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Extended Hybrid Genetic Algorithm for Solving Job Shop Scheduling Problem

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Abstract: In this paper, a hybrid genetic algorithm (HGA) to solve the job shop scheduling problem (JSSP) to minimize the makespan is presented. In the HGA, heuristic rules are integrated with genetic algorithm (GA) to improve the solution quality. The purpose of this research is to investigate from the convergence of a hybrid algorithm in achieving a good solution for new benchmark problems with different sizes. The results are compared with other approaches. Computational results show that a hybrid algorithm is capable to achieve good solution for different size problems.

Keywords: Extended a hybrid genetic algorithm; Job Shop Scheduling; Makespan

1. INTRODUCTION

Scheduling is defined as the allocation of resources over time to perform a collection of tasks. Most scheduling problems are complex combinatorial optimization problems and they are mainly very difficult to solve. Job shop scheduling problem (JSSP) is a well know one of the hardest combinatorial optimization problems where the main goal is find a schedule with minimized makespan for processing of n jobs on a set m machines. Since the problem is well known as NP-Hard class and therefore no deterministic algorithms can solve them in a reasonable amount of time [1]. That means, exact algorithms, such as (branch and bound method, dynamic programming) can be used only for small size problems. Therefore, more complex problem must be solved by heuristic methods. Successful heuristic methods include approaches based on simulated annealing [2], tabu search [3], and genetic algorithms [4 ,5]. These approaches have been employed to deal with complex scheduling problems which are capable of producing high quality solutions with a reasonable computational effort [4].

Genetic algorithms were first proposed by Holland in the 1970s and have been successfully used in a variety of problems. Genetic algorithm (GA) is a heuristic search that mimics the process of natural evolution. The first applied a genetic algorithm to the JSSP in 1985 successfully, and now genetic algorithms have been proved to be an effective approach for the JSSP. First applied a genetic algorithm to the JSSP in 1985 successfully, and now genetic algorithms have been proved to be an effective approach for the JSSP as mention by Janes et al [6]. The genetic algorithm is an effective meta-heuristic method to solve combinatorial optimization problems, thus many researchers have applied them also to the scheduling problems [7 - 10]. The implementation time of the GA can be defined as the time required by the algorithm to render an optimal or satisfactory solution. This time reflects the solution quality comprising each generation. If the quality of the solutions is poor, i.e. the individuals are beyond the fitness function or imposed constraints, then the results seem to be hopeful, but, the GA will take more time to render or reach the best solution. Some techniques and operators are used to improve the solution quality. The performance of GAs solutions depends on the quality of the initial population [7, 11] on which the quality and performance of the next populations generations will depend on. All previous algorithms and approaches, there are positives and negatives of every optimization method. Therefore, combinations of two or more techniques are used to solve JSSP. These methods are called hybrid algorithms. Hybrid methods are frequently employed for solving JSSP for example, hybrid GA and heuristic rules [14], hybrid GA and local search [9], and GA with simulated annulling [12,13]. The hybrid algorithms perform better than its corresponding individual counterparts as with the hybridization convergence rate is usually high and it also helps in escaping local minima. All the algorithms developed for JSSP have their strengths and weaknesses [14]. Therefore, researchers are constantly in search of new algorithms and a lot of efforts have been put in to optimize and improve existing methods. Our intention in this article is to investigate the effects of the varying size of problem on hybrid genetic algorithm proposed by (Boushaala, et. al., 2013) [15] for solving JSSP. To check the effectiveness of a hybrid genetic algorithm, the results obtained is compared with other approaches.

The remaining contents of this research article are organized in different sections as follows. Section 2 covers the conventional problem definition. Section 3 discusses a hybrid genetic algorithm. Section 4 provides experimental results and analysis. Finally, the conclusion is presented in section 5.

2. PROBLEM DEFINITION

The job shop scheduling problem (JSSP) can be described as follows: a set of n jobs (J) to be scheduled on a set of m machines (M). Each job j visits a number of machines in a predetermined order. The processing times for each job at each machine are given and no machine can process more than one job at a time. If a job is started on a machine, then it cannot be interrupted. The problem is finding a schedule of the jobs on the machines. The assumptions of the present problem are:

- Every job has a unique sequence on *m* machines. There are no alternate routings;
- There is only one machine of each type in the shop;
- Processing times for all jobs are known and constant;
- All jobs are available for processing at time zero;
- Machine absences are not allowed;
- Transportation time between machines is zero;
- Each machine can perform only one job at a time;
- Each job visits each machine only once;
- An operation of a job can be performed by only one machine;
- Operation cannot be interrupted;
- A job does not visit the same machine twice;
- An operation of a job cannot be performed until its preceding operations are completed;
- There is no restriction on queue length for any machine;
- There are no limiting resources other than machines/workstations;
- The machines are not identical and perform different operations. [15].

