



Modeling of catalyzed activated carbon scrubber and green fuels emission analysis

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ABSTRACT

Over population created sudden rise in energy demand, as a result of which the depletion of fossil fuels has started. In aspect to meet the energy crisis renewable energies in all forms are available in abundance on the earth. Modern era paved a way for the Plant Biomass to satisfy the needs. Major out- come of this project is "Production of Green Energies through Physico-chemical process, biological fermentation process and thermo-chemical process which results in obtaining liquid, gaseous and solid fuel. This project emphasize on the scrubbing of the pollutants like CO₂, Soot particles emitted during combustion of fossil fuels and green fuels using the Activated Carbon which is obtained as a by-product of the end process. In this project a scrubber is designed; fabricated and it is filled with the catalyzed activated carbon in different proportions. Carbon adsorbing capacity is tested. The result of the project is plotted as graph and discussed. The efficiency of scrubber over various gas parameters was estimated. This enhances net Carbon emission and Carbon footprint maintenance by waste harvesting and energy conversion process for sustainable future.

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Introduction

Energy today has become a key factor in deciding the product cost at micro level as well as in dictating the inflation and the debt burden at the macro level. Energy cost is a significant factor in economic activity on par with factors of production like capital, land and labor. The imperatives of an energy shortage situation calls for energy conservation measure, which essentially mean using less energy for the same level of activity. The life of convectional fossil fuels has become limited in the present era, where the use of energy and their source has been growing faster than the world population. It is expected that, the world population would increase by 0.9 percent per year, from 6498 million in 2005 to 8469 million in 2035. Indian population will increase from 1165 million to 1528 million between the years 2007 to 2035. Along with increase in population, the energy needs are also increasing. The world energy consumption would increase by 49 percent, or 1.4 percent per year, from 495 quadrillion Btu in 2007 to 739 quadrillion Btu in 2035[3].

On the global scale, increase in the emissions rates of greenhouse gases produced from the use of these conventional fossil fuels present a threat to the world climate. The major exhaust emissions that contribute to pollution and global warming are SO₂ and CO₂. World carbon dioxide emissions would grow from 29.7 billion metric tons in 2007 to 33.8 billion metric tons in 2020 and 42.4 billion metric tons in 2035 and in India it is expected to increase by 1.8 per year from 314 million metric tons in 2005 to 606 million metric tons in 2035. Same trends are expected for SO₂ emissions. In the year 2000 the SO₂ levels in India was about 7919.6 thousand metric tons and it is expected to increase further [3]. The major sources of this energy include liquid fuel, natural gas, coal and electricity.

Literature Survey

Biomass energy production which is the main concept of this project obtained from the literature reviews of the following works done by various authors. In the literature survey, [1] **George W. Huber and et al**, conducted a study on the composition of different biomass and discussed the methods suitable for energy production for every biomass sources. [3] **Vikranth Volli and et al.**, conducted an experimental work on recovering bio-fuels from agricultural residues through different pyrolysis process and analyzed the emission characteristics of the green biomass fuel. [4] **E.F Aransiola and et al.**, conducted a study on production of biodiesel from Non-edible oils like jatropha and neem oils through two – step transesterification process. They also conducted the performance of the internal combustion engine and the emission characterization. [6] **Mohammed Jibril and et al.**, conducted an experimental work on the characterization of the biodiesel produced from jatropha and neem oil. They estimated the properties like free fatty acid content, Iodine value, saponification value, and etc., and also estimated the fuel properties like cloud point, pour point, calorific values of the biodiesel obtained. [8] **B.M.Sangeetha and et al.**, conducted study on biodiesel production from neem oil through base catalyzed trans-esterification process and analyzed the emission reduction methods for biodiesel based generators. [13] **Md. Nurun Nabi and et al.**, conducted a research on the production of biodiesel from first generation crops and the performance of combustion engine were analyzed.[15] **Ajay Popat and et al.**, prepared a report for different anaerobic reactors for pulp and paper industry waste water treatment and discussed the optimum conditions for the working of the reactor. [14] **F. Straka and et al.**, conducted a research on the Anaerobic fermentation of biomass and their biogas production based on the sulphur and nitrogen content in the biomass.[17] **Dr.S.Chinnaraj** prepared a case study report at

pulp and paper industry on the energy recovery and emission reduction through the biomethanation process. [19] **Shilpkar Prateek et al.**, conducted an experimental work on the co-digestion of the Buffalo dung and jatropha seed cake in Biomethanation process and discussed the result obtained and the variation in the biogas yield. [22] **B.M.Sangeetha and et al.**, conducted an experiment on the production of the biogas through Bio-methanation process of the bagasse waste and suggested the steps to upgrade the Bio-methane composition. [23] **Dr.P.Sugumaran and et al.**, obtained the biomass briquettes from the various biomass source through carbonization process and provided the cast and emission analysis of the briquettes. [24] **N.Tippayawong and et al.**, conducted laboratory study on the Biogas quality upgrading by scrubbing of CO₂ and H₂S using plastic bioball packed column reactor and with catalyst like MEA and NaOH. [28] **Nick Soelberg and et al.**, conducted a research in scrubbing of mercury from the exhaust gas using the sulphur impregnated activated carbon scrubber. The scrubber was designed to pilot scale and implemented for the calcinators and incinerators. Based on these reference works all the experimental test procedures and methods are selected.

