low, moderate and high. In line with the feedback as shown in the Figure1, majority of the respondent (N=80, representing 67.8%) indicated that the level of prefabricated construction is low in the country, followed by the moderate (N=30, representing 25.4%) lastly, high (N=8, representing 6.8%)



Demographic item	Frequency	Percentage
Employment status		
Government employed	27	22.9
Self employed	46	39
Private organisation	45	38.1
Highest level of education		
HND	2	1.7
Bachelor's degree	38	32.2
Master's degree	69	58.5
Master of philosophy	7	5.9
Doctorate	2	1.7
Type of construction firm		
Main contractor	12	10.2
Specialist subcontractor	9	7.6
Architectural firm	16	13.6
Quantity surveyor	29	24.6
Civil/Structural engineering firm	14	11.9
Project management firm	38	32.2
Years of experience		
1-10	82	69.5
11-20	30	25.4
21-30	4	3.4
31-40	2	1.7

Figure 1: State of prefabricated construction in Ghana

4.3 Barriers to the adoption of Prefabricated Construction

In this section, respondents were asked to indicate the potential barriers hindering the adoption of prefabricated construction in Ghana. Their response was ranked on a five-point Likert scale of 1 to 5 where; Least important = 1,

Fairly Important = 2, Important = 3, Very Important= 4 and Most Important = 5. The responds were ranked from 1st to 13th as shown in table 4.4.

The data retrieved from the survey was ranked using the mean score (MS) ranging from 1.000 to 5.000 to rank the barriers to the adoption of prefabricated construction in Ghana. Thirteen barriers were analysed and nine of them are represented on the table below.92% thus, twelve out of the thirteen barriers analysed have MS above the midpoint of 3.000 which indicates that in general the respondents agree to the potential barriers listed in the survey.

Disapproval by the market in the use prefabricated construction was ranked 1st with MS of 4.1017 and a standard deviation of 0.70879, Lack of skilled personnel to carry on with prefabricated components on site was ranked 2nd with MS of 4.0763 and a standard deviation of 0.76412, Difficulty in transporting prefabricated components to site was ranked 3rd with MS of 4.0593 and a standard deviation of 0.69544.

Table 2: Barriers to prefabricated construction

	Hindrances	1 = Least important…. 5 =Most important.					Descriptive Statistics			Rank
		1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	Mean	Mode	Standard Deviation	
1.	Disapproval by the market	0 (0%)	2 (1.7%)	18 (15.3%)	64 (54.2%)	34 (28.8%)	4.1017	4.00	0.70879	1
2.	Lack of skilled personnel to carry on with prefabricated components on site	0 (0%)	2 (1.7%)	24 (20.3%)	55 (46.6%)	37 (31.4%)	4.0763	4.00	0.76412	2
3.	Difficulty in transporting prefabricated components to site	1 (0.8%)	22 (18.6 %)	64 (54.2%)	31 (26.3%)	1 (0.8%)	4.0593	4.00	0.69544	3
4.	Low investment into prefabrication	7 (5.4%)	4 (3.4%)	24 (20.3%)	53 (44.9%)	30 (28%)	4.0424	4.00	0.81013	4
5.	High employee training cost	1 (0.8%)	1 (0.8%)	26 (22%)	57 (48.3%)	33 (28%)	4.0169	4.00	0.78428	5
6.	Monotone aesthetics issues	3 (2.5%)	2 (1.7%)	25 (21.5%)	55 (46.6%)	33 (28%)	3.9576	4.00	0.89054	6
7.	Lack of necessary technical expertise	2 (1.7%)	1 (0.8%)	32 (27.1%)	49 (41.5%)	34 (28.8%)	3.9492	4.00	0.86575	7
8.	High initial construction cost	0 (0%)	6 (5.1%)	28 (23.7%)	55 (46.6%)	29 (24.6%)	3.9068	4.00	0.82677	8
9.	Inflexible changes in design	2 (1.7%)	8 (6.8%)	21 (17.8%)	59 (50%)	28 (23.7%)	3.8729	4.00	0.91096	9

4.4 Strategies to Enhance Prefabrication Adoption

This section required respondents to indicate on a five-point Likert scale from strongly disagree to strongly agree the strategies to enhance the adoption of prefabrication in Ghana. Where strongly disagree =1; Disagree =2; Neutral =3; Agree =4 and strongly agree =5. The data retrieved from the respondents were ranked as shown in table 3.

The data retrieved from the survey was subsequently ranked using the mean score (MS) ranging from 1.000 to 5.000 to rank the strategies to enhance the adoption of prefabrication.

Train workers by offering appropriate technical guidance was ranked 1st with MS of 4.1441 and standard deviation of 0.65731, the need to encourage stakeholders to adopt prefabrication was ranked 2nd with MS of 4.1271 and standard deviation of 0.63443, Filling gaps in industry standards was ranked 3rd with MS of 4.0847 and standard deviation of 0.69892

Table 3: Strategies to enhance the adoption of prefabricated construction

	Strategies to enhance prefabrication	1 = Strongly disagree……. 5 = Strongly agree					Descriptive Statistics			Rank
		1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	Mean	Mode	Standard Deviation	
1	Train workers by offering appropriate technical guidance	5 (3.5 %)	1 (0.8%)	10 (9.2%)	68 (57.6%)	34 (28.8%)	4.1441	4	0.65731	1
2	Encourage stakeholders to adopt prefabrication	0 (0%)	1 (0.8%)	14 (11.9%)	72 (61%)	31 (26.3%)	4.1271	4	0.63443	2
3	Filling gaps in industry standards	0 (0%)	2 (1.7%)	18 (15.3%)	66 (55.9%)	32 (27.1%)	4.0847	4	0.69892	3
4	Effectively reduce upfront cost	0 (0%)	2 (1.7%)	22 (18.6%)	61 (51.7%)	33 (28%)	4.0593	4	0.73138	4
5	Government to vigorously cultivate professional talents	0 (0%)	2 (1.7%)	20 (16.9%)	65 (55.1%)	31 (26.3%)	4.0593	4	0.70762	4

5.0 Conclusion

The study identified the major barriers to the adoption of prefabricated construction and elaborated on potential strategies to enhance its adoption. The knowledge gained from this study will help industry professionals and policymakers adopt prefabricated construction in Ghana. This study will also serve as a source of empirical data to motivate others to conduct further studies on the subject to confirm or otherwise, the findings of this study. The conclusion of this study will aid researchers, people in academia, construction professionals, individuals and even the government to know more about prefabricated construction, its benefits, the major barriers that impede its adoption in Ghana and adopt the strategies outlined to enhance its adoption in Ghana. To help raise the bar on the use of prefabricated construction and to ensure it is used more often in the construction industry of Ghana, some recommendations have been stated. These recommendations are based on data collected and the study performed; 1) that government and manufacturers of prefabrication would reduce overall cost which includes the manufacturing, transportation, and finishing to boost the patronage. 2) Government to show maximum interest in prefabricated construction thorough regulations, and the provision of incentives to significantly affect stakeholders' desire to adopt prefabrication. Again, government should by example adopt prefabrication in the construction of government project to draw the attention of many to this method.

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Hailu Yifru Mengesha(Author) *Abnet Woube Building Construction*	**Safety and Security Evaluation of Three-Wheeler Taxis as a Public Transport in Kombolcha City, Ethiopia.**

Abstract

Motorized three-wheeler taxis provide an important means of transportation in Ethiopia. Although these motor vehicles have been designed for the purpose of public transportation, there is a lack of sufficient studies on their safety and security. Therefore, this study aimed to evaluate the safety and security status of these three-wheeler taxis as a public transport in Kombolcha city. To do that, questionnaire data from 395 respondents (passengers and drivers) and police-recorded crime as well as crash data were collected and analyzed. From the analysis, it was found that pedestrian collisions, overturning or topping, and passengers jumping and falling while the vehicle was in motion were the most common types of accidents in 3-wheeler (Bajaj) taxis. In addition, logistic regression analysis results indicated that the most common type of injury in 3-wheeler accidents was injury (slight and serious) crashes, and pedestrian collisions were found to be the leading cause of the severity of the crashes. Related to security, the logistic regression analysis result revealed that male passengers were more likely to be beaten or hit, whereas female passengers were more likely to be robbed, snatched, or stolen. Besides this, theft crimes were higher inside 3-wheelers; however, robbery/snatching and beating/hitting crimes were more common outside the three-wheelers. In general, passengers' feelings of safety and satisfaction level with security-related services significantly depended on gender, age, travel frequency, and occupation, with female passengers feeling more unsafe and dissatisfied than male travelers.

Key words: Three-wheeler, safety, security, public transport, crime, Kombolcha, Ethiopia

1. INTRODUCTION

Transportation is an indispensable component of any society, and it closely related to the way of life, the variety and location of activities, and the goods and services that will be available for use. An efficient transport system provides social, economic, political, and cultural benefits such as market access, investor infusion, resource distribution, and so on, all of which have an indirect impact on a country's growth and development [1] [2]. In terms of modes, city buses, mini-buses, and 3-wheel rickshaw (Bajaj) taxis are the types of public transportation in Ethiopia; particularly, minibuses and 3-wheeler taxis are extensively available modes of public transportation in secondary cities and towns of the country. Three-wheeler autorickshaws are known by the name "Bajajs", and both sides of these three- wheeler bodies are open, allowing for free airflow [3]. With only three passengers, the 3-wheeler makes few stops to allow passengers to load and unload, resulting in shorter waiting times at stations. However, in some rural and peri-urban areas of the country, where there is no traffic control and no other public transport modes are available, the drivers load up to six and seven passengers in a single journey [4]. Many users reported that 3-wheelers were a reliable mode of transportation in an emergency and used as an ambulance in low and victims of emergency conditions [5] [6]. As a result, it is apparent that many people consider 3-wheelers to be highly useful and that their services should be well integrated in small

towns [5]. Even though, transportation has the above benefits it has its own negative impact like safety problems, air pollution, noise pollution and energy consumption. Transportation has a tremendously negative impact on society in terms of accidents. Increased fluctuation in speed and vehicle density resulted in a significant risk of accidents, which resulted in loss of life, permanent disability, injury, and property damage [2]. Further on this, 3-wheelers are generally less stable than four-wheel vehicles and can roll over if driven too rapidly around sharp curves or turned when braking hard and analysis of three-wheeler accidents reveals that toppling occurred in the majority of cases before the impact (hitting the other vehicle/obstacle) and it was the main constraint when attempting to avoid an obstacle by turning, braking, and accelerating [7] [4]. The most prevalent type of accident was the vehicle tipping over [8] [9]. Furthermore, the main challenge in the transportation sector is security. Travelers today have repeatedly expressed concerns about the safety and security of public transportation, particularly females [10] [11] of young and adolescent ages [12], who are the most commonly victimized group in public transportation, fearing for their safety [13]. Evidence from Debre Markos City (Ethiopia) indicated that the security dimension of three-wheeler (Bajaj) service quality had the least impact on its users' satisfaction [14]. Three-wheeler drivers reported as they fear night times of being hired for unlawful activities and being kidnapped by gangsters [5]. Additionally, during night travel and 3-wheeler terminal were not safe from crime [14]. Despite the fact that they are now the most widely used mode of public transportation in towns, secondary cities, and the city sides of large cities, in the majority of public transport security studies, 3-wheelers have not been studied as a mode of public transportation. Existing studies also didn't include the actual condition, including the types of accidents that involved 3-wheelers, severity levels, and causes of accidents related to safety. Besides this, related to security, there is a lack of evidence on the crime types by place of crime, the association of cities, in the majority of public transport security studies, 3-wheelers have not been studied as a mode of public transportation. Existing studies also didn't include the actual condition, including the types of accidents that involved 3-wheelers, severity levels, and causes of accidents related to safety. Besides this, related to security, there is a lack of evidence on the crime types by place of crime, the association of 2. OBJECTIVES The main objective of this study is to evaluate safety and security status of three-wheeler taxis in Kombolcha city and the specific objectives are: - To investigate types of 3-wheelers crashes and causes of crashes in Kombolcha city To examine the factors that affect the severity of crashes To identify the 3-wheeler crime types and crime-committing techniques To evaluate the relation between crime types, victim types, driver's involvement in crimes, and crime-occurring places 3. METHODOLOGY The research study was conducted in Kombolcha City, which is located in Amhara regional state in north-central Ethiopia. The rationale for selecting Kombolcha was the fact that the city is one of the industrial villages and a center for connecting the northern part of the country to the central part of the country, and the main public transport mode in the city is three-wheeler taxis, which need consideration about their safety and security. 3.1 Sample Size Determination Quantitative study design was employed. Using Cochran's (1977) correction formula; Sample = Size (1.96)^2(0.5)(1−0.5) (0.05)^2 (Si) = (Z−score)^2(p)(1−p) (margin of error)^2 =384.16=384. By adding 10 percent to account for possible non-responding questions, the total sample size for the questionnaire was 430. 3.2 Sources of data and sampling technique The study adopted both primary and secondary sourced data. The primary data was structured questionnaires designed to gather information from drivers and passengers of 3-wheeled vehicles in the city. Questionnaires for both drivers and passengers contained three parts separately: basic information about them, safety-related questions, and