The objective of the scheduling job is to optimize a certain criterion. This criterion is used as a performance measure of the schedule. A common objective criterion is to minimize the makespan (C_{max}), which is the time needed to complete all the jobs.

3. A HYBRID GENETIC ALGORITHM

Genetic algorithm (GA) for job shop scheduling is an optimization method of searching based on evolutionary process which works with a population of solutions. In this paper, a hybrid genetic algorithm (HGA) based on an integration of a genetic algorithm and some developed and recommended heuristic rules is used. Also, the effects of the implemented new benchmark problem with different size on the proposed algorithm are investigated to check the effectiveness of a hybrid algorithm against the problem size variety. This algorithm is described in detail in paper [15]. The flowchart of a hybrid Genetic algorithm is shown in Figure 1.

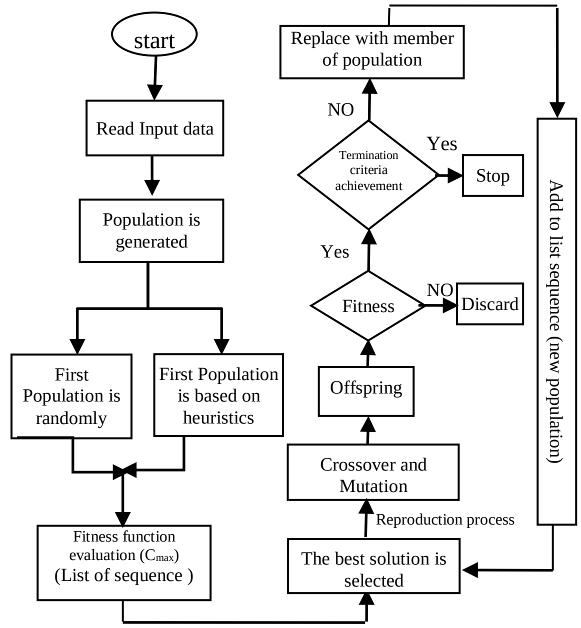

Fig:1 Proposed algorithm flow chart

4. COMPUTATIONAL EXPERIMENTS

This section gives a detailed explanation about the date used and the results obtained. For this study, the benchmark problems with different sizes were considered to investigate the efficiency of a hybrid genetic algorithm (HGA) against the problem size variety. These problems have varying sizes with the number of jobs varying from 4 to 6 and the number of machines varying from 3 to 10. There are 25 benchmark problems, 5 each of sizes 4×3, 5×4, 5×6, 6×6, and 5×10. The HGA is implemented to obtain the best solutions. The results of HGA are compared with Recommended Heuristic Rules (RHR), Developed Heuristic Rules (DHR), and GA based on randomization Algorithm (GA-R) addressed in the paper [15], The result comparison is presented in table 1. In this table the first column presents number of problem. The second column presents makespan from RHR while the third column presents makespan from DHR. The fourth column presents makespan from GA-R while the fifth column presents makespan from HGA.

Table 1. Result Comparison of Different Approaches

Problem number	RHR	DHR	GA-R	HGA
4×3				
1	23	26	23	23
2	26	26	26	26
3	21	21	21	21
4	21	21	21	21
5	22	22	22	22
5×4				
1	24	29	23	24
2	25	25	26	25
3	29	33	29	28
4	21	21	21	21
5	26	26	29	26
5×6				
1	29	29	29	27
2	33	34	33	31
3	39	39	39	39
4	30	33	33	27
5	31	31	30	29
6×6				
1	37	36	38	36
2	31	33	36	30
3	37	39	37	34
4	29	29	29	29
5	27	27	27	27
5×10				
1	52	53	55	51
2	44	44	44	42
3	42	43	43	41
4	33	33	32	32
5	30	32	31	26

From the above table it is evident that the performance of the HGA is better than other approaches. As it can be seen, the HGA could obtain the best solutions in most benchmark problems and compete with compared algorithms. It achieves the best for 24 instances of all the thirty considered instances (96%), compared to 44% when applying GA based on randomization population from the domain search space. In case of applying only the developed heuristic rules the best solution is obtained by 44%, while it is 44% when applying the recommended heuristic rules.

Figs. 2–6 show the results of benchmarks 4×3, 5×4, 5×6, 6×6, and 5×10 obtained using the HGA and other approaches, respectively. The comparison between HGA and other approaches for all benchmark problems are presented in Fig.7. As evident from these figures, the HGA could solve the problem considered for this study efficiently and compete with compared approaches.