Methodology

Methods of Biomass Energy Extraction

In this project, Green biomass energy is harvested from the seasonal crops like mustard, sugarcane bagasse, and coconut seed cake. This project proceeds from the physico-chemical process following TRANS-ESTERIFICATION PROCESS, which involves the process of breaking triglycerides using methanol and Sodium Hydroxide as catalyst. As the result of the process acid value of the MUSTARD OIL is estimated and Bio-diesel production process is carried out. It is entirely carried out under the water bath laboratory process.

Waste to Energy concept is more suitable for providing cleaner production in the work environment. In pulp and paper making industry, waste generated from the sugar mills (i.e. BAGASSE) is used as a raw material for the paper making. Hence a huge quantity of the bagasse wash water is obtained. Bagasse which is high in lignin and polymer content is used for generation of BIOGAS through BIO-METHANATION PROCESS. At the end of the process auditing is conducted to calculate the CO₂ equivalent emission reduction reached and fossil fuel substitution achieved. To meet the demand for coal and solid fuel, the project eyes at the conversion of the low density biomass into the high density biomass. The biomass is initially carbonized and mixed with the binding matter and it is briquetted out with the briquetting machine. The briquettes are dried and used in the boilers for heating purpose.

By-Product obtained during the process is utilizes as filter media without wasting it. Hence a scrubber using the activated carbon generated during the briquetting process is saturated with the suitable catalyst and converted for gas scrubber. The scrubbing technique is analyzed at various time intervals and tested in diesel engine. Figure 1 shows over view of the process procedure and principle involved.

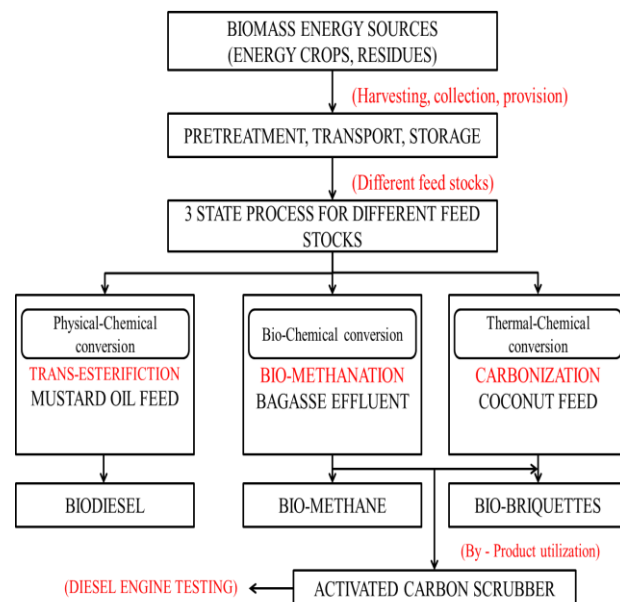


Fig. 1 Overall process of Biomass energy extraction
Physico-Chemical Conversion

The physico-chemical conversion process is mainly categorized for the biomass sources which pose a complex of Triglycerides or fats and oils are found in the plant and animal kingdom and consist of water insoluble, hydrophobic substances that are made up of one mole of glycerol and three moles of fatty acids. Fats and oils are used mainly for cooking and food purposes, as well as for lubricants and raw materials for soap, detergents, cosmetics, and chemicals. From the more than 350 known oil-bearing crops, those with the greatest potential for fuel production, according to Peterson, are sunflower, safflower, soybean, cottonseed, rapeseed, canola, mustard, and peanut [1]. This process of biodiesel production is termed as Trans-Esterification process. Biodiesel is the eco-friendly product made from vegetable, animal fats and non-edible plant oils. It takes the replacement role for the petroleum-based fuel used for the mobile transport. But producing biodiesel alone won't help in reducing emission from automobiles. Figure 2 represents the laboratory process involved in the fatty acid methyl esters (FAME) preparation from mustard oil.

In this project the bio diesel is produced from MUSTARD OIL. Here the mustard oil is extracted from the mustard seed formed in the initial oil extraction process. The composition of mustard oil extracted contains the following substances depending upon the method of extraction. *Brassica juncea* (mustard) plants have high yield when they are cultivated in dry and hot areas. The composition of MUSTARD oil is given below; the MUSTARD oil contains mainly of triglyceride. Bio diesel is produced by the process of trans-esterification process by reacting triglycerides of the oil with alcohol solutions like methanol or ethanol is used in presence of the catalyst sodium hydroxide/KOH to give esters of fatty acids and glycerol. The traces of water and residual methanol must be removed through the washing process. The bio diesel thus produced is separated from the glycerol and then can be used as the fuel in automobiles. The emission is reduced when the bio-diesel is blended with the petroleum based diesel used in automobiles in proportions like B50 instead of B20 proportion.