security related questions. The number of 3-wheelers assigned per distribution route varies based on the social and economic activities of the society. Considering that, a crime types and crime place, victims by demographic characteristics, three-wheeler driver characteristics (their involvement in criminal activities), and the volume of crime related to social activity. Therefore, this study aimed to address the above-mentioned gaps, which are not adequately addressed by scholars in terms of the mode and geographical area of the study. probability sampling technique called stratified sampling techniques was adopted. The breakdown of the questionnaire for each distribution route was made by proportioning the number of respondents to the number of 3-wheelers assigned to each distribution route. Finally, the questionnaires were distributed around 3-wheeler terminals. Secondary data used for the research was collected from Kombolcha city transport bureau (the number of distribution routes, their locations, and the respective number of 3-wheelers assigned per distribution route), the city three-wheeler and taxi owners' association (yearly registered three-wheeled public transport vehicles), and the city police departments (recorded crime and crash data). 3.3 Data analysis The collected data were analyzed using Microsoft Excel and Statistical Analysis Software (SPSS.v26). SPSS was used to generate both descriptive and inferential statistics from quantitative data. The descriptive statistics were percentages, medians, and mode; however, the inferential statistics were regression analysis applied to both crime and crash data. 4. Results and Discussion 4.1 4.1.1 Results from crash data Back ground information of drivers involved in crash According to Kombolcha city traffic police data (2011/12 to 2020/21), the majority (212, 99%) of 3 wheeler drivers were males, and the remaining 1% (2) were females. This was consistent with earlier similar studies in southeast Asian countries and others, indicating that the crash involvement of male three-wheeler drivers outnumbered female three wheeler drivers [9] [15], and the reason for this was stated as the presence of more male drivers in the field than female drivers. Regarding age, 65% of three-wheeler drivers were in the age group of 18 26, followed by 27–31 (20%), and the age group of 32–40 covered 9% of the drivers. 41-50, ≥51, and <18 cover 3, 2, and 1%, respectively. This result shows that the majority of three-wheeler drivers fall under the age group of 18–31, and there were very few drivers in the age <18 and ≥ 41. An earlier study found approximately the same result: that the majority of three-wheeler drivers involved in accidents were between the ages of 21 and 30 [9]. Again, regarding the educational qualification of drivers, the majority (64%) of three-wheeler drivers had an academic qualification of secondary school education (9–12 grade), and 19% (41) were college graduates. The remaining 15% (32) completed primary school education. Additionally, drivers of 3 wheelers who drive the three-wheeler as employees account for about 72% of the accidents, owners account for about 26%, and the remaining 2% are others. The fact that the majority of the drivers involved in crashes were employees is due to the fact that the number of employee drivers in the field was higher than the number of owner drivers. 4.1.2 Crash distribution by vehicle types Crash data collected in the study area indicated that vehicles most frequently involved in accidents were motorized 3-wheelers (41%), and the second most frequently involved vehicle in an accident was large and medium trucks, accounting for about 23%, followed by minibuses with a loading capacity of ≤ 15 passengers (13%).

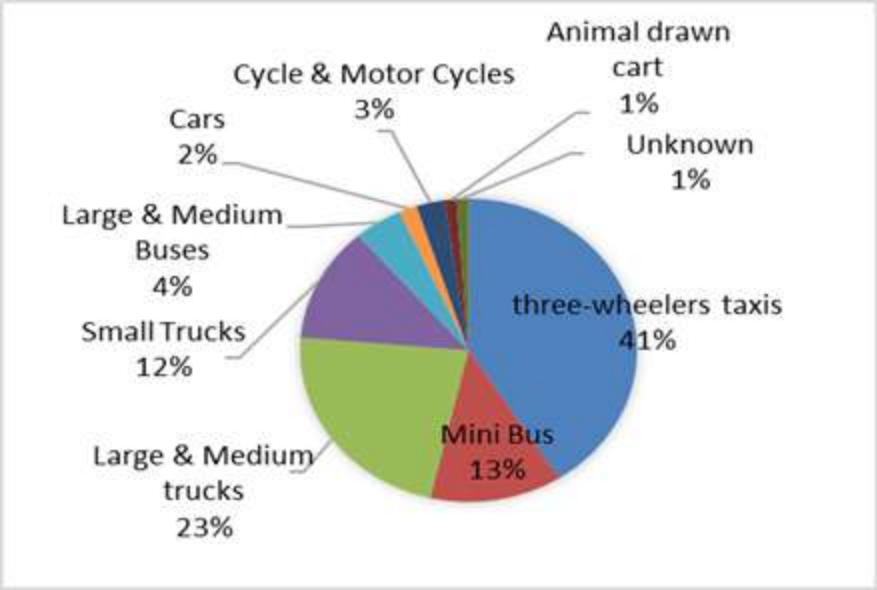

Figure 4. 1 Crashes by vehicle types in Kombolcha city

4.1.3 Crashes per days of the week As indicated in the figure below, the highest number of crashes were observed on Wednesday (108 incidents), which accounted for 21% of the total incidents in the area, and the next worst day was Saturday (94 incidents), which accounted for about 18% of the incidents that happened in the city. For three-wheeler accidents, the worst days were Wednesday and Saturday, which accounted for 23% and 17% of the total accidents (213 incidents), respectively. As these two days are market days in the city, they involve more socio-economic activities and traffic interaction than other days that result in more

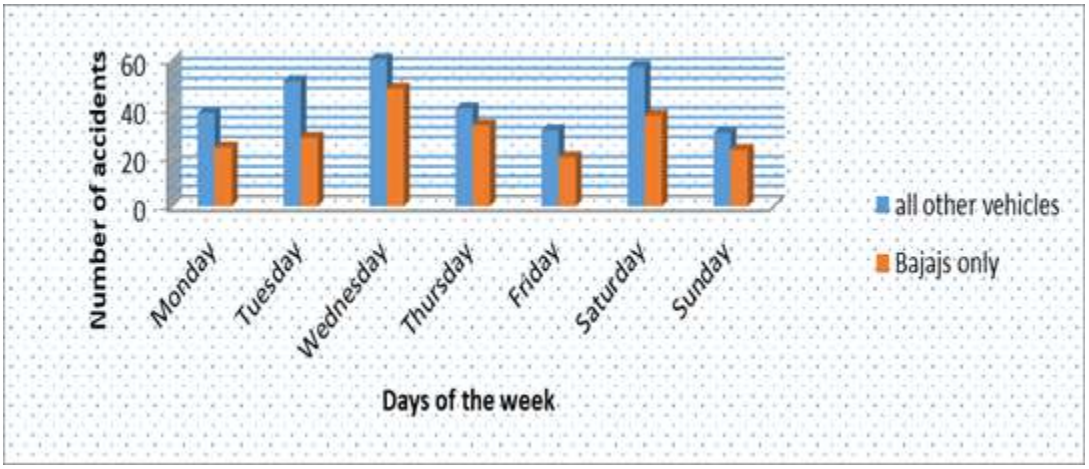

Figure 4. 2 Crashes over days of the week

4.1.4 Most common collision types In terms of collision types, the majority of accidents that were registered among road users resulted from pedestrian collisions; of total three-wheeler accidents, pedestrian collisions accounted for about 56%. According to the data, pedestrian collisions were more common in 3-wheel vehicles than in other vehicle types. The reason for this is that the three wheelers serve in a mixed traffic system, and due to the lack of separate roadways for both vehicles

and pedestrians, there is a higher level of interaction between vehicles and pedestrians. As a result, pedestrian collisions will happen. Following pedestrian collisions, overturning (toppling) was the most common accident type observed in three wheeler accidents. It accounted for about 21% of the total three-wheeler crashes in the city. On the other hand, previous studies showed that toppling was the leading type of accident among 3-wheelers [16]. Exceptionally, the accident types involving the falling of passengers from the vehicle and passengers jumping and falling from the vehicle while the vehicle is in motion were observed mainly in three wheelers. This type of accident occurred due to the open structure of the three-wheeler and a lack of caution for passengers.

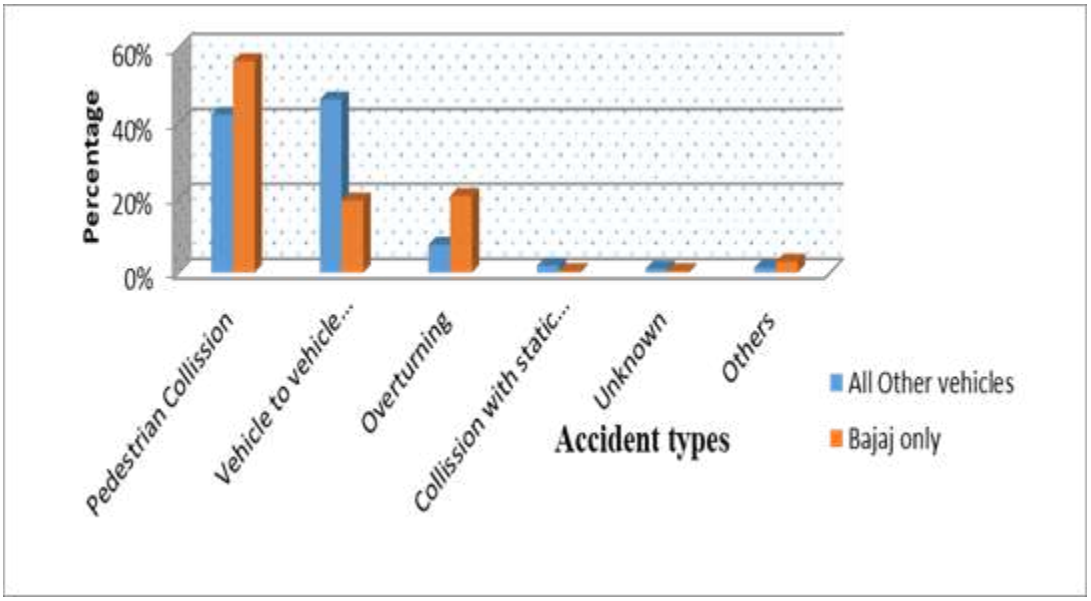

Figure 4. 3 Percentage of crashes by collision type

4.1.5 Causes of accidents

Causes of accidents can be characterized as vehicle factors, road factors, and road user factors. In line with these facts, the analysis results of the study indicated that the major causes of traffic accidents in Kombolcha city were associated with road user behaviors' that include a lack of caution (unethical driving and underestimating of things), which accounted for 37% of the total 3-wheeler accident causes. with the next leading cause being speeding, which accounted for 22%, followed by failure to give way for pedestrians (20%). Evidence obtained from the questionnaire survey indicated that the narrowness of the road (inadequate capacity to accommodate the present traffic) was the major cause of crashes in the city.