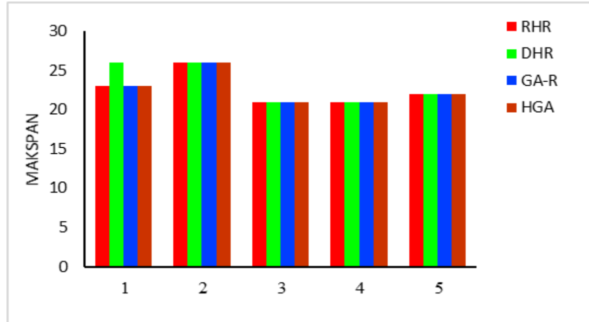

Figure 2. 4×3 problem

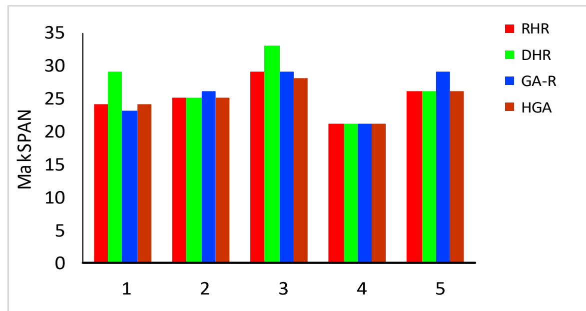

Figure 3. 5×4 problem

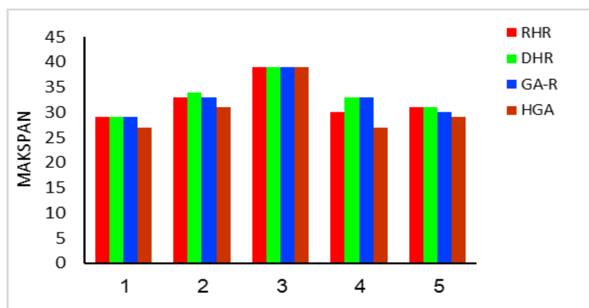

Figure 4. 5×6 problem

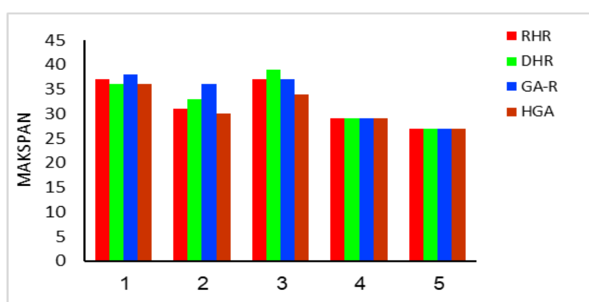

Figure 5. 6×6 problem

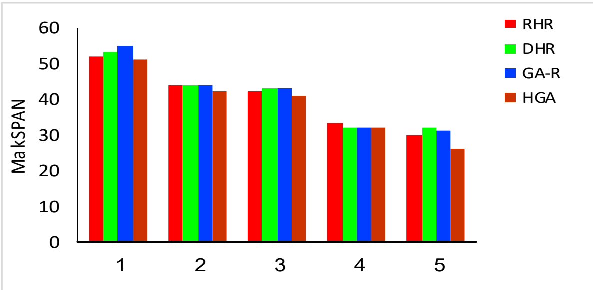

Figure 6. 5×10 problem

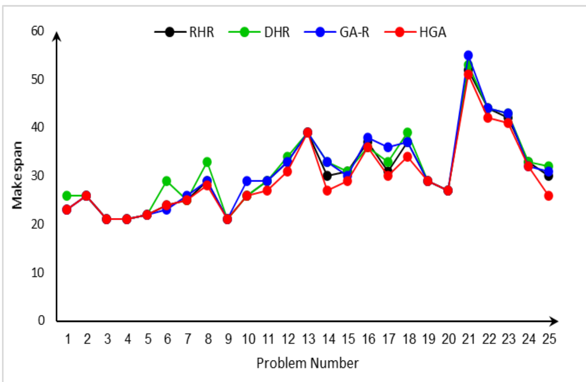

Figure 7. The comparison results obtained in Table 1

5. CONCLUSION

In this paper, the effects of selected new benchmark problem with different sizes on a hybrid genetic algorithm (HGA) for solving job shop scheduling problem (JSSP) to minimize the makespan are investigated**.** Also, the HGA is compared with the other approaches, and the results showed the HGA could find the best solutions for all kinds of problems and could find them in shorter computational times compared to the other approaches. In other words, there is a gradual growth in the makespan and it is evidently seen when the machine size starts increasing. When the machine size is less as 3 machines, all the approaches behave similarly in producing the results. But when the machine size increases, the HGA algorithm gives the best result compared to other approaches.