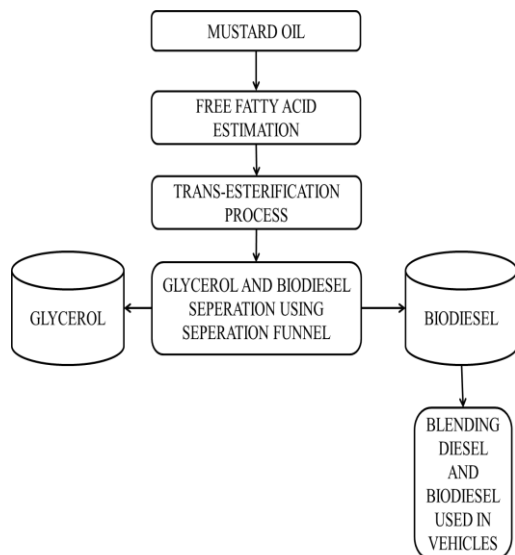


Fig. 2 Experimental process

Trans-Esterification Process

Animal fats and vegetable oils are basically triglycerides, containing glycerin. The catalyst and alcohol are mixed together to form Meth-oxide, which is mixed vigorously into the oil for a period of time. This process “breaks” the oils into esters and glycerin. The heavier glycerin, soaps and waxes sink to the bottom while the Biodiesel floats to the top where it is siphoned or decanted off and the Glycerin is purified. We can use either ethanol or methanol in our process. Ethanol is less dangerous but Methanol is much less expensive so most people use Methanol over Ethanol. We can use either sodium hydroxide (caustic soda, NaOH) or potassium hydroxide (KOH) as our catalyst. Sodium hydroxide is much easier to get and it is cheaper.

One-step alkali base catalyzed trans-esterification was carried out for methyl ester production process from *Brassica juncea*. It was established that trans-esterification depends on several basic variables, namely, catalyst type, alcohol type, catalyst-to-oil ratio, alcohol-to-oil ratio, reaction temperature, reaction time, agitation rate, FFA, and water content of oil. In this work, extensive preliminary experimentation with vegetable oils samples indicated that it was most efficient to fix reaction temperature at 65°C, agitation and reaction time for 2hrs. Firstly, in the trans-esterification process, different catalyst NaOH-to-oil ratios and different methanol-to-oil ratios were used to investigate their influence on the methyl ester yields of the oils. All the reactions were carried out in the reaction conical flask, which were immersed in a water bath placed on the plate of magnetic stirrer of 400 rpm. The temperature and the reaction time for all process were maintained at 65.0 ± 0.5°C and for 2hrs, respectively. After the reaction, the mixture was allowed to settle for 2hrs to overnight before separating the glycerol layer and the top layer including methyl ester fraction was removed in a separated bottles. In practical, the separated methyl esters must be conducted to remove impurities by washing with hot water until washing water was neutral[11]. However, yield of biofuel increases when the FFA in the oil is low. Since crude mustard oil contains more fatty acid, refining of mustard oil is necessary to continue the work in methyl ester extraction. Figure 3 shows the glycerol and biodiesel layer formed during the process of trans-esterification.



Fig. 3 Double Layers of Glycerol and Biodiesel – Removed fatty acids

Free Fatty Acid Estimation

A small quantity of free fatty acid is usually present in oils along with the triglycerides. The free fatty acid content is known as acid number or acid value. It increases during storage. The storing quality of oil and bio-diesel therefore relies upon the free fatty acid content.

The free fatty acid in oil is estimated by titrating it against KOH in the presence of phenolphthalein indicator. The acid number is defined as the mass of KOH required for neutralizing the free fatty acids content and is expressed as oleic acid equivalents.

Figure 4 shows the fatty acid content removed from the mustard oil by using the NaOH catalyst in pre-treatment. This fatty acid removal will improve the biodiesel yield. Around 150gm of fatty acid was removed from 1 liter of the oil. Through calculations it is estimated that the free fatty acid is calculated as oleic acid using the equation 1ml N/10 KOH = 0.35g oleic acid. But the obtained value cannot be considered as the acid value, it is the %FFA in the oil. Acid value is estimated as [6] follows:

$$\text{Acid value (mg KOH/g)} = \% \text{FFA (as oleic)} \times 1.99$$

$$\text{Acid value} = 0.35 \times 1.99 = 0.659 \text{ g.}$$



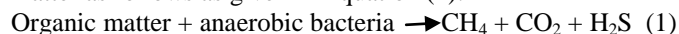
Fig. 4 Fatty Acids and Salt removed from Mustard Oil Bio – Chemical Conversion

The process of bio-chemical conversion of biomass carried out by Anaerobic digestion is the conversion or degradation of organic wastes through microbial actions in the absence of oxygen to reducing gases (biogas) that mainly consist of methane and carbon dioxide and contain various trace components such as hydrogen sulfide, acids and the oils. A typical example is the landfill gas (LFG) from the MSW buried in sanitary landfill sites. The collected LFG, which generally consists of up to 50% methane, can be purified and then burned in engines or turbines to produce heat and electricity. Practically, the biogas is commonly produced by using animal manure in an airtight container (digester). Due to the high heating value

(5400–6000 kcal/Nm³) of biogas, the biogas thus generated can be directly combusted in burners for cooking, or used as gas fuel in internal combustion engines to generate electricity, or further upgraded to natural gas quality by the removal of carbon dioxide and hydrogen sulfide [3]. Figure 5 shows the biomethanation process flow chart.