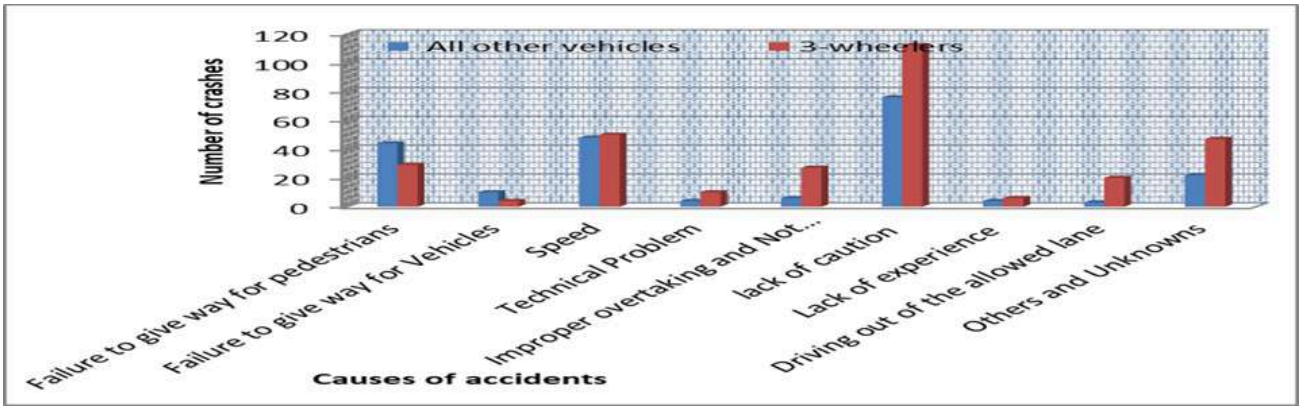

Figure 4. 4 Causes of accidents in the study area

4.1.6 Prediction of accident type as a dependent variable

Multinomial logistic regression analysis was performed primarily to understand the relationship between the type of accident involved and the vehicle type, cause of the accident, and road geometry. In doing so, all the assumptions of logistic regression were checked and met the criteria. This Table 4. 1 Model fitting information criteria was done after the elimination of other variables that were not significant and then continuing testing of interaction effects with only significant variables. The full model shows a significant improvement in fit over a null model (χ^2 (10) =153.335, p<.001), and Pearson's and Deviance's chi-square both indicate a good fit of the model to the data ($p > 0.05$).

Table 4. 1 Model fitting information criteria

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	266.088			
Final	112.754	153.335	10	0.000

The likelihood ratio test indicates that all three predictor variables (vehicle types involved in an accident, road geometry, and causes of the crash) were significant predictors of accident type, and the result indicates that on curved portions of the road, vehicle-to-vehicle collisions had a greater chance of occurring than pedestrian collisions; however, overturning/toppling had a greater chance of occurrence in curved sections than vehicle-to-vehicle collisions. Another interesting point that can be drawn from the analysis result was that 3-wheelers were more responsible for pedestrian collisions at a rate 2.5 times higher than vehicle-to-vehicle collisions. In Kombolcha city, 3-wheeled vehicles serve in a mixed-traffic system where there are inadequate roadways to accommodate the

existing traffic. Due to that, these public transport vehicles highly interact with pedestrians, and consequently, it increases the likelihood of 3-wheeler crashes being pedestrian collisions rather than vehicle-to-vehicle collisions. In comparison with other accident types, overturning was more commonly experienced by 3-wheelers than other vehicles. Previous studies also indicated that, due to their lower stability than four-wheel vehicles, three-wheelers roll over if driven fast on sharp turns or turned while breaking hard [4] [8] [16]. According to the logistic regression results of this study, the likelihood of overturning accidents occurring in 3-wheelers was 9.4 (95% CI: 4.948, 17.76) and 3.8 (95% CI: 2.096, 7.023) times higher than the likelihood of vehicle-to-vehicle and pedestrian collisions occurring due to 3-wheelers, respectively.

Additionally, the relationship between accident types and accident causes indicated that lack of caution was the leading cause of all crash types, and speeding was the second. Besides this, the result indicated that the chance that failure to give way causes pedestrian collisions (OR = 19.7, 95% CI (2.592, 150.297) and vehicle-to-vehicle collisions (OR = 7.2, 95% CI (0.916, 55.927)) was higher than the chance that it causes overturning. There was a higher chance for the occurrence of overturning/toppling (OR = 5.34, 95% CI (2.528, 11.27)) and pedestrian collisions (OR = 3.612, 95% CI (2.112, 6.17)) than vehicle-to-vehicle crashes due to over speeding of the vehicles, compared to a lack of caution causing toppling and pedestrian collisions rather than vehicle-to-vehicle collisions; however, according to the result, lack of caution and speeding nearly equally likely contributed to the occurrence of pedestrian collisions and overturning. Moreover, lack of experience and technical problems of the vehicle were highly accounted for the occurrence of overturning than both pedestrian (OR = 2.2, 95% CI (1.05, 4.44)) and vehicle-to-vehicle (OR = 4.122, 95% CI (1.944, 8.73)) collisions.
Finally, the chance that lack of experience and technical problems being cause for vehicle-to-vehicle collisions was 1.9 times less than their chance of being the cause for pedestrian collisions (OR = 0.524, 95% CI = 0.306, 0.898).

Table 4. 2 SPSS output of parameter estimates for accident type as a dependent variable

Type of crash	Predictors	B	Std. Error	Wald	df	Sig.	Exp(B)	95% CI for Exp(B) Lower Bound	95% CI for Exp(B) Upper Bound
Over turning/Toppling	Intercept	-1.434	0.379	14.296	1	0.000			
	vehicle types involved in an accident (3-wheelers=1)	1.345	0.308	19.007	1	0.000	3.837	2.096	7.023
	vehicle types involved in an accident(others=2)	0[b]			0				
	Road geometry [Straight =1]	-1.009	0.343	8.66	1	0.003	0.364	0.186	0.714
	Road geometry [Curved =2]	0[b]			0				
	Cause of accident (FTW=1)	-2.982	1.036	8.291	1	0.004	0.051	0.007	0.386
	Cause of accident(S=2)	0.391	0.338	1.336	1	0.248	1.478	0.762	2.868
	Cause of accident (TP & LE=3)	0.77	0.368	4.374	1	0.036	2.159	1.05	4.442
	Cause of accident (LC=4)	0[b]			0				
Vehicle to vehicle collision	Intercept	1.198	0.231	27.001	1	0.000			
	vehicle types involved in an accident (3-wheelers=1)	-0.893	0.207	18.62	1	0.000	0.409	0.273	0.614
	vehicle types involved in an accident(others=2)	0[b]			0				
	Road geometry [Straight =1]	-0.766	0.235	10.611	1	0.001	0.465	0.293	0.737
	Road geometry [Curved =2]	0[b]			0				
	Cause of accident (FTW=1)	-1.014	0.265	14.691	1	0.0000	0.363	0.216	0.609
	Cause of accident(S=2)	-1.284	0.274	22.007	1	0.0000	0.277	0.162	0.473
	Cause of accident (TP & LE=3)	-0.647	0.275	5.529	1	0.019	0.524	0.306	0.898
	Cause of accident (LC=4)	0[b]			0				

a. The reference category is: Pedestrian Collision.
b. This parameter is set to zero because it is redundant.

4.2 Three- wheeler Related Crimes in Kombolcha city Three-year period crime data was collected from Kombolcha city police department, and all crimes committed inside 3-wheelers at 3-wheeler stations, as well as crimes committed on commuters and drivers while walking or driving towards one of the 3 wheeler stations, were recorded as three-wheeler related crimes. Primarily, it should be noted that the volume of crime is much higher than that recorded by the police. According to [17] out of the total actual crime incidents, only one-fourth were recorded by the police, and with no identifiable known offenders. However, the victims can be easily identified from reports. According to this study, both males and females were crime victims; in contrast, males were victimized in the majority of the criminal incidents reported each year. Additionally, the number of 3 wheeler-related crimes increased in consecutive years, and the increase in crime incidents indicates an increase in the number of crime-involved parties (perpetrators). More on this: crimes can be related to political, economic, and security instabilities [18]. Particularly those public transport-related crimes have a relationship with economic and security instability; for instance, an increase in the unemployment rate will result in an increase in criminal activities [19].

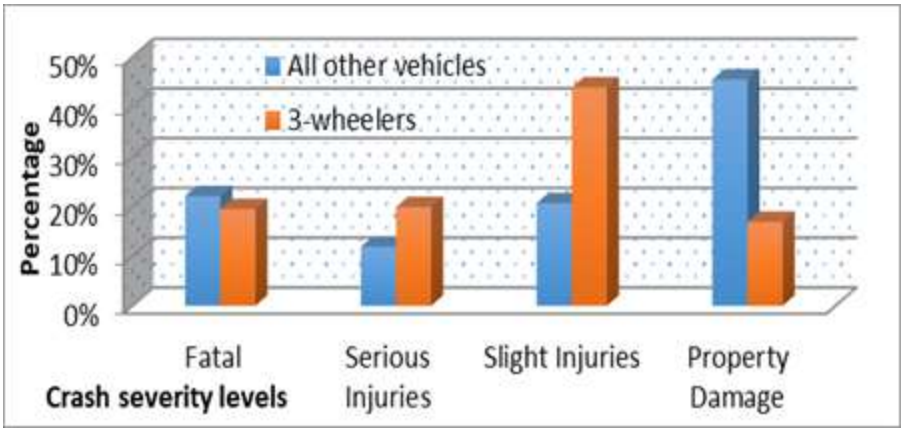

Figure 4. 6 Gender based statistics for crime data

In the study area, Wednesday is the biggest market day, which creates favorable conditions for perpetrators to commit a crime. Offenders use a method of distraction and deception to steal someone's property (mainly a cell phone and money). When there is a lot of chaos and there is not enough transport access, the criminals may pretend to be a coordinator and confuse the passengers, or they may take advantage of the situation by mixing with the passengers by pretending to be a passenger. As a result, the largest number of incidents (114, or 18%) of crimes were committed on Wednesday. The evidence obtained from the police data indicated that three-wheeler drivers were victims of the crime, and in another way, they were also involved in criminal activities. From the total (584) crimes committed in the city, in 23% (133 crime incidents), the drivers were involved; out of these (133 crimeincidents), 6% of the crimes were committed by the drivers alone; and in 100 incidents (17%), the drivers involved themselves directly with their associates.