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Determination of the Electrical Energy Potential of Sawdust and its Products

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Abstract: Sawdust is often used as fuel for basic domestic needs like cooking, heating etc, with the application of the right technological procedure, the chemical energy in sawdust can be converted to electrical energy. sawdust is a usually a waste from timber processing industries and can pollute the environment if not properly disposed or utilized. Electricity can be generated from sawdust directly and sawdust can be processed into other products such as sawdust briquettes, pyrolysis oil, bioethanol and producer gas which can all be used to produce electricity using either a coal based thermal plant, oil based thermal plant and gas depending on the most suitable and efficient. As the calorific value of sawdust is dependent on the moisture content of the wood and the type of wood used, hence average calorific value of sawdust was used for this research work. In this study, the heat contents of sawdust and its various products were considered as fuels for divers power plants that is most suitable accordingly. This paper uses mathematical analysis to determine the amount of electrical energy produced from sawdust and it's products. Sawdust briquettes was found to be the most efficient in terms of output power when a coal based thermal plant is utilized, the next being the utilization of a plain sawdust as fuel for a coal based thermal plant, the most optimal for the generation of electrical energy among the derivative of sawdust was pyrolysis oil being used as fuel in an oil based thermal plant.

Keywords: Sawdust briquettes, Thermal plants, Pyrolysis oil, Calorific value, moisture content

1.0 INTRODUCTION

Due to the increase in population, there is also great need for increase in electricity generation, improvement in the transmission and distribution of the electrical power generated. Due to global warming and other effects of CO_2 emissions and the potential depletion of other fossil energy resources, renewable sources of generation of electrical power has been developed. Though some renewable methods of electricity generation are still in early stages of implementation like Tidal energy and Ocean Thermal Energy Conversion (OTEC), since ancient times biomass has been utilised for electricity generation.

There is currently high demand of electrical energy all over the globe and the utilization of fossil sources of energy poses devastating to the environment which includes the emission of Green House Gases, acid rain etc, due to this and other factors there is a need to supplement fossil sources of energy production with sources that are sustainable with little or no negative impact to the environment. [1]

The proportion of renewable energy in the global energy mix should be increased as soon as possible as this promotes sustainability and biomass is regarded as a renewable source of energy and it's regarded as a significant source of renewable energy worldwide. Making use of the energy stored in biomass to produce heat or electricity undergoes a carbon-neutral cycles as the CO_2 emitted during the process of energy release is of the same proportion which was absorbed from the atmosphere by the plant for growth and other biological processes during its lifespan.

Biomass belongs to these group of renewable energy despite its emission of greenhouse gases, it has the potential to increase the cost of electrical energy, because it's among the cheapest source of electricity generation due to the fact that it is readily available and relatively cheap and can be utilized in various ways.

Biomass refers to the plant or animal materials that is used for the production of heat, energy and can also be used for the manufacture of diverse range of product after it has been processed industrially. According to [2] Biomass is produced when green plants through the process of photosynthesis utilize energy from the sun for growth and other biological processes. This green plant includes plants on land and on water bodies in the earth. The classification of a biomass resource as organic or inorganic depends on the mannerism of the storage of energy. If the sunlight energy is stored in chemical bonds, it is considered to be organic. The release of the energy stored in a chemical form occurs when bonds between carbon, oxygen and hydrogen molecules are broken either by the process of combustion, decomposition or digestion. It was discovered that only 1% or less of the sunlight available is stored by plant as chemical energy during the process of photosynthesis. The structural components of a biomass is the location where all the solar energy which facilitates photosynthesis are converted to chemical bonds and stored. During the process of energy utilization from biomass either through a chemical or biological process then the energy stored in form of the chemical bonds in the structure of the biomass is released in combination with oxygen, the carbon produced during the process undergoes oxidation producing CO_2 and water.

Sawdust can be directly converted to heat by combustion or it can be densified through the process of palletization or briquetting.

The combustion of plant derived biomass release CO2, this is classified as renewable by the UN and the EU legal framework because the CO2 is recycled into new plants during the process of photosynthesis.

According to various researches, there are various ways of classifying biomass, the simplified method is to classify into four groups;

a) woody plant manure
b) Aquatic plant
c) Herbaceous grasses/plants
d) Woody Plants

Among this groups, herbaceous grasses/plants can be sub-divided into two main groups namely: High moisture content and Low moisture content herbaceous plants. For the sake of this research, we will concentrate on saw dust and illustration and mention will be made of other woody plants biomass as well as similarities and differences will be duly stated out. Woods and wood residues possess the largest resource of biomass worldwide.

Sawdust is a very small particle of wood that falls as dust from wood when a wood work operation is carried out. Sawdust can be found in paper industries, saw mills, pulp industries and wood processing industries. They come most times in heaps of very large quantity and the method of disposal is by burning which directly lead to environmental pollution.

According to [3], Sawdust is a seen as a byproduct of wood industries and as an environmental pollutant but Sawdust is also a very important raw material utilized directly in the production of wood boards and other cheap construction material. Sawdust is also utilized in power industries as fuel processed directly or indirectly to generate electricity.