Introduction to Biomethanation Process

Bio- methanation process is one of the most essential processes for treating the Bio- degradable portion of solid waste. In this process the organic matter is converted into biogas that is a very useful form of energy. Anaerobic processing of organic material is a two-stage process, where large organic polymers are fermented into short-chain volatile fatty acids. These acids are then converted into methane and carbon dioxide. In the absence of oxygen, anaerobic bacteria decompose organic matter as follows as given in Equation (1):



Biogas is a mixture of gases composed of methane (CH₄) 40 - 70 % by volume, carbon dioxide (CO₂) 30 - 60 % by volume other gases 1 - 5 % by volume including hydrogen (H₂) 0-1 % by volume and hydrogen sulphide (H₂S) 0- 3 % by volume. The most important process parameters that must be taken into consideration when choosing the reactor configuration are:

- The organic loading of the wastewater (COD)
- The biodegradability (as indicated by the BOD/COD ratio)
- The temperature of the wastewater
- The versatility of the wastewater composition
- The presence of inhibitory or toxic compounds such as ammonia, sulphate or heavy metals
- The availability of seed sludge
- The technical skill of the local future operators [22].

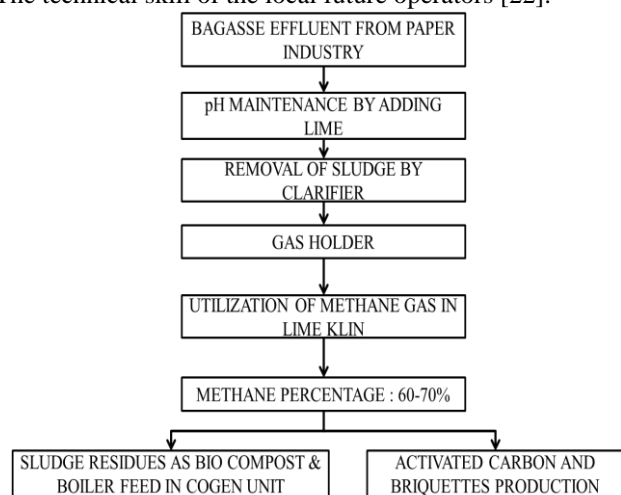


Fig. 5 Biomethanation plant process

Industrial Biomethanation Process

In this project, at paper and pulp industry the bio-methanation process was carried over with the bagasse wash water. Initially, the water was sent into equalization tank and then to neutralizing tank, where lime was added to reduce the pH of the bagasse effluent. Next step was to feed the neutralized bagasse water to the clarifier to remove excessive bagasse sludge and reduce the COD (chemical oxidation demand) of the bagasse waste. Since, UASB reactor is a high rate anaerobic reactor it is able to retain very high concentration of active biomass in the reactor. Thus extremely high SRT could be maintained irrespective of HRT. For a loading of 5-20 kg/m³-COD the removal efficiency was 80-90%.

Once the sludge was removed it is fed to the buffer tank where Di-Ammonium phosphate and urea are added as nutrients

to enhance biological activity of bacteria's. Finally it is fed to the UASB reactors with a retention time of 12-18hrs. The methane gas produced is collected and stored in the gas holder. This can be used as a replacement for the furnace oil used in the lime kiln. This eventually reduces the fossil fuel economy as well as the carbon emission levels. Periodically the sludge will be removed from the UASB reactor and then it is treated in decanter to remove moisture from the sludge which can be used as a bio-compost or can be burnt in the boiler along with coal to reduce fuel economy. A foam trap and a sediment trap are provided with the UASB reactor to remove the dust particles and the moisture content in the biogas. Fig.6 shows the biomethanation plant at the paper industry.

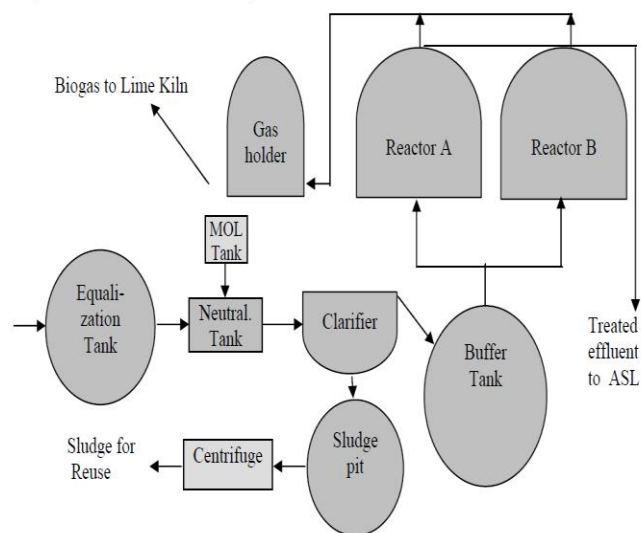


Fig. 6 Biomethanation plant layout at paper industry UASB Reactor (Up Flow Anaerobic Sludge Blanket Reactor)

Based on the above mentioned criteria's the suitable type of anaerobic reactor is UASB reactor. The Up-flow Anaerobic Sludge Blanket reactor (UASB) was a successful improvement for anaerobic wastewater treatment. High volumetric loading rates (up to 10-15 kg COD/m³ per day) can be reached on certain wastewaters. The reactor can be divided in three different areas: 1) the sludge bed, 2) the sludge blanket, and 3) the three-phase separator. In natural selection process, the good settling sludge is the active sludge that will be present at the bottom of the reactor. The wastewater is fed at the reactor bottom through a distribution system. While flowing upwards through the dense sludge bed, the organic pollutants are converted into biomass and biogas. This biogas creates a more turbulent area above the sludge bed which is covered by a thin film called the sludge blanket. On top of the reactor the three-phase separator first separates the biogas from the sludge-water mixture. Then, because of the lower turbulence, the sludge will begin to settle and return to the sludge blanket. To improve the sludge-water separation, parallel plates can be installed inside the separator to increase the settling surface area. The methanation process takes place through four stages with different bacterial action in the reactor is as follows:

1. Hydrolytic Bacteria
2. Fermentative Bacteria
3. Acetogenic Bacteria
4. Methanogenic Bacteria

Figure 7 shows the internal arrangement and function of the UASB reactor.