4.2.1 Three-wheeler related crime types The criminal activity accounting for the highest statistics (69%, 437 incidents) was theft (pickpocketing). Perpetrators use different methods to steal property from passengers, including hitting or striking, deception, and stealing/pickpocketing by distraction. Throughout the three-year period, the second most popular crime was beating, which accounted for 11% of the total crimes committed in the city. Snatching (48 incidents, 8%) was the other crime type that takes the third rank in the total crime category. Perpetrator's snatch some one's bag, phone, or money, then immediately escape by three-wheeler. Robbery, including attempted robbery, accounted for about 5% (29 incidents) of total crimes, followed by fraud and kidnapping, which accounted for 3% each with 20 and 17 incidents, respectively. The criminal events (especially theft) showed an increasing trend for the three consecutive study years. The main reason here is the low-level enforcement of crime control by the police. The increase in three-wheeler taxis and social activities in the city creates a favorable environment for criminals. Following that, the security monitoring should grow together, but in reality, it does not show that. Evidence obtained from questionnaire data in this study indicated that out of the total crime victims who participated in the survey, 64% didn't report the crime to the police, and their reason was that "others who have applied before me have not received a favorable response (I think I won't get a solution)", not only this, but the majority of the respondents who reported the crime to the police also said that they didn't get any response from the police. To investigate the relationship between victims' gender, shift of the day, and driver

involvement in criminal incidents as independent variables and crime types (dependent variables), crime data obtained from police stations was analyzed using multinomial logistic regression. Null hypothesis: H0= adding the independent variables of victims' gender, driver involvement, and shift of the day do not have a significant relationship with crime. In testing the interaction effects, the independent variables were found to affect the dependent variable (the null hypothesis was rejected). And the analysis result indicated that 3-wheeler-related theft crimes were more commonly committed during the day than at night. The reason for this is that during the day, human activities to perform different tasks are higher than at night, and following that, three-wheeler activity is also higher to serve the people. Not only this, but the majority of theft crimes were also committed inside three-wheelers. As a result, theft crimes were higher during the day than at night. In considering the gender of victims, there was a lower probability for male three-wheeler users to be stolen, snatched, and exposed to other crimes (insulting, sexual assault, and grabbing) than their probability to be beaten or hit. To the contrary, female travelers were exposed to these crime types rather than beating and hitting. Based on the evidence obtained from multinomial logistic regression, the chance of male passengers being exposed to robbery or snatching was about 75% (3 times) lower than the chance that they were exposed to beating crimes (OR = 0.333, 95% CI (0.154–0.722). Regarding driver involvement in crimes, the driver's involvement in other crimes (insulting, sexual assault, threatening with weapons, and grabbing) was higher than their involvement in theft crimes. Additionally, the likelihood that the driver's involvement in robbery/snatching and beating crime types was 5.9 and 3 (95% CI (1.691, 5.352)) times higher than the likelihood of their involvement in theft crimes, respectively. Moreover, the drivers were more likely involved in robberies and snatchings than in beating or hitting crimes (OR = 0.512, 95% CI (0.268, 0.975)). Related to this, most of the crimes recorded as robbery in this study were either committed by the drivers or the drivers directly involved in it with their associates. For instance, shops and restaurants were robbed by three wheelers, and indirectly, it indicates the driver's engagement in the crimes.

Table 4. 4 Estimated parameters for crime type

Parameter Estimates

Crime Types	predictor variables	B	Std. Error	Wald	df	Sig.	Exp(B)	95% CI for Exp(B) Lower Bound	95% CI for Exp(B) Upper Bound
Theft	Intercept	1.815	0.386	22.167	1	0.000			
	shift of the day (night time=1)	-1.146	0.332	11.951	1	0.001	0.318	0.166	0.609
	shift of the day (day time=2)	0[b]			0				
	gender of victim(male=1)	-0.916	0.347	6.943	1	0.008	0.400	0.203	0.791
	gender of victim(female=2)	0[b]			0				
	Driver involvement (not involved at all=1)	1.101	0.294	14.036	1	0.000	3.008	1.691	5.351
	Driver involvement (driver involved=2)	0[b]			0				
Robbery/ snatching	Intercept	1.513	0.416	13.246	1	0.000			
	shift of the day (night time=1)	0.078	0.377	0.043	1	0.836	1.081	0.517	2.262
	shift of the day (day time=2)	0[b]			0				
	gender of victim(male=1)	-1.099	0.395	7.759	1	0.005	0.333	0.154	0.722
	gender of victim(female=2)	0[b]			0				
	Driver involvement (not involved at all=1)	-0.670	0.329	4.144	1	0.042	0.512	0.268	0.975
	Driver involvement (driver involved=2)	0[b]			0				
Other crimes	Intercept	1.176	0.454	6.716	1	0.010			
	shift of the day (night time=1)	0.308	0.442	0.484	1	0.486	1.360	0.572	3.236
	shift of the day (day time=2)	0[b]			0				
	gender of victim(male=1)	-1.236	0.450	7.553	1	0.006	0.291	0.120	0.702
	gender of victim(female=2)	0[b]			0				
	Driver involvement (not involved at all=1)	-1.351	0.394	11.736	1	0.001	0.259	0.120	0.561
	Driver involvement (driver involved=2)	0[b]			0				

a. The reference category is: Beating/hitting.
b. This parameter is set to zero because it is redundant.

1.1.1 Application of binomial logistic regression on crime place

In this study, "crime place" is defined as the location of crimes committed by offenders using three wheelers, including inside the vehicle, at stations, while traveling, and in nearby areas like villages, hotels, and off-street locations. Descriptive statistics showed that 57% of crimes were committed inside the vehicle, with 21% occurring at stations and 12% on the way to or from stations. Other categories included crimes in villages, robbery from restaurants, kidnapping, and theft of the three-wheeler itself, which account for 10% (59 incidents) of the total crime. The analysis categorized crime places as binomial dependent variables, with crimes committed outside the vehicle and inside the vehicle. Null hypothesis: the variables (crime type, victims' type, shift of the day, and the drivers' involvement in crimes) do not have a significant relationship with the dependent variable (the place where the crime was committed). Omnibus tests of model coefficients were used to test the model fit; hence, the model is showing a good fit. Therefore, the null hypothesis was rejected, and the full model has a significant prediction performance ($\chi 2 = 122.873$; $df = 6$; $P < 0.001$), which means that the independent variables had a significant relationship with the dependent variable. According to the regression result, the likelihood of nighttime crimes being committed inside the three wheeler was 2.2 (1/0.457) times higher than the chance of daytime crimes being committed inside the three-wheeler (OR = 0.457, 95% CI (0.27–0.773). As the drivers spent most of the time inside the vehicle, the likelihood that the crimes committed on three wheeler drivers being inside the vehicle was 2.4 (95% CI: 1.507, 3.845) times higher than the likelihood that passengers were attacked by perpetrators inside the vehicle. When offenders work in collaboration with the drivers, they use different techniques like distraction and deception in order to divert the target passenger's attention, and the majority of the crimes were also committed by loading the perpetrators as

passengers and coordinating with the drivers. As a result, the three-wheeler drivers had a higher chance of involvement in crimes that were committed inside the vehicle than outside the vehicle (OR = 1.499, 95% CI = 0.955–2.354). Regarding crime types, there was a higher chance of theft crimes (7.4 times higher) being committed inside the three-wheelers than robbery and snatching being committed in the same place. In this case, there should be enough space and time for the offenders to snatch/rob something and to escape before they are caught by either the police or the victim himself. Due to that, there was a greater chance of snatching and robbery being committed outside the vehicle than inside it. Similarly, beating and hitting crimes were less likely to be committed inside the vehicle than theft crimes. When the comparison was made between beating and robbery/snatching, there was a relatively higher probability for robbery and snatching to occur inside the vehicle than beating crimes (OR = 1.55, 95% CI = 0.729–3.275). In general, theft crimes were more likely to occur inside the three-wheeler than other crimes included in the analysis of this particular model; however, beating, robbery, and snatching crimes were less likely to occur inside the vehicle than other crimes (insulting, sexual assault, fraud, and grabbing). In addition to the secondary data, ordinal logistic regression was employed on the primary data (passengers security feelings and their satisfaction level related to security). The result revealed that male travelers and more frequent travelers feel more secure and satisfied than female travelers and less frequent travelers, respectively. Besides this, passengers aged between 16 and 26 also had a higher security and satisfaction level than older and younger travelers. Furthermore, students feel more secure than others. Related to their satisfaction level, travelers who use the 3-wheeler to travel for shopping and for recreation purposes are more satisfied with the 3 wheeler than other travelers. More generally, the majority of three-wheeler users felt unsecure and dissatisfied with three-wheeler services.

Table 4. 5 Odds ratio table for binomial logistic regression

Variables in the Equation									
Predictor Variables	Categories	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I for EXP(B)	
								Lower	Upper
Shift of the Day	day	-0.78	0.269	8.502	1	0.004	0.457	0.27	0.773
	night								
Crime Victim	driver	0.878	0.239	13.508	1	0.000	2.407	1.507	3.845
	passengers								
Driver Involveme	drivers involved	0.405	0.23	3.095	1	0.079	1.499	0.955	2.354
	not involved at all								
Crime Types	theft			86.303	3	0.0000			
	robbery/snatching	-1.99	0.279	51.234	1	0.0000	0.136	0.079	0.235
	other crimes	-1.24	0.337	13.527	1	0.0000	0.289	0.149	0.56
	beating	-2.43	0.333	53.263	1	0.0000	0.088	0.046	0.169
	Constant	1.272	0.276	21.265	1	0.0000	3.569		

Table 4. 6 Ordinal logistic regression results for passengers' satisfaction level

Predictors		B	Exp(B)	Predictors		B	Exp(B)
Gender	Male=1	0.541	1.717	Age	<=15=1	-0.92	0.397
	Female=2	0a	1		16-26=2	0.208	1.231
Marital status	Married=1	-0.481	0.618		27-40=3	0.083	1.087
	in a relationship=2	-0.609	0.544		>=41=4	0a	1
	Others=3	-2.912	0.054	Educational level	Un-educated1=1	-0.09	0.919
	Divorced=4	-0.732	0.481		Basic education=2	0.089	1.093
	Single (never married) =5	0a	1		Primary school (1-8) =3	0.452	1.571
Purpose of travel	Work=1	0.067	1.07		Secondary school (9-12)	0.19	1.209
	Market/Shopping=2	1.33	3.78		Collage graduate=5	0.88	2.41
	Recreation=3	1.728	5.632		Degree and above=6	0a	1
	Others=4	0.346	1.413	Travelers's occupation	Student=1	1.101	3.006
	School/Education=5	0a	1		Government=2	0.505	1.657
Travel frequency	1-2 days=1	-0.187	0.83		Private=3	0.99	2.691
	3-4 days=2	-0.333	0.717		Daily labor=4	0.907	2.476
	5 days and more=3	0a	1		Others=5	2.243	9.418
source: - spss output from questionnaire survey data					Un employed=6	0a	1

5. CONCLUSIONS

- The study revealed that pedestrian collisions were the most common type of collision in 3 wheelers, followed by overturning, with overturning having a higher likelihood than pedestrian collisions and vehicle-to-vehicle collisions.
- The types of accidents involving the falling of passengers from the vehicle and passengers jumping and falling from the vehicle were observed mainly in three-wheelers.
- Three-wheeler crashes in the city were primarily caused by lack of caution, speeding, failure to give way to pedestrians and vehicles, technical problems, and lack of experience. Additionally, Inadequate capacity of the road to accommodate the existing traffic was the major cause of crashes in the city.
- Factors affecting crash severity include vehicle type, crash type, and cause. Most 3-wheeler crashes result in injury, with pedestrian collisions being the leading cause of injury and fatal crashes. Lack of caution was more likely to cause injury and property damage in accidents than fatal ones, while speeding was more likely to cause fatal crashes.

The following conclusions are drawn from the analysis results in relation to the study's objectives.

- In Kombolcha city, the most common three wheeler crime types include theft, beating,

snatching, robbery, fraud, and kidnapping, with theft being the most prevalent.