Sawdust possesses a characteristic that is similar to that of wood, this is due to the fact that they are just tiny wooden particles and it's also different owing to the fact that some of the structure of the wood have been modified [4]. In order for Sawdust to be utilized in a way similar to that of woods, it has to be modified or enhance. When using Sawdust to generate energy of any sort, consideration has to be made to it's heating value and hence there need to be a comparison between the heating value of Sawdust and that of other fuel. The bulk density of sawdust is below Sawdust 150-200kgm^{-3} [3]. can also be used as an insulating material used in the reduction of heat loss via conduction owing to the very low thermal conductivity of Sawdust. Sawdust can also made into briquettes which has its diverse advantages. The Density of a typical Sawdust briquette is above 100kgm^{-3}.

Very dense sawdust briquettes can be made without a binder in a process involving high pressure and high temperature. With development in sawdust technology shows its positive use, for example, the advancement in different classes of materials including chemical such as methanol has also improved the general efficiency when utilizing sawdust. The technology involved in utilizing sawdust for energy production is still a developing one and still possesses some few unaddressed challenges. [5]

Sawdust belongs to the family of plant biomass and is further classified as a wooden biomass and sub divided to a group known as wood-waste. Among the wood-waste include, Sawdust, woodchips and wood pellets. Sawdust however as other wooden biomass can be used directly or converted using different methods and processes to obtain higher efficiency and great heat.

Irrespective of the fact that when utilizing biomass for energy generation the net emission of CO_2 is zero, due to the segregation of biomass during the planting cycle, environmental impacts are inevitable. Wood constituents also includes sulfur and nitrogen, during combustion yield SO_2 and NO_x are emitted. Yet the emission level of these compounds is minimal in sawdust when compared with a coal-based generation [6].

When a bomb calorimeter was used, the High Heating Value (HHV) and Lower Heating Value (LHV) of sawdust was found to be 18.23 MJ kg^{-1} and 16.54 MJ kg^{-1} respectively with a moisture content of 8.25%. When calculations are made for the gasification process, The Lower Heating Value is used for the calculation and not the Higher Heating Value (HHV) because the gasifier's final product is in a gaseous form [7].

2.0 SAWDUST PRODUCTS

2.1 Densification Process of Briquetting

This is a process where a compressive stress is applied to a certain volume of loosed sawdust separately or combined with other biomass materials, which causes a substantial reduction in the volume of the loosed sawdust and other constituents and therefore leading to its compression, and the products remains in a permanent compressive state. [9]

The product obtained after densification will remain at a solid compressive state until it is utilized as fuel. Some of the technical advantages of densification includes:

1. Reduction in moisture content
2. Increase in bulk density
3. Increase in the calorific value of the product
4. Improvement in the handling and transporting capabilities
5. The burn with high flame and emits little smoke
6. The products of densification (briquettes) are easier to feed into plants.
7. The ash remnant is minimized

2.2 Oxygen Gasification of Sawdust

Gasification can be defined as a process of converting carboniferous materials into hydrogen, carbon monoxide, and carbon dioxide. It is done by reacting biomass or fossil fuel at a high temperature (>700^{O}C). Combustion is not occurred here and a controlled amount of oxygen sometimes with stream produces syngas or producer gas as a fuel [10].

The process of gasification of sawdust occurs in an environment where the is controlled and limited supply of oxygen or air. The composition of sawdust gas includes carbon (ii) oxide, hydrogen, methane and carbon (iv) oxide in various proportions. The process of gasification consists of a two-stage reaction which are oxidation and reduction. The oxidation and reduction occur under sub-stoichiometric conditions of air with biomass. The first section of the sub-stoichiometric oxidation is an exothermic reaction and causes the exit of volatiles from the biomass, leading to peak temperature as much as 1400 to 1500 K and the production of gases like carbon (ii) oxide, carbon (iv) oxide, hydrogen as well as steam, this products are further disintegrated into carbon (ii) oxide and hydrogen by the bed of hot charcoal which is generated during the gasification process. Table 1 below shows the composition of gasification of sawdust in air neglecting water vapour

Table 1: Composition from gasification of sawdust in air.

Hydrogen (H_2)	20
Carbon (ii) oxide (CO)	25
Carbon(iv) oxide (CO_2)	10
Methane (CH_4)	3
Higher hydrocarbon	1
Nitrogen	40
Others	1
Total	100

However, there may be some deviations, this is because the overall composition of biomass gas is to a great extent independent of the composition of the raw material but simply the mixture of gases. In some situations, if there is the presence of any Sulphur content in the raw material, hydrogen sulphide gas may be produced. The removal of hydrogen sulphide can be carried out by passing the biomass gas through water. Also, if the air supplied for the gasification process is 100% oxygen, the nitrogen content will be eliminated and the energy density will be up to 9 MJ/m3.