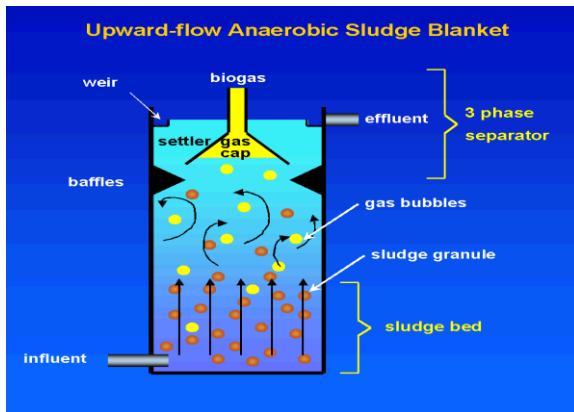


Fig. 7 Schematic Representation of UASB Reactor
Thermo-Chemical Process

The decreasing availability of fuel wood in most of the developing countries has necessitated the efforts be made towards efficient utilization of agricultural residues. Raw agricultural residues have many disadvantages as an energy feed-stock. These include (i) relatively low calorific value, (ii) difficulty in controlling the rate of burning, (iii) difficulty in mechanizing continuous feeding, (iv) Large volume or area required for storage, and (v) problems in its transportation and distribution [23]. These disadvantages may be attributed to the low bulk density of agricultural residues which can be converted into high density fuel briquettes through carbonization process. Agricultural residues constitute one of the important biomass feed stocks in India. In general agricultural residues can be classified into two groups; crop residues and agro –industrial residues. In this project briquettes are obtained using the feed stock of coconut biomass, bagasse, rice husk, coconut shell, coir pith, and ground nut shell [23].

Charcoal is usually prepared by slow pyrolysis process, the heating of wood, bone char, or other agricultural substances in the absence of oxygen environment at 450- 510°C by using a kiln [2]. Briquetting is the process of converting the low density biomass into high density and energy concentrated fuel briquettes. Figure 8 shows the sequential process of briquettes production at a cost effective rate.

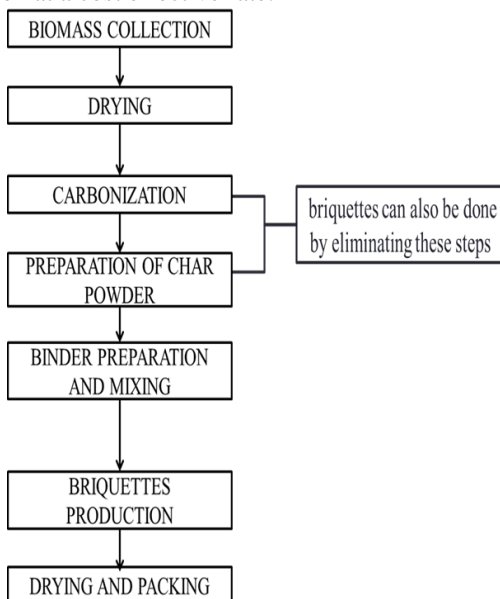


Fig. 8 Briquetting process flow chart

Properties and Cost Effectiveness Of Briquettes

Charcoal briquettes can be used as fuel in rural houses for cooking, laundering, and in boilers. The heat stability of the

briquettes is around 2 hours. Briquettes are used as a substitute for wood, coal and many other natural resources. India being an agricultural based country, so on a year basis million tons of forestry and agricultural waste is produced. Due to no proper usage of the waste, it causes various types of pollution such as air pollution, water pollution, and various hygienic problems. Such problem can be reduced if the waste is disposed through briquettes technology.

- Low cost
- Causes no pollution
- Renewable source of energy

The important properties of briquettes are given below:

1. Smokeless: the charcoal briquettes burn without much smoke during ignition and burning.
2. Low Ash content: minimum residual ash formed is less than 5% of the original weight of the charcoal. The calorific values of different biomass in percentage [34]-
 - Bagasse -1.80 %
 - Coir Pitch - 9.10 %
 - Sugarcane - 10.00 %
 - Mustard Stalk - 3.40 %
 - Mustard Shell -3.70 %
3. Calorific value of briquettes – 6243.58 Kcal/Kg. The following are the calorific values of briquettes obtained from various biomass [34],
 - Bagasse - 4380 Kcal/Kg
 - Coir Pitch - 4146 Kcal/Kg
 - Sugarcane -3996 Kcal/Kg
 - Mustard Stalk - 4200 Kcal/Kg
 - Mustard Shell - 4300 Kcal/Kg
4. Odorless: Contains minimum evaporative substances thus eliminating the possibility of odour.
5. CO₂ - potential is neutral.
6. Sparkles: no sparks are produced like wood charcoal.
7. Less cracks and better strength: helps for a longer time.
8. Each kilogram of briquettes costs only Rs.9/kg.
9. Cost for binder preparation is Rs.5/ 30 kg of briquettes.
10. Monthly profit possible – Rs.3000-4500/ month.