- Nighttime crime rates were higher for beating and robbery, while theft rates were higher during the day. 3-wheeler drivers were involved in all criminal activities.
- Criminals use deception and distraction techniques to commit crimes, including boarding as a passenger by coordinating with drivers and renting a three-wheeler.
- Regarding crime-occurring places, victim type, driver involvement, and crime types had a significant relationship with the crime places (inside the vehicle or outside the vehicle).
- Drivers are more likely to be involved in crime within 3-wheelers than passengers, and are more exposed to criminal incidents inside the vehicle.
- Theft crimes were more common inside the three-wheelers, while beating, robbery, and snatching crimes were less common inside the vehicle

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Experimental and simulation analysis of biogas production from beverage wastewater sludge for electricity generation

Abstract

This study assessed the biogas and methane production potential of wastewater sludge generated from the beverage industry. The optimization of the biogas production potential of a single fed-batch anaerobic digester was operated at different temperatures (25, 35, and 45 ℃), pH (5.5, 6.5, 7.5, 8.5, and 9.5), and organic feeding ratio (1:3, 1:4, 1:5, and 1:6) with a hydraulic retention time of 30 days. The methane and biogas productivity of beverage wastewater sludge in terms of volatile solid (VS) and volume was determined. The maximum production of biogas (15.4 m3/g VS, 9.3 m3) and methane content (6.3 m3/g VS, 3.8 m3) were obtained in terms of VS and volume at 8.5, 35 ℃, 1:3 of optimal pH, temperature, and organic loading ratio, respectively. Furthermore, the maximum methane content (7.4 m3/g VS, 4.4 m3) and biogas production potential (17.9 m3/g VS, 10.8 m3) were achieved per day at room temperature. The total biogas and methane at 35 ℃ (30 days) are 44.3 and 10.8 m3/g VS, respectively, while at 25 ℃ (48 days) increased to 67.3 and 16.1 m3/g VS, respectively. Furthermore, the electricity-generating potential of biogas produced at room temperature (22.1 kWh at 24 days) and optimum temperature (18.9 kWh) at 40 days was estimated. The model simulated optimal HRT (25 days) in terms of biogas and methane production at optimum temperature was in good agreement with the experimental results. Thus, we can conclude that the beverage industrial wastewater sludge has a huge potential for biogas production and electrification.

Keywords: Anaerobic digestion, Methane, Biogas, Beverage industry wastewater sludge, Volatile solids, Simulatio

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Energy System Management in Historic Cities, Yazd World Heritage Area

The emergence of the smart city concept has successfully influenced various dimensions of urban space. In this context, it is crucial to re-evaluate urban area management systems in the context of smart concepts. Energy management systems have become one of the most affected areas of urban management systems. Energy management systems include a set of technologies and processes aimed at monitoring, controlling and optimizing energy consumption. These systems are used to increase energy efficiency, reduce costs, promote sustainable energy use, and minimize

environmental impacts.
The energy management systems of historic cities that are World Heritage Sites are of particular importance in achieving sustainable development goals and in preserving, revitalizing, and improving the quality of life. In addition, energy management systems should be integrated in historic cities to reduce environmental impacts and lower energy costs. The application of these systems should be diverse and take into account the unique characteristics of different climates.
This article focuses on the energy management system of the historic city of Yazd, a UNESCO World Heritage Site. The aim is to rethink Yazd's energy management system within the framework of the smart energy concept and propose a new framework. The use of smart methods and advanced technologies will play a crucial role in increasing the city's sustainable energy potential. The integrated analysis, monitoring and use of data collected through the proposed methods within the energy management system aim to increase the city's energy efficiency. The research addresses the question of how to increase energy efficiency and enhance the quality of life in historic cities, specifically focusing on the case of the Yazd World Heritage Site. It aims to explore the potential benefits of integrating smart methods and advanced technologies in the city's energy management system. The study employs a mixed-method research methodology, combining experimental research, survey research, and case study research. This approach allows for a comprehensive analysis of the current energy management system in Yazd and the potential improvements that can be made.
The aim of the article is to examine the increase in energy efficiency in world heritage sites. In this context, a new energy management system is proposed for the Yazd World Heritage Site by reviewing the framework and elements of the smart city concept. It is aimed to positively impact the dimensions of preservation, revitalization, and improvement of the quality of life through the integrated management of the city's energy system within the framework of sustainable energy.

Keywords: Sustainable Energy, World Heritage Area, Energy Efficiency, Energy Management, Yazd

Dr. Florence Appiah-Twum (Author) *Jiangsu University*	**Dynamic Environmental Efficiency Assessment and determinants; Evidence from Asia Pacific Countries.**

Abstract

The pursuit of socio-economic growth has come at a cost and at the expense of eco-protection. Globally, countries are experiencing alarming climate change due to the excessive use of energy inputs, resulting in the indiscriminate release of gaseous pollutants, hazardous to human survival. It is, therefore, essential to identify the convergence point of economic growth and eco-performance today. Whiles past researches have mostly focused on the use of static efficiency, the dynamic connectors of the crossover factors in productivity have seriously been neglected, especially in studies of the Asia Pacific countries. Moreover, eco-efficiency trends and patterns over time have also been ignored, giving need for this study. This study employs the dynamic slack-based measurement (DSBM) within the Data Envelopment Analysis (DEA) model to evaluate dynamic environmental efficiency of 15 Asia pacific countries from the period 2010 to 2018, applying energy

stock as the crossover variable factor. Moreover, this research examines the inputs, output and crossover factors inefficiency within the model to point out likely areas of inefficiencies. The findings show that the selected Asia Pacific countries are environmentally inefficient and seriously need to consider adjustments and projections on their use of inputs, output as well as crossover factors in order to enhance eco-efficiency. Policy makers need to keenly strengthen and enforce measures such as the adoption of clean and green technologies, enforcement of carbon and pollution taxes on dirty industries.

Keywords: Socio-economic growth, eco-protection, gaseous pollutants, climate change, eco-performance, environmental efficiency, Asia Pacific countries, eco-efficiency trends and patterns

Bless Kofi Edziah (Author) *Jiangsu University*	**Analyzing Material Efficiency in Sub-Saharan Africa: Does Technology Transfer Matter?**

Abstract

In recent years, Africa has seen a rise in demand for food, energy, minerals, and traditional bulk materials, contributing to increased greenhouse gas emissions. Despite international commitments to limit emissions, such as those outlined in the Paris Agreement, achieving these objectives necessitates significant technological investment and substantial modifications to energy and production systems. Given Africa's limited R&D and financial constraints, countries in the region rely on foreign technology to enhance productivity and efficiency. However, the effectiveness of these technologies in improving material efficiency remains uncertain. This research looks at how technology transfer from outside of Africa affects the efficiency of materials in 23 SSA countries from 1990 to 2019 using the material distance function of stochastic frontier analysis. Through various robustness tests, the results indicate that technological transfer significantly enhances material efficiency across SSA countries, with energy prices, economic structure, and population density also exerting significant influences. These findings indicate that there are significant synergies among SDG 13, SDG 12, and SDG 9. Furthermore, the study shows that even though material efficiency scores are generally high, a test that separates unobserved country effects from persistent and transient inefficiencies to figure out total material efficiency shows lower levels because of persistent inefficiencies. This emphasizes the long-term nature of material inefficiency, stressing the need for government policies focused on improving managerial skills, advancing technology, and organizing production processes effectively. While this study shows how technology enhances material efficiency in Africa, we acknowledge data limitations in some cases, highlighting the need for further research to validate these findings.

Keywords: material demand, material efficiency, technology transfer, productivity, stochastic frontier analysis

Owusu Elvis Agyemang (Author) *Naagee Automobile Enterprise*	**Emergency Response and Disaster Management in Africa – A Case study in Ghana**

Abstract:

Emergency response and disaster management in the transport sector are critical for ensuring the safety and resilience of transportation systems, particularly in Africa where infrastructural challenges often exacerbate the impact of disasters. This study examines the case of Ghana to assess its emergency response and disaster management strategies within the transport sector.

Introduction:

Transportation networks are vulnerable to various natural and man-made disasters, including accidents, floods, and infrastructure failures, which can disrupt services and endanger lives. In Africa, these challenges are often compounded by limited resources and infrastructure deficiencies. Understanding the effectiveness of emergency response and disaster management in the transport sector is essential for mitigating risks and improving resilience.

Method:

This research employs a mixed-method approach, combining qualitative analysis of policy documents, interviews with key stakeholders, and quantitative assessment of disaster response metrics. Data collection includes review of relevant literature, government reports, and field observations to provide a comprehensive understanding of Ghana's emergency response and disaster management framework within the transport sector. The method employed involved a comprehensive literature review, analysis of existing policies and practices, as well as interviews with key stakeholders involved in disaster management efforts in Ghana.

One significant challenge in Ghana is the state of road infrastructure, which can contribute to road accidents and other transportation-related emergencies. Poor road conditions, inadequate signage, and a lack of enforcement of traffic laws increase the risk of accidents. In response, the Ghanaian government, with support from international organizations and NGOs, has been working to improve road safety through initiatives such as road maintenance programs, public awareness campaigns, and training for drivers and emergency responders.

A case study illustrating emergency response and disaster management in transport in Ghana is the June 2015 fuel tanker explosion on the Accra-Tema motorway. The explosion resulted from a collision involving multiple vehicles, including a fuel tanker carrying petroleum products. The incident led to numerous casualties and extensive damage to infrastructure.

In response to the disaster, emergency services, including firefighters, medical personnel, and law enforcement agencies, were deployed to the scene to provide immediate assistance. However, challenges such as limited resources, traffic congestion, and communication difficulties hampered the response efforts. Additionally, the incident highlighted the importance of pre-planning and coordination among emergency responders to effectively manage such emergencies.

Following the fuel tanker explosion, there was increased attention to improving emergency response capabilities in Ghana. The government implemented measures such as the establishment of emergency response teams, training programs for first responders, and the procurement of equipment and resources. Additionally, efforts were made to enhance coordination among relevant agencies and stakeholders to ensure a more efficient response to future transportation-related disasters.

Moving forward, ongoing investment in infrastructure development, capacity building, and community engagement will be crucial for enhancing emergency response and disaster management in transport across Africa, including Ghana. By addressing these challenges and implementing proactive measures, countries can better mitigate the impact of transportation-related emergencies and protect the safety and well-being of their citizens.

Results:

Preliminary findings indicate that while Ghana has established policies and frameworks for emergency response and disaster management in the transport sector, there are significant gaps in implementation and coordination among relevant agencies. Challenges such as inadequate funding, limited resources, and capacity constraints hinder effective disaster preparedness and response efforts. However, there are also notable examples of successful interventions and community resilience initiatives that offer valuable insights for improvement.

Keywords:

Emergency Response, Disaster Management, Transport Sector, Africa, Ghana, Resilience, Preparedness, Coordination, Infrastructure, Risk Mitigation.

Conclusion:

The study underscores the importance of strengthening emergency response and disaster management capabilities within Ghana's transport sector to mitigate the impact of disasters and enhance overall resilience. Addressing key challenges such as institutional coordination, resource allocation, and community engagement is crucial for improving preparedness, response, and recovery efforts. Lessons learned from Ghana's experience can inform policy and practice not only within the country but also across the African continent.

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Numerical Simulation of Biomass Pyrolysis for Increasing Bio-Oil Yield: Insights for Renewable Biofuels from Solid Wastes in a Biomass Pyrolysis Process.

Abstract

Pyrolysis process of biomass materials, wherein the feedstock is heated in the absence of oxygen, is an attractive method for producing bio-oil, providing a sustainable substitute for fossil fuels. In this study, the pyrolysis of an individual biomass particle has been simulated under various conditions, examining the effects of parameters such as particle density, moisture content, and reactor wall temperature on tar yield mass fraction and time to reach 95% conversion. It was observed that at higher temperatures, the tar yield mass fraction increases, and porous particles with smaller size and lower density exhibit potential for achieving higher tar yields. Additionally, regarding the application, the virgin biomass decomposes into tar (liquid phase) and gas (gas phase), along with char (solid phase); the tar and liquefied gas, with minor refining, could serve as a liquid fuel akin to diesel, while the char or ash could be utilized as a base for new applications, primarily in green concrete applications. Finally, the model has been validated against experimental results, showing good agreement.