2.3 Bioethanol

The production of ethanol can be carried out from any biological material which contains considerable amount of sugar or any substance that can be broken down or changed to sugar through any natural process examples are cellulose and starch k. In different parts of the world ethanol are produced from different plants for example, ethanol is primarily produced from starch crops in the US mostly corn, in the EU nations from starch here barley and wheat and sugar (beet) crops are primarily used, also in the primary sources for ethanol production in China are from starch (corn and wheat) and for secondary production sugar crops like sugar canes are used [12]. Ethanol is produced through the process of fermentation. Fermentation depends on yeast which does the work of converting glucose to ethanol with carbon dioxide as its by product. Starch is also converted to sugar by the process of acid or enzyme hydrolysis. There is ready availability in commercial quantity of enzymes, organism or acid needed to convert starch to sugar and catalyze the process of glucose fermentation.

Presently, there are notable researches carried out in the area of production of ethanol from cellulose, however there is currently no known commercial production of ethanol from cellulose [12]. The main sources of cellulose feedstock are:

1. Wooden residues from wood processing/utilization industries

2. Agricultural residues
3. Energy crops
4. Municipal solid waste which includes paper and materials

It has been experimentally derived between that the 30.9 mg mL^{-1} to 28.43 mg mL^{-1} of ethanol can be produced from 10kg of wood sawdust [13].

2.4 Pyrolysis oil

Pyrolysis is carried in the absence of oxygen in a large steel tub. The process is a powerful process yet simple. The process begins with the reduction of a wood into tiny pieces and the wood is quickly heated to the temperature of 450^oC as quickly as possible. The instantaneous rise in temperature will cause the wood chips to evaporate in seconds and the wood vapour is capture and cooled to room temperature, this causes the condensation of the wood vapour which becomes liquid. Other by product also occur as a result of this thermal processing this are char and gas. The liquid obtained is very efficient as a kilogram of wood can produce up 700 grams of pyrolysis oil [14].

BTG-BTL's oil also called pyrolysis oil can be produced by almost any kind of cellulosic material. The oil consist of small portions of ash and the energy density is greatly increase to up to 400% compared with the original (parent) biomass material. Pyrolysis oil has a characteristic pungent odour and it has reddish brown appearance. Pyrolysis oil contains other functional groups like ketones, carbohydrates, furans, pyrans, hydrocarbons etc. Pyrolysis oil has a density of approximately 1170 kg/m^3, which makes it denser than any other known fuel oil and also denser than the parent biomass that it was derived from. Pyrolysis oil has the propensity to undergo degradation if not properly handled. The pH value of about 3, and the HHV of the oil ranges from 16MJ/l to 23MJ/l [15].

The oil does not easily fuse as a mixture with hydrocarbons because it is polar in nature and it contains a huge number of oxygenated components. Pyrolysis oil can be applied in the generation of electricity either in a large scale or a much smaller scale. These systems are found in power industries and large companies in other to meet the demand for electricity [15].

The aim of this study is to find out the magnitude of electrical energy that can be derived from 1kg of sawdust.

3.0 METHODOLOGY

Sawdust and its direct derivatives will be considered separately and its heating value, will be derived and utilized using a thermal power plant to generate the energy and this will be demonstrated mathematically.

The heating value, will be derived and utilized using a thermal power plant to generate the energy and this will be demonstrated mathematically.

The plant that will be utilized will be a coal-based thermal power plant whose efficiency is between 35-38% will be utilized for generation using regular (plain) sawdust and sawdust briquettes.

The oil-based thermal plant with overall efficiency of 42-46%% will be utilized for the generation using cellulosic ethanol produced derived from sawdust.

A gas-based thermal plant with overall efficiency of 35-42% will be utilized for the generation of electrical power using hydrogen produced from the gasification of sawdust.

Our analysis will be done based on Higher Heating Value (HHV) and the Lower Heating Value (LHV) and using a steam engine ant each of the samples as a fuel to the steam generator.

Density of sawdust = 210Kg/m^3

Table 2: Calorific value of sawdust and its products (derivatives)

Sawdust and Products	Lower Heating Values (LHV) MJ/Kg	Higher Heating Values (HHV) MJ/Kg
Plain Sawdust	16.54	18.23
Sawdust Briquettes	35.6	38.98
Bioethanol	21.2	26.4
Pyrolysis Oil	13.68	19.66
Producer (wood) Gas	4.2	5.4