Alternative Briquetting Method

Briquettes can also be made by grinding Biomass and sawdust into a homogeneous pulp and forming this into a briquette under very high pressure. High pressure & pressing releases one of the natural components of wood - lignin which has the property of becoming liquid at high pressure (temperature) and, as it subsequently cools, it binds the wood together in its new form Briquettes. This method involves briquetting process without carbonization of biomass [34]. The process is given as below:

- Raw material like Saw Dust and biomass are chopped by cutter chipper.
- For using material of two or more types, it should be mixed in suitable form.
- If raw material has high moisture it should be reduced by Sun drying or using flash drier.
- Hammer mill grinder is used to grind the material to get desired grain size.
- Raw material is transported by pneumatic system to holding bins fixed over Briquetting Press. Before the briquetting process the grinded mixture is added with binder to increase the strength of the briquettes.
- By Screw conveyor, material is discharged from bin to the press.

- Material is compressed by ram through taper bored die. By compression temperature is raised.
- Briquettes are formed in shape of log and it is automatically pushed through cooling line to the storage point.

Modeling Of Activated Carbon Scrubber

Diesel Engines are the major source of BLACK CARBON which is the unburnt hydrocarbon emitted as the result of combustion process in the engine. In addition to it, Green House Gases like CO₂, NO_x, and SO_x are emitted in to the atmosphere. In order to reduce the emissions of CO₂ and Black Carbon, catalytic convertors are used. These Catalytic convertors are high cost and use catalysts like palladium, titanium which are highly precious and costly. Designing a Green Filter is a suitable approach to reduce cost and the increase the production efficiency. As we know that ACTIVATED CARBON absorbs the SOOT/ Black Carbon with high efficiency. Following the SNCR (Selective Non- Catalytic Reaction) process, which is a method used to lessen nitrogen oxide emissions in conventional power plants that burn biomass, waste and coal. The process involves injecting either ammonia or urea into the firebox of the boiler at a location where the flue gas is between 1,400 and 2,000 °F (760 and 1,093 °C) to react with the nitrogen oxides formed in the combustion process. The resulting product of the chemical redox reaction is elemental nitrogen (N₂), carbon dioxide (CO₂), and water (H₂O).

In this present work we used SODA LIME, as a catalyst to reduce CO₂ into Calcium carbonate and water vapor. To hold the catalyst, a suitable base is utilized which could be useful during regeneration of the activated carbon. This filter will have the arrangement of wire mesh at the base with the calcium hydroxide catalyst and activated carbon mixture over the top. This filter is fitted to the exhaust of the diesel engine and the emission level is tested using the total gas analyzer. Once the filter gets exhausted, it could be refilled with the filter media at low cost. Hence net Carbon emission and Carbon footprint can be maintained.

Activated Carbon from Biomass Feed

Activated Carbon is a porous form of Carbon manufactured from Coconut shell, wood or coal. Activation is achieved with steam and it develops myriad of pores with enormous internal surface area.

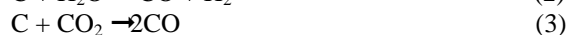
The porosity creates a remarkable power of Adsorption, an indispensable process in industrial separation, purification; decolorization and recovery techniques. The Carbon atoms at the internal surface of Activated Carbon exert an attraction (van der waals force) on the molecules of surroundings liquid and gas and fixes on to its pore walls. This is the basis of mechanism whereby Activated Carbons may be used to remove one or more components from a mixture. In this project activated carbon of granular shape is used in the mesh size of 4/8 which is shown in the figure 9. The iodine value and moisture content of the purchased coconut shell activated carbon is given below:

- Iodine : 550 – 650
- Moisture : 25% ± 3%



Fig.9 Coconut shell Activated carbon

The coconut shells are steam activated. They are first carbonized to create a char. High temperature kilns (up to 1000°C) are used to activate the char in a steam atmosphere i.e. are steam activated rather than chemical. The activation involves the reaction of the carbonized material with steam as follows as given in the equation (2) and (3):



The activation process can be manipulated to produce desired characteristics in the product. Steam concentrations, temperature, and CO₂ concentrations control pore development, which in turn affect pore size distributions and the level of activity. Un-impregnated or base carbon is a good adsorbent for organic vapors, but a poor adsorbent for low molecular weight or polar gases such as chlorine, sulphur dioxide, formaldehyde, and ammonia. Impregnation is the process where activated carbon is treated with a chemical reagent that reacts with these types of gases, binding them up on the carbon and thereby removing them from an airstream. This process, commonly referred to as chemisorption, may involve neutralization or catalysis reactions.

Analysis Of Activated Carbon

The process of activated carbon generation begins with the selection of a raw carbon source. The element carbon occurs naturally in two different forms diamond and graphite. These sources are selected based on design specifications since different raw sources will produce activated carbon with different properties. Some of the more common raw sources include wood, sawdust, lignite, peat, coal, coconut shells, and petroleum residues. The form used by Molecular Products is from coconut shells and coal.