Keywords: Biomass Pyrolysis, Bio-oil, Tar yield, Mass fraction, Moisture content, Particle density, Numerical simulation, biofuels, biodiesel, waste management, renewable energy, Green concrete, environmental sustainability.

NOMENCLATURE

A_i	pre-exponential factor, s^{-1}	V	volume, m^3
C	specific heat capacity, $J \cdot kg^{-1} \cdot K^{-1}$	ε	emissivity
D	diffusivity, $m^2 \cdot s^{-1}$	λ	thermal conductivity, $W \cdot m^{-1} \cdot K^{-1}$
d_p	particle pores diameter, m	ρ	density, $kg \cdot m^{-3}$
E_i	activation energy, $J \cdot mol^{-1}$	σ	Stefan–Boltzmann constant, $W \cdot m^{-2} \cdot K^{-4}$
e_p	Porosity		***Subscripts***
H	enthalpy, J	*0*	initial value
h_c	convection coefficient, $W \cdot m^{-2} \cdot K^{-1}$	*B*	virgin biomass
k_i	reactions rate constants, s^{-1}	*C*	Char
m	mass, kg	*con*	conduction
q_i	heat of reaction, $J \cdot kg^{-1}$	*eff*	effective
R	gas constant, $J \cdot mol^{-1} \cdot K^{-1}$	*G*	Gas
r	radius, m	*m*	moisture
S	area, m^2	*rad*	radiation
T	temperature, K	*s*	Solid
t	time, s	*T*	Tar

1. Introduction

Securing adequate energy supplies in an environmentally responsible manner is a key challenge of the 21st century. Addressing this issue will demand significant resources, and every proposed solution is likely to be contentious [1]. Fossil fuels have been known as the main contributor to the world climate change. Confronting the global warming, decreasing in emissions of greenhouse gases is needed and critical. An attractive and effective solution can be replacing fogassil fuels by renewable, widely available, cheap and clean fuels. Today, wood waste (such as bark, sawdust, timber waste, and sawmill scraps), agricultural residues (including straw from grains, husks from rice, fruit and vegetable peels and scraps, and sugarcane bagasse), and municipal solid wastes (MSW), collectively known as biomass, are extensively used as renewable energy sources and sustainable alternatives to fossil fuels. The process of using biomass for power generation is considered carbon neutral, as the CO2 released during combustion is offset by the CO2 absorbed by the plants from which the biomass is derived.

Biomass is used in heat or power generation system in two categories, modern and conventional [1]. The practice of heating feedstock in the absence of oxygen, initially undertaken commercially by a company in London in 1812, leads to the thermal decomposition of the fuel into solid carbon and volatile gases. This process occurs during gasification, liquefaction, or carbonization [2]. Using the pyrolysis route, low chemical energy density biomass fuel can be transformed into high energy density char, a high energy density liquid (condensed vapors known as tars), and a medium energy density gas. Tars are typically separated and can be utilized as liquid fuel. Examples of modern fuels include biodiesel, ethanol, synthetic gas, and liquor, as they are either manufactured fuels or byproducts of manufacturing processes. Conventional fuels encompass unprocessed wood waste, straw, and charcoal, which are utilized in combustion systems. Combustion stands as the most direct method for converting biomass into usable energy and finds application in various sectors. Igniting biomass materials necessitates high temperatures, and once ignition occurs, assuming a sufficient air supply, combustion will progress in either a fixed or fluidized bed [3-4].

The design of a combustion or gasification system is significantly influenced by the specific biomass material, including its structure, moisture content, and the presence of contaminants. Understanding the mechanisms and processes involved in biomass particle devolatilization is vital for enhancing the efficiency of combustion or gasification systems. Devolatilization of large particles, typically those larger than a few micrometers, occurs in the thermally thick regime, leading to the overlapping of different degradation stages. The process of biomass particle devolatilization is complex, with various factors such as particle size and shape, density, heating rate, porous structure, and moisture content influencing the pyrolysis process and its outcomes. Pyrolysis modeling comprises two main components: kinetic modeling of chemical reactions during the pyrolysis process and modeling of transport phenomena. Developing an optimal thermo-chemical conversion system requires extensive studies on the kinetics of different materials under various operating conditions [5]. Peters and Bruch developed a numerical model to simulate the thermal decomposition of wood waste particles undergoing drying and pyrolysis. They employed a one-step global kinetic model that treats pyrolysis as a single-step first-order reaction [6]. These one step global kinetic models pyrolyze the biomass into volatiles and a fixed char yield. In large particles, volatiles and tars don't leave the particle immediately, so they would be influenced by secondary reactions. Secondary tar cracking respected, Shafizadeh suggested a kinetic model which decomposes tar to light gases and char [7]. This kinetic model is particularly valuable as it considers primary pyrolysis products along with their secondary cracking. Based on the kinetic model proposed by Shafizadeh [7], Hagge and Bryden developed a numerical method for modeling the shrinkage of biomass particles. They noted that shrinkage has minimal effect on pyrolysis in both the thin ($Bi < 0.2$) and thick ($0.2 \leq Bi \leq 10$) pyrolysis regimes. However, under thermal wave pyrolysis conditions ($Bi > 10$), shrinkage impacts both the duration of pyrolysis and the resulting pyrolysis products. Nevertheless, their model has limitations concerning particle size and disregards the influence of drying [8].

Moisture content is another crucial factor that can influence reaction pathways. Saastamoinen and Richard proposed a straightforward method for modeling simultaneous drying and pyrolysis within a biomass particle. They treated drying as a sink in the energy equation at 100°C [9-10]. Alves and Figueiredo took drying as an additional reaction and described it in an Arrhenius form with fitting parameters. With this approach they presented a numerical model of the pyrolysis of particles with high content of moisture. Their model can simulate satisfactorily the weight loss due to pyrolysis of cylinders of dry wood between 300°C and 800°C [11]. Janse et al. devised a numerical model for flash pyrolysis of an individual wood particle [12]. According to their study, the bio-oil yield is scarcely affected by particle size and shape. In a comprehensive review paper, Di Blasi extensively elaborated on the current state of modeling the chemical and physical processes involved in wood and biomass pyrolysis [13]. She listed some important parameters which determine the pyrolysis route and alter the composition of product.

Since particles which are used in modern combustion systems are in the range of lower than few millimeters, it is reasonable to assume that all particles are spherical in shape. In this study, the pyrolysis process of a spherical biomass particle is simulated and the effects of some physical parameters have been numerically investigated. In the next section, mathematical model considering complete description of assumptions and detail of chemical kinetic and transport phenomena is presented. In the result section, the effect of the dominant parameters is investigated.

1. Mathematical Model

Biomass materials exhibit both chemical and physical heterogeneity, resulting in pyrolysis products that are similarly diverse. As a single particle of biomass exchanges energy by both radiation and convection heat transfer mechanisms and by chemical reactions in a reactor, it undergoes drying and pyrolysis processes. The objective of this study is to construct a model capable of simulating the pyrolysis process of an individual biomass particle. Thus, a biomass particle of spherical shape of radius R is considered and some assumptions are made in developing a tractable mathematical pyrolysis model, the most important of them being:

- One-dimensional particle geometry is assumed;
- The particle is homogenous;
- A local thermal equilibrium is present between the gas phase and the solid matrix within the particle,
  ensuring uniform internal temperatures and gradients for all species; Particle porosity will remain constant during the conversion process;
- Heat transfer inside the particle takes place by conduction and the effect of other possible mechanisms is
  represented by heat transfer coefficients;
- Mass transfer of pyrolysis products occurs by diffusion.

The model consists of three components: (1) Kinetic modeling, (2) Mass conservation modeling and (3) Energy conservation modeling.

1.1. Kinetic Modeling

Based on kinetic model suggested by Shafizadeh [7], shown in Figure 1, the pyrolysis process occurs in primary and secondary steps. Inside the pyrolyzing particle, at the primary step, biomass decomposes to tars, gases and char. At the secondary step, the secondary cracking reactions decompose produced tars to gases and char. Beside these, using a chemical reaction model, wood drying under heat fluxes would be described. In this model, the evaporation rate of moisture proceeds by a chemical reaction rate expression.

According to the above discussions, the model involves five different species: virgin biomass, gases, tars, char and moisture. The primary and secondary reactions are represented as first order and having an Arrhenius type to describe the temperature dependence of the kinetic rate coefficients as indicated in Eq. (1):

$$ki = Ai\ exp\ (-\frac{Ei}{RT})$$

Various rate coefficients describing chemical reaction kinetic of biomass pyrolysis have been reported in literature. It seems that primary reactions are endothermic while secondary reactions are slightly exothermic. The applied kinetic parameters in the present study are chosen from [14-18], and appear in Table 1.

1.1. Mass conservation modeling

According to the chosen kinetic model, the differential equation describing the mass conservation of virgin biomass is:

$$\frac{\partial m_B}{\partial t} = -(k1 + k2 + k3)m_B \quad (2)$$

where $m_B = \varrho_B V$ and V is defined as the volume of the solid matrix instead of the volume of the particle. However, with respect to this point and neglecting the shrinkage and swelling of the particle, Eq. (2) could be expressed as:

$$\frac{\partial \varrho_B}{\partial t} = -(k1 + k2 + k3 + k6)\varrho_B \quad (3)$$

As seen in Eq. (3), based on the primary reactions, there are four consumption terms for virgin biomass, one each for the reactions to gases, tars, and char and one term for the vaporization of particle moisture content reaction. Unlike the virgin biomass, mass conservation of tars would be expressed by a partial differential equation due to the transport phenomena:

$$\frac{\partial m_T}{\partial t} = \frac{\partial}{\partial r}\left(S_T D_T \frac{\partial (m_T / V)}{\partial r} V\right) + k_2 m_B - (k_4 + k_5)m_T \quad (4)$$

On the right-hand side of Eq. (4), the first term refers to the diffusion of tars derived from Fick's law, second term stands for the primary reactions source term and third the term represents the consumption of tars due to the secondary reactions. Similar to the virgin biomass, $m_T = \varrho_T V_v$ and V_v is defined as the void volume of the particle pores instead of the volume of the particle. An expression for the particle porosity is:

$$ep = \frac{V_v}{V} \quad (5)$$

Based on the above discussions and making some simplifications with respect to model assumptions, Eq. (4) can be written as:

$$\frac{\partial (e_p \varrho_T)}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\{r^2 [D_T \frac{\partial (e_p \varrho_T)}{\partial r}]\} + k2\varrho_B - ep(k4 + k5)\varrho_T \quad (6)$$

Similar to the virgin biomass and tars, mass conservation equations of gases, char and moisture are, respectively:

$$\frac{\partial m_G}{\partial t} = \frac{\partial}{\partial r}\left(SD \frac{m_G}{m_V}\right) \frac{\partial(\quad)}{\partial r} + k_1 m_B + k_4 m_T \quad (7)$$

$$\frac{\partial m_C}{\partial t} = k_3 m_B + k_5 m_T \quad (8)$$

$$\frac{\partial m_m}{\partial t} = \frac{\partial}{\partial r}\left(SD \frac{m_m}{m_m}\right) \frac{\partial(\quad)}{\partial r} + k_6 m_B \quad (9)$$