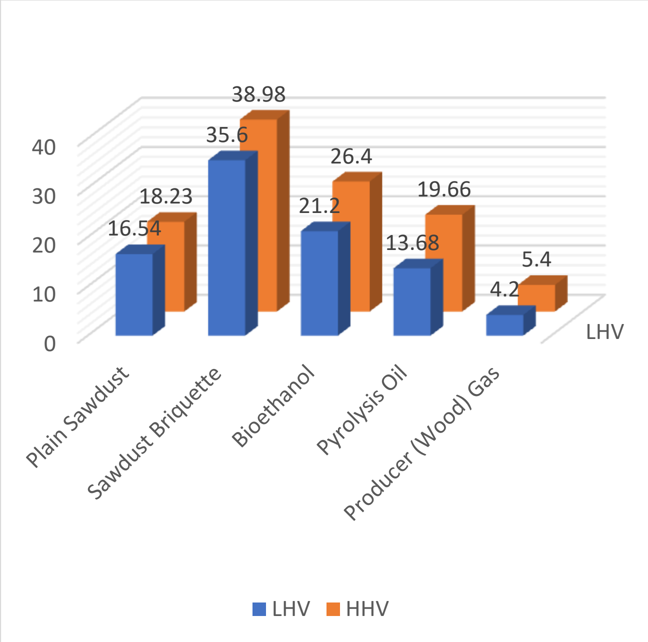

Fig. 1: Calorific Values of Sawdust and its products

Table 3: Sawdust/products and its corresponding power plants used with their efficiencies respectively

Sawdust and Products	Power plants utilized	Overall efficiencies of power plants
Plain Sawdust	Coal based thermal power plants	42%
Sawdust Briquettes		
Bioethanol	Oil based thermal power plants	45%
Pyrolysis oil		
Producer (wood) Gas	Gas based thermal Power plants	52%
	Combined cycle gas Turbine plants	62%

3.1 Analysis

Energy (J)= Power(w) × time(s)
One watt = 1 Joules per second
One watt second = 1 Joules
3.6MJ = 1Kwh
1MJ = 1⁄(3.6)Kwh
1MJ = 0.2778Kwh
Energy leaving each plant = Energy Input (Heating Values) × Overall efficiency of individual power plants

3.2 Energy leaving the Power Plant

3.2.1 Plain Sawdust

A plain sawdust undergoing direct combustion in a coal based thermal power plant of efficiency of 42% will yield:
LHV = 16.54MJ/Kg × 0.42 = 6.95MJ/Kg
HHV = 18.23MJ/Kg × 0.42 = 7.66MJ/Kg
1Kg of Plain sawdust will yield:
6.95 × 0.2778Kwh= 1.93Kwh
18.23 × 0.2778Kwh = 2.13Kwh

3.2.2 Sawdust Briquette

Sawdust Briquette undergoing a direct combustion and utilized in a coal based thermal plant of efficiency of 42% will yield:
LHV = 35.6MJ/kg × 0.42 = 14.95MJ/Kg
HHV = 38.98MJ/Kg × 0.42 = 16.37MJ/kg
1Kg of Sawdust briquette
14.95 × 0.2778Kwh = 4.15Kwh
16.37 × 0.2778Kwh = 4.55Kwh

3.2.3 Bioethanol

Bioethanol from sawdust undergoing combustion in an oil based thermal plant of efficiency of 45% will yield:
1kg of sawdust will yield 250grams of bioethanol
LHV = 26.4MJ/Kg × 0.45 ×0.25 = 2.77MJ/Kg
HHV = 30.2MJ/Kg × 0.45 × 0.25 = 3.4MJ/Kg
1Kg of Bioethanol produced from sawdust will yield:
2.77 × 0.2778Kwh = 0.77Kwh
3.4 × 0.2778Kwh = 0.94Kwh

3.2.4 Pyrolysis oil

LHV = 16MJ/l
HHV = 23MJ/l
Density of pyrolysis oil = 1.17Kg/l
LHV = 16/(1.17) = 13.68 MJ/Kg
HHV = 23/(1.17) = 19.66 MJ/Kg
Pyrolysis oil being used as fuel in an oil-based plant with efficiency of 45% will yield:
LHV = 13.68MJ/Kg × 0.45 = 6.16MJ/Kg
HHV = 19.66MJ/Kg × 0.45 = 8.85MJ/Kg
But 1kg of Sawdust will yield 700grams of Pyrolysis oil,
LHV = 6.16 × 70% = 4.31MJ/Kg
HHV = 19.66 × 70% = 6.19MJ/Kg
1kg of pyrolysis oil will produced from sawdust will yield:
4.31 × 0.2778Kwh = 1.19Kwh
6.19 × 0.2778Kwh = 1.72Kwh

3.2.5 Producer (wood) Gas

Density of Producer gas = 0.95Kg/m3
1Kg of sawdust yields 1.5m3 of producer gas
1Kg of sawdust produces =0.95Kg/m3 × 1.5m3 = 1.425Kg
1Kg of sawdust yields = 1.425Kg of producer gas
The LHV and HHV for producer gas for 1kg of sawdust is given as:
LHV = 1.425 × 4.2MJ/Kg = 5.985MJ/Kg
HHV = 1.425 × 5.4MJ/Kg = 7.695MJ/Kg

3.2.5.1 Gas based thermal power plant with the efficiency of 52% Energy leaving the plant is given by:

5.985MJ/Kg × 0.52 = 3.112MJ/Kg
7.695MJ/Kg × 0.52 = 4.00MJ/Kg
1Kg of sawdust converted to producer gas will yield:
3.112 × 0.2778Kwh = 0.86Kwh
4.00 × 0.2778Kwh = 1.1Kwh