The working mechanism of activated carbon is Adsorption –the process by which activated carbon removes substances and is defined, as ‘the collection of a substance onto the surface of adsorbent solids’. It is a removal process whereby certain particles are bound to an adsorbent particle surface. Adsorption (or chemisorption) is often confused with absorption (or physisorption), where the substance being collected or removed actually penetrates into the other solid and alters its structure [31].

Pore size distribution – Determination of the pore size distribution of an activated carbon is an extremely useful way of understanding the performance characteristics of the material. The International Union of Pure and Applied Chemistry (IUPAC) define the pore size distribution as:

- Micro-pores $r < 1\text{nm}$
- Meso-pores $r 1\text{-}25\text{nm}$
- Macro-pores $r > 25\text{nm}$

Design of Activated Carbon Scrubber

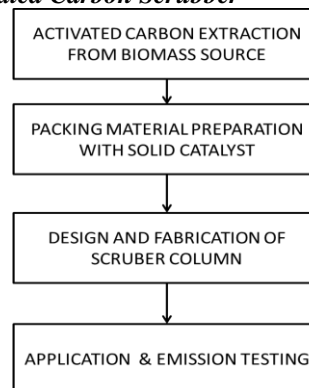


Fig.10 Scrubber design process

Emissions are not only emitted from the fossil fuel burning in automobiles, even from the combustion of green fuels produce considerable amount of carbon based emissions like CO₂, hydrocarbons, carbon monoxide and other trace gases. In this project the proposed design of the scrubber consist of four carbon beds proportioned with the solid catalyst of soda lime. Figure 10 shows the fabrication steps for designing the scrubber. The coconut activated carbon of mesh size 4/8 is proportioned and mixed with the catalyst soda lime in the ratios of 70:30 and 50:50. The scrubber is designed in such a way that no pressure drop occurs when installed in the vehicle exhaust. Hence a perforated tube is provided in the design. This tube will enhance the more contact period of the exhaust gas from the engine manifold. The scrubber design with packed layers will be provided proper air passages to minimize the back pressure. Total length of the scrubber is around 40cm and diameter is about 10cm, the scrubber column is divided into five empty sections and four packed section. Three packed section of thickness 2.5cm and the final section with 5 cm thickness, inlet and outlet port of 3cm diameter. The design will be implemented in two-wheeler and four-wheeler exhaust and carbon absorbance will be tested using the multi-gas analyzer and smoke density analyzer. The cross sectional view of proposed design of the scrubber is given in the 3-D representation in the figure 11. The 2-dimentional representation of the proposed is given in the APPENDIX 1.

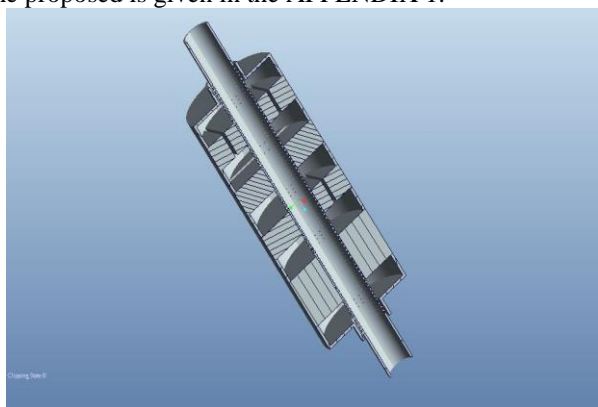


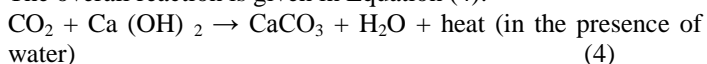
Fig.11 Cross-sectional 3-D representation of proposed design of scrubber

Solid Catalyst

Soda lime is a mixture of chemicals, used in granular form in closed breathing environments, such as general anesthesia, submarines, re-breathers and recompression chambers, to remove carbon dioxide from breathing gases to prevent CO₂ retention and carbon dioxide poisoning. It is made by treating slaked lime with concentrated sodium hydroxide solution. The main components of soda lime are

- Calcium hydroxide, Ca (OH)₂ (about 75%)
- Water, H₂O (about 20%)
- Sodium hydroxide, NaOH (about 3%)
- Potassium hydroxide, KOH (about 1%).

The overall reaction is given in Equation (4):



The reaction can be considered as a strong base catalyzed, water facilitated reaction. In this project, soda lime is mixed to the activated carbon in-order to enhance the CO₂ in the exhaust gas. This approach to apply soda lime is based on the concept of re-breather in undersea purpose. The following equations show the basic mechanism of soda lime reactions is given in the Equation (5), (6) and (8):

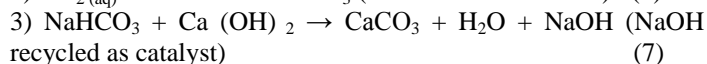
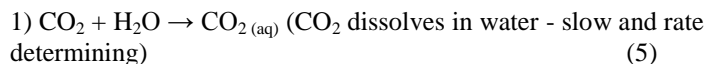


Fig.12 Activated carbon and soda lime used

Each mole of CO₂ (44g) reacted produces one mole of water (18g). The soda lime even if gets saturated it could be regenerated using the most common method of back washing to reverse the reaction of CO₂ absorbance. The mixed composition of the soda lime and activated carbon used in the scrubber is shown in figure 12.