Using the apparent density of species and porosity of the particle, Eqs. (7)-(9) could be rewritten as:

$$\frac{\partial(\varepsilon_p \rho_G)}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\{r^2 [D_G \frac{\partial(\varepsilon_p \rho_G)}{\partial r}]\} + k_1 \rho_B + \varepsilon_p k_4 \rho_T \quad (10)$$

$$\frac{\partial \rho_C}{\partial t} = k_3 \rho_B + \varepsilon_p k_5 \rho_T \quad (11)$$

$$\frac{\partial(\varepsilon_p \rho_m)}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\{r^2 [D_m \frac{\partial(\varepsilon_p \rho_m)}{\partial r}]\} + k_6 \rho_B \quad (12)$$

It should be noted at this juncture that there is a constraint on the moisture content of the virgin biomass. When employing the existing model, the moisture content of the virgin biomass must be specified as an input parameter. Initial conditions for a virgin particle at $t = 0$, are:

$$\rho_B = \rho_{B0} \quad (13)$$
$$\rho_T = \rho_G = \rho_C = \rho_m = 0$$

Due to the spherical symmetry existing at the center of the particle, related boundary conditions for the Eqs. (6), (10) and (12) at $r = 0$, are:

$$\frac{\partial \rho_T}{\partial r} = \frac{\partial \rho_G}{\partial r} = \frac{\partial \rho_m}{\partial r} = 0 \tag{14}$$

On the other hand, boundary conditions regarding the Eqs. (6), (10) and (12) at $r = R$ could be derived from a mass balance equation on the surface of the particle which results in:

$$k_3\rho_B - e_p(k_5 + k_6)\rho_T = {}_r[D_T \frac{3}{r} \frac{\partial(e_p\rho_T)}{\partial r}] \tag{15}$$

$$k_1\rho_B + e_p k_4\rho_T = {}_r[D_G \frac{3}{r} \frac{\partial(e_p\rho_G)}{\partial r}] \tag{16}$$

$$k_6\rho_B = {}_r[D_m \frac{3}{r} \frac{\partial(e_p\rho_m)}{\partial r}] \tag{17}$$

2.3. Energy conservation modeling

As mentioned previously, it is assumed that heat transfer inside the particle occurs by conduction only. Thus, the partial differential equation which describes the energy conservation could be expressed as:

$$\frac{\partial H}{\partial t} = \frac{\partial}{\partial r}(S\lambda_{eff}\frac{\partial T}{\partial r}) + (k_1q_1 + k_2q_2 + k_3q_3 + k_6q_6)m_B + (k_4q_4 + k_5q_5)m_T \tag{18}$$

where

$$H = (m_Bc_B + m_Cc_C + m_Tc_T + m_Gc_G + m_mc_m)T \tag{19}$$

Substituting Eq. (19) into Eq. (18) and making some simplifications, energy conservation of the particle could be expressed in another way:

$$\frac{\partial}{\partial t}[(\rho_B c_B + \rho_C c_C + \varepsilon_p \rho_T c_T + \varepsilon_p \rho_G c_G + \varepsilon_p \rho_m c_m)T] = \frac{1}{r^2}\frac{\partial}{\partial r}\left(\lambda_{eff} r^2 \frac{\partial T}{\partial r}\right) + (k_1 q_1 + k_2 q_2 + k_3 q_3 + k_6 q_6)\rho_B + \varepsilon_p(k_4 q_4 + k_5 q_5)\rho_T \quad (20)$$

This form of the energy conservation equation corresponds to standard theoretical analyses for multi-component systems. On the left-hand side of Equation (20), the first term represents the temporal rate of change of energy, while on the right-hand side, the first term pertains to conduction heat transfer, and the second and third terms account for the reaction source term. As explained earlier, other heat transfer mechanisms would be covered by heat transfer coefficients. With respect to this point, radiation between the gas and solid phase in the particle is taken into account by the effective thermal conductivity. The effective particle conductivity which involves radiative heat transfer and conductive heat transfer, could be written as:

$$\lambda_{eff} = \lambda_{con} + \lambda_{rad} \quad (21)$$

where

$$\lambda_{con} = \varepsilon_p \lambda_G + (1 - \varepsilon_p)\lambda_s \quad (22)$$

$$\lambda_{rad} = \frac{\varepsilon_p \sigma T^3 d_p}{\varepsilon_s} \quad (23)$$

and the properties like λ_s and ε_s are the mass-weighted result of each solid component:

$$\lambda_s = \frac{\rho_B}{\rho_B + \rho_C}\lambda_B + \frac{\rho_C}{\rho_B + \rho_C}\lambda_C \quad (24)$$

$$\varepsilon = \frac{\rho_B}{\rho_B + \rho_C}\varepsilon_B + \frac{\rho_C}{\rho_B + \rho_C}\varepsilon_C \quad (25)$$

Applied physical properties to simulate the pyrolysis process in this study taken from [19-21], appear in Table 1.

Initial condition of Eq. (2) for a virgin particle at $t = 0$, is:

$$T = T_0 \quad (26)$$

Because of the spherical symmetry, boundary condition for Eq. (20) at $r = 0$, is:

$$\frac{\partial T}{\partial r} = 0 \quad (27)$$

While at the surface, radiation and convection are the dominant heat transfer mechanisms. Thus, related boundary condition for Eq. (20) at the surface is:

$$-\lambda_{eff}\frac{\partial T}{\partial r} = h_c(T_{inf} - T) + \varepsilon_s \sigma(T_w^4 - T^4) \quad (28)$$

2.4. Numerical Solution

The one-dimensional mathematical model presented for the pyrolysis process of a single biomass particle encompasses a series of partial differential equations designed to simulate heat and mass transfer within the particle. All governing equations are solved simultaneously based on a control volume method. Using a fully implicit scheme, governing equations are discretized into a set of algebraic equations which are solved by TDMA (Tri-diagonal Matrix Algorithm) method. Finally, a FORTRAN code is developed to solve the algebraic equations.

1. Results and Discussion

The model proposed for the pyrolysis process of an individual biomass particle was utilized to explore the effect of particle size, particle density, moisture content, , and reactor wall temperature on product distribution and the required time to achieve 95% total conversion. Furthermore, to assess the reliability of the predicted outcomes using this model, the results were compared with experimental and numerical findings reported in existing literature. First of all, since the pyrolysis process is greatly affected by reactions kinetics, it is useful to examine the chosen kinetic parameters, to have a better understanding about the products distribution of the process. As illustrated in Figure 2(a), decomposing rate of virgin biomass to tar, is nearly always faster than the other two products. With respect to this fact, it is postulated that the tar yield mass fraction would be greater than the other two products and the char yield has the least proportion in the process products distribution which is clearly obvious in Figure 2(b). Based on Figure 2(b), gas and tar yields mass fractions increase as the primary reactions promote while the char yield mass fraction decreases continuously. Considering the beginning of the process indicates that the decomposing reaction rate of virgin biomass to char has the highest rate at the beginning but rises slower than the other two rates (Figure 2(a)). Thus, at the beginning of the process the char yield mass fraction has its greatest value.

At this point, the model predicted mass fractions have been compared with experimental results of Wagenaar *et. al.* [14] and Horne and Williams [22].In experiments conducted by Wagenaar et al. [14], dried wood particles with diameters ranging from 100 to 212 μm were utilized to investigate the kinetics of sawdust pyrolysis in the range of 300 to 600°C. Their experiments involved the use of a thermogravimetric analyzer for temperatures ranging from 300 to 450°C, while an entrained flow reactor was employed for measurements within the temperature range of 450 to 600°C. Additionally, Horne and Williams [22] conducted pyrolysis experiments on mixed wood waste using a fluidized reactor within the range of 400 to 550°C. As shown in Figure 3(a), though generalized wood pyrolysis kinetics data are applied in the model calculations, the correlation between the model and the experimental data is acceptable. It seems that in the temperature range of 723 to 800K the agreement between the model and the experimental results is better than other temperatures. To test the model further, the temperature profile of the particle at different locations has been compared with the numerical study of Janse *et. al.*[12]. Figure 3(b) demonstrates a high level of agreement between the predicted results and the findings reported by Janse *et al*.

Next, the effects of the particle density and size on the conversion time are investigated. Time to reach 95% conversion has been calculated for particles with different densities and different radii and the results have been illustrated in Figure 4. As shown in Figure 4, it seems that there is a linear relationship between time to reach 95% conversion and the particle radius for particles with different densities where an increase of each one of density or radius of the particle increases conversion time of the particle.

Figure 5 presents the variation of the tar yield mass fraction under effect of some parameters like reactor wall temperature, diffusion of products, porosity and moisture content of the particle. As depicted in Figure 5(a), the mass fraction of tar yield initially increases and then decreases with the rise in reactor wall temperature. This behavior of the tar yield mass fraction refers to the secondary reactions which decomposes tar to the gas and char. As hinted previously, an increase in the reactor wall temperature increases the entrance heat flux which results in the particle with higher temperature. On the other hand, the biomass particle and produced char have a porous

media, so, the producing tar and gas would be trapped inside the particle pores and tar would be decomposed to char and gas through the secondary reactions. According to the above discussions, since the reactions rates depends to the temperature, an increase in the particle temperature, increases the rate of the secondary reactions. Thus, as the reactor wall temperature is increasing, the tar yield mass fraction becomes more affected. Hence, the tar yield mass fraction in the reactor with wall temperature of 923K has been influenced by secondary reactions more than the other two cases. According to the above discussion, it seems that to decrease the effect of the secondary reactions and increase the tar yield mass fraction, decreasing the entrance heat flux would be inevitable. The other results to be discussed hereafter refer to the influence of the diffusion of the volatiles inside the particle on the products mass fractions. Figure 5(b) illustrates that the mass fraction of the produced tar increases first and then decreases with time for the case which diffusion mass transfer is neglected while the tar yield mass fraction increases firstly and then approaches a constant value for the case which diffusion mass transfer is contemplated. This behavior can be explained in terms of the secondary reactions occurring inside the particle. As mentioned previously, secondary reactions decompose tar which is trapped in the pores of the particle to the char and gas. Thus, when diffusion is neglected, since there is no other mechanism for escaping of the produced tar, more proportion of the produced tar is trapped in the particle pores and is affected by the secondary reactions. Therefore, mass fraction of the tar yield decreases with time. On the other hand, in the case which diffusion of products is contemplated, a large amount of the produced tar is escaped, so a fewer proportion of the tar would be decomposed and the tar yield mass fraction approaches to a constant value.

Based on Figure 5(c) in which tar yield mass fraction has been shown as a function of temperature, particle porosity has a greater effect on the tar yield mass fraction in lower temperatures. Meanwhile, more porous particle has a greater tar yield mass fraction in lower temperatures while it seems that the porosity has a negligible effect on the tar yield mass fraction in higher temperatures. Thus, to maximize the tar yield mass fraction for more porous particles imposing higher temperatures would be rational.

As another result, the influence of moisture content of the particle has been considered. Drying of the particle is the first process in the pyrolysis process of the particle which consumes a portion of the entrance heat flux to the particle. As illustrated in Figure 5(d), moisture content has a negligible effect on the ultimate tar yield mass fraction. Moreover, the differences at the beginning of the process refer to the time zone which a portion of the entrance heat flux is consumed for drying of the particle and a decrease in entrance heat flux decrease the tar yield mass fraction. Based on this point, a particle with more moisture content has a less tar yield at the beginning of the process while it is nugatory on the ultimate tar yield mass fraction.

3. Conclusions

Utilizing temperature-dependent particle physical properties, the pyrolysis process of a wet biomass single spherical particle was modeled. The presented model was employed to analyze the pyrolysis process of a individual biomass particle as a representative sample, aiming to discern the impact of key parameters such as reactor temperature, porosity, moisture content, and species diffusion on the mass fraction of tar yield. Ultimately, the following results were obtained. Temperature of the process has a great effect on the conversion of the particle and the process products. While, imposing higher temperatures to the reactions not only decreases the conversion time of the particle, but also facilitates production of the tar. Pyrolysis of small

particle with low density results in higher heating rate which facilitates the production of tar. The more porous the particle, the greater the amount of tar produced. Additionally, the mass transfer of volatiles within the particle reduces the influence of secondary reactions. Thus, less amount of produced tar has been trapped through the particle pores and decomposes to the char and gas. Future research would be well served to examine the products of other biomass plants in the pyrolysis process and to investigate parameters which could affect the bio oil mass fraction.