3.2.5.2 Combined cycle gas power plant with efficiency of 62% Energy leaving the plant:

5.985MJ/Kg × 0.62 = 3.71MJ/Kg
7.695MJ/Kg × 0.62 = 4.77MJ/Kg
1Kg of sawdust converted to producer gas to run a combined cycle power plant will yield:

$3.71 \times 0.2778Kwh = 1.03Kwh$
$4.77 \times 0.2778Kwh = 1.33Kwh$

4.0 DISCUSSION

From the Table 4.1 below, it is clearly seen that the electrical energy potential ranges from 0.77Kwh to 4.55Kwh per kilogram of sawdust. The difference owing to losses during the process of conversion to various products (derivatives) and the method of generation.

Sawdust briquette has the highest energy electrical energy potential with 4.55Kwh of energy per kilogram of sawdust while the least is bioethanol with least energy potential of 0.77Kwh of energy derived from a kilogram of sawdust. However, despite the reduced energy potential of other derivatives (products) of sawdust like bioethanol, pyrolysis oil, producer (wood gas) they have several advantages like effective transportation and application in multiple systems.

Therefore, for electricity generation the use of sawdust briquette in a coal based thermal plant is the most optimal way of generating electricity when cost is considered but might not be optimum when carbon emissions and versatility is being used as the yardstick.

Table 4: Maximum and minimum power potential of sawdust and its products (derivatives)

Sawdust and Products	Minimum Possible Power Output (Kwh)	Maximum Possible Power Output(Kwh)
Plain Sawdust	1.93	2.13
Sawdust Briquettes	4.15	4.55
Bioethanol	0.77	0.94
Pyrolysis oil	1.19	1.72
Producer (wood) Gas (Gas Thermal plants)	0.86	1.10
Producer (Wood) Gas using CCGP	1.03	1.33

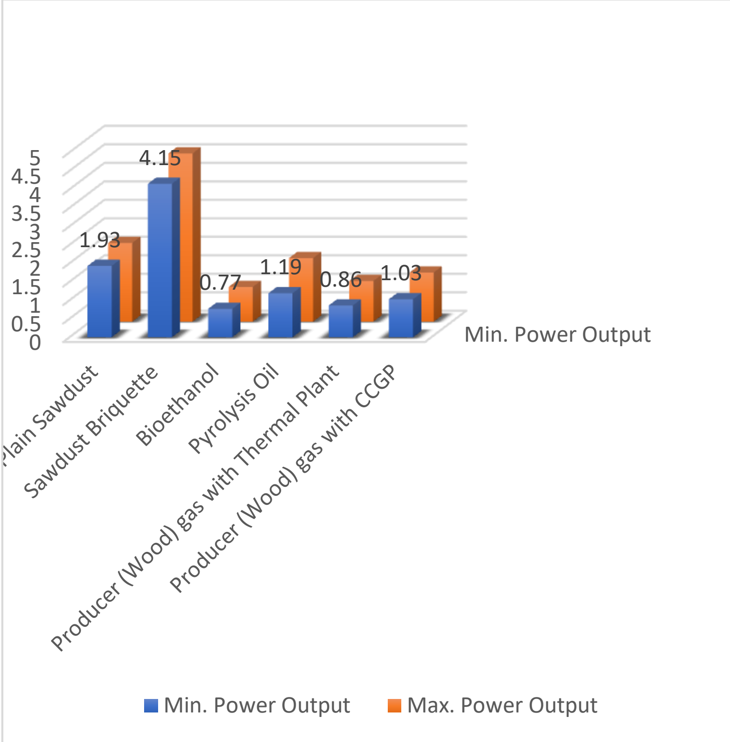

Fig. 2: A graph of maximum electrical energy output of sawdust and various sawdust materials

5.0 CONCLUSION AND RECOMMENDATION

The world energy mix is incomplete with the energy derived from biomass. Sawdust/wood waste is one of the main constituents for the generation of energy from biomass. Sawdust has many products (derivatives) whose electrical energy potential in terms of electrical energy in Kwh and heat content in Joules varies.

The energy potential of sawdust is seen to be dependent highly on the LHV and HHV of the product/derivative and also dependent on the efficiency of the process used in the conversion from the chemical form of energy into electrical energy. The energy content of the sawdust and its derivatives differs based on the type of wood(trees) and the moisture content. In this work, the nature and type of wood is not considered as the average energy content of wood is utilized.

In this research the electrical energy potential of sawdust briquette is the highest when burnt as fuel in a coal based thermal, the second best is that of plain sawdust and the least in this category is the bioethanol owing to reduced efficiency in the conversion process.

The integration of biomass in the energy mix of every society is very beneficial as it is proven to be a carbon reduction technology and also cost effective.

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