Fabrication of Scrubber

The scrubber fabrication is carried on with the 3mm thickness iron pipe and wire mesh. The fabrication of scrubber included some design parameter changes. The filled scrubber sections will be provided support grid of wire mesh to hold the activated carbon and soda lime mixture. The scrubber fabrication process is completed by mounting each separate ring which is hold together by arc welding. Once the full scrubber is welded together and inlet, outlet ports are inserted and sealed. The scrubber is checked for gas leaks and it grinded to level the welded surface. Then the scrubber is coated with white plaster and it is piled. Finally scrubber is painted to provide cooling effect. Figure 13 shows the cross section of the scrubber section.



Fig.13 Ring sections of scrubber with wire mesh before fabrication

The quantification of the scrubbing layers is shown below:

The entire scrubber is in the form of cylinder .The formula for

calculating volume of cylinder is **Volume $V = \pi r^2 H$**

For section with thickness H=5 cm, r=5 cm

$$V = 5 \times (5^2) 3.14$$

$$V = 400\text{mL} \sim 400\text{gm.}$$

Assigned Activated carbon and soda lime Ratio =70:30,

Activated carbon: 280 gm.

Soda Lime: 120 gm.

For section with thickness 2.5 cm,

$$V = 2.5 \times (25) \times 3.14$$

V = 196.25~200gm.

Assigned Activated carbon and soda lime Ratio =70:30,

Activated Carbon: 140 gm.

Soda Lime: 60 gm.

Assigned Activated carbon and soda lime Ratio = 50:50, (two sections)

2 x Ratio = 50:50

Activated Carbon: 100gm.

Soda Lime: 100gm.

The fabricated design in 2-dimentional view is given in APPENDIX 2.

Result And Discussion

Emission of fossil fuels increases the potential of global warming and temperature rising. Through this project the capability of the green fuels to retard the potential effects of the global warming and a comparative analysis of emission level between green fuels and fossil fuels, the effectiveness of the activated carbon scrubber and results of various tests are discussed in this section.

Biodiesel Property Analysis

Extraction of biodiesel from mustard oil was conducted by determining the composition in the mustard oil and their fatty acid compositions. The sample of mustard oil was sent for testing and results are obtained. The estimated fatty acid content is 0.35gm of Oleic acid per liter. This acid value is estimated to be 0.659gm and the determination of the NaOH catalyst necessity is quantified as 25gm. Total free soap content is around 150gm per liter. This is removed by settling process due to the addition of the acid catalyst like H_2SO_4 or HCL in small quantity. This process is known as Acid catalyzed transesterification process which may be optional based on the oil composition. Table 1 shows the composition of mustard oil.

After the extraction of biodiesel, the next step is to justify the obtained product, biodiesel by the estimation of the following parameters like calorific value, specific gravity, viscosity, cetane number, flash point, pour point, cloud point are relatively equal to the petroleum based diesel. Hence when the biodiesel is used as a blend in automobiles there will be a same result the petroleum diesel. The result of the properties analysis is given in Table 2.

Emission Analysis of Biodiesel

On verifying the data obtained from test results provided from the laboratory where the biodiesel is sent for emission analysis, the comparison of emission level for Biodiesel (which is blended in the ratio of 50:50 with diesel) and petroleum based diesel fuel is given in the table 2. It has been found that "by substituting biofuel for diesel, CO emission has reduced by 20%, hydrocarbon has reduced by 40% and PM by 65% in reference with emission standards of the **Bharath stage emission standards**. But NO_x is showing reverse effect from others. Its emission is found to be increasing by 30%. Hence it is necessary to reduce the NO_x emission which could bring trouble to environment and human. Table 3 shows the emission

Biogas Composition Estimation

Biogas from waste biomass through microbial digestion is an excellent alternative fuel and economical waste disposal method. Utilization of biogas for various purposes reduces the resulting emission from biogas flaring. In pulp and paper industry, bagasse effluent is used in biogas generation through anaerobic digestion process. The bagasse sludge removed from the effluent which is in excess quantity is given as boiler feed along with the coal. The composition of biogas obtained is found to possess 70% of methane, 30% of CO_2 and 3% of H_2S . Even

though CH_4 (methane) is in high composition the calorific value is only around the 3000-4000 GCV. CO_2 scrubbing can increase the GCV of the biogas to 7000-8000 GCV and also produces 99% pure bio-methane.

Table 4 and Table 6 shows the respective biogas generation estimated and their potential sources utilized it as fuel and the other parameters like COD, recirculation rate of the bagasse effluent in the Biomethanation plant. The average design capacity for gas production is 23000 m^3 . The entire operations of this biomethanation process are depending on the following factors given Table 5. The formula for calculation of the given parameters is given in APPENDIX 3.

Emission and Cost Reduction by Fuel Savings at Paper Industry

Biogas generation is a common in rural areas to manage the agricultural, human and animal waste properly. In order to minimize the cost of disposing the bagasse sludge generated from the industry biogas generation is included. The biogas substitution for the furnace oil in lime kiln, as the boiler fuel, and bagasse sludge as the raw feed to boiler along with the coal reduce the cost of importing coal and impact of emission on environment.

Emission