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Table 1: Applied Kinetic Data, Heat of Reactions and Physiscal Properties

Pre-exponential factor (A_i), s^{-1}	Reaction 1	1.11×10^{11}	[14]
	Reaction 2	9.28×10^{9}	[14]
	Reaction 3	3.05×10^{7}	[14]
	Reaction 4	8.60×10^{4}	[15]
	Reaction 5	7.70×10^{4}	[15]
	Reaction 6	5.13×10^{10}	[16]
activation energy (E_i), $kJ\cdot mol^{-1}$	Reaction 1	177.0	[14]
	Reaction 2	149.0	[14]
	Reaction 3	125.0	[14]
	Reaction 4-5	87.8	[15]
	Reaction 6	88	[16]
Heat of Reactions (ΔH_i), $kJ\cdot kg^{-1}$	Reaction 1-3	-418	[17]
	Reaction 4-5	42	[18]
	Reaction 6	-2440	[16]
Virgin Biomass Density (ρ_{B0}), $kg\cdot m^{-3}$		650	[4]
Diffusivity (all species) (D), $m^2\cdot s^{-1}$		3×10^{-5}	[19]
Porosity (e_p)		0.29	[12]
Emissivity (ε)	Virgin biomass	0.85	[4]
	Char	0.95	[4]
particle pores diameter (d_p), m		3.2×10^{-6}	[4]
Specific thermal capacity (c), $J\cdot kg^{-1}\cdot K^{-1}$	Virgin biomass	$1500+T$	[20]
	Gas	$770+0.629T-0.000191T^2$	[20]
	Tar	$-100+4.4-0.00157T^2$	[20]
	Char	$420+2.09T+0.000685T^2$	[20]
thermal conductivity (λ), $W\cdot m^{-1}\cdot K^{-1}$	Virgin biomass	$0.13+0.0003T$	[21]
	Gas	0.026	[20]
	Char	$0.08-0.0001T$	[21]

Figure 1 - Pyrolysis process kinetic modeling

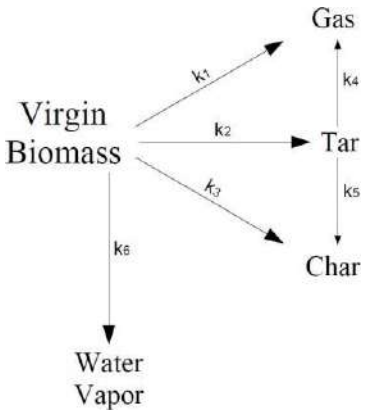


Figure 2 - (a) Primary reactions rates as a function of time; (b) Products mass fractions; (*Tw*=850K; *hc*=500W·m^{-2}·K^{-1}; *r*=0.5mm; moisture content=0%)

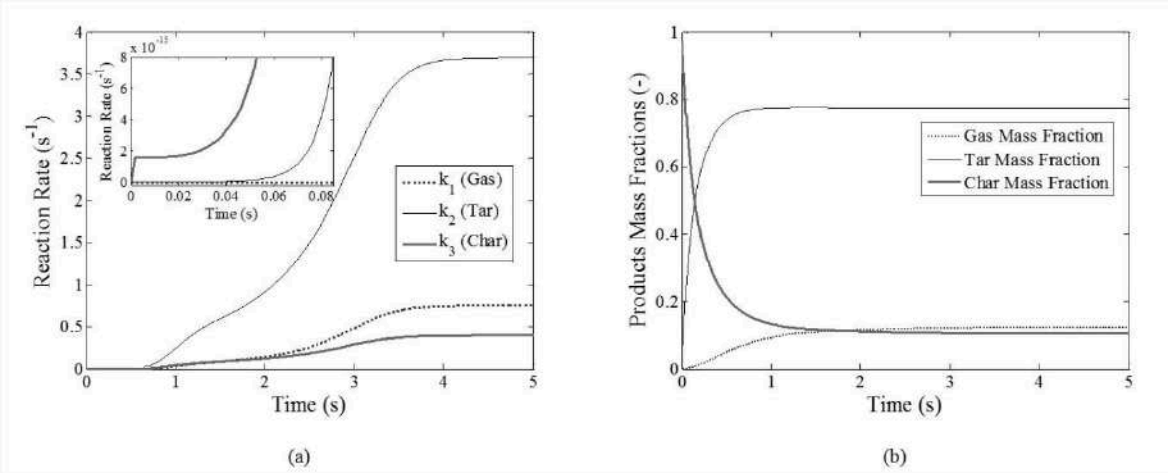


Figure 3 - Model validation: (a) Predicted tar mass fraction in comparison with experimental works of Wagenaar *et. al.*[14] and Horne and Williams[22] (*r*=0.1mm); (b) Predicted temperature profile of the particle in comparison with numerical work of Janse *et. al.*[12]

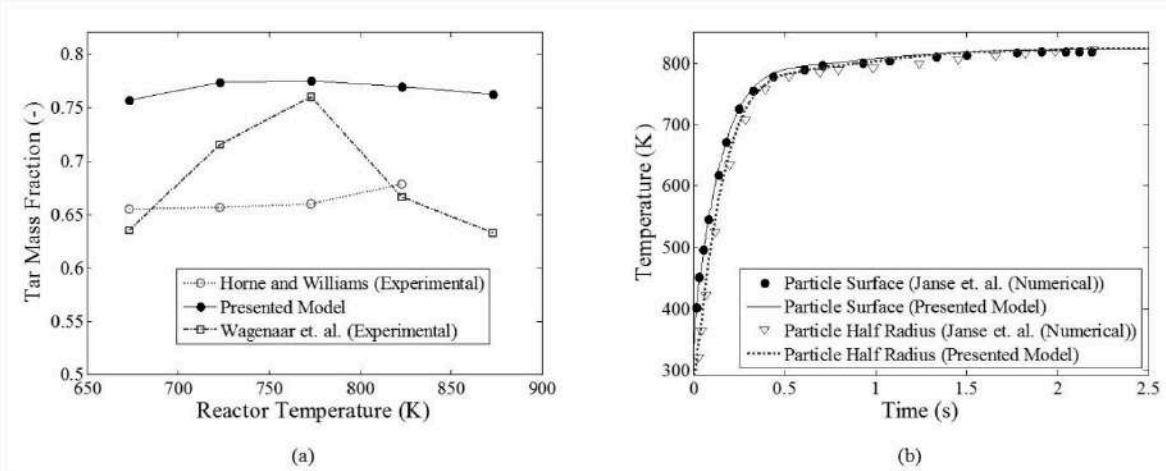


Figure 4 - Time to reach 95% conversion for particles with different densities and different radius (*Tw*=850K; *hc*=500W·m^{-2}·K^{-1}; moisture content=0%)

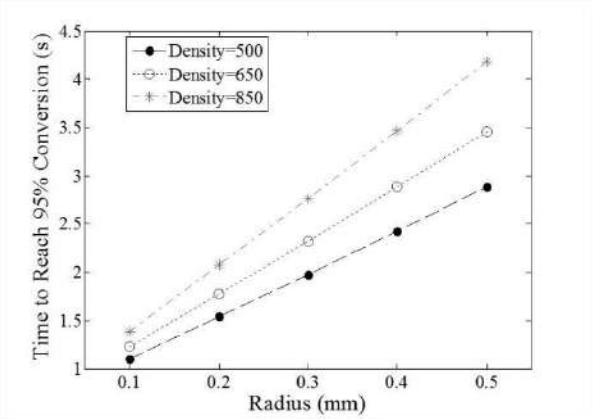
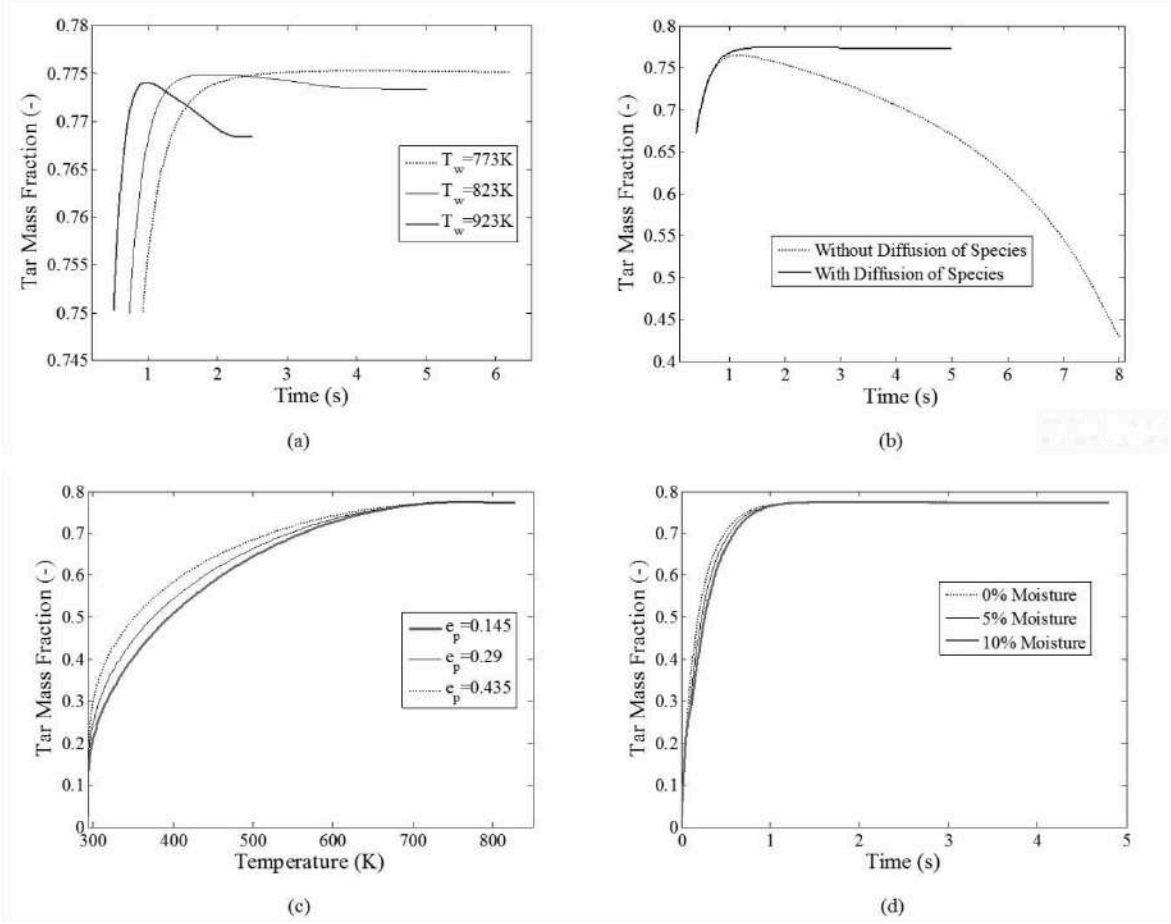


Figure 5 - (a) Effect of reactor wall temperature on the tar yield mass fraction (moisture content=0%); (b) Effect of diffusion mass transfer on the tar yield mass fraction (moisture content=0%); (c) Effect of the particle porosity on the tar yield mass fraction (moisture content=0%); (d) Influence of particle moisture content on the char yield mass fraction; (Tw=850K; hc=500W·m^{-2}·K^{-1}; r=0.5mm)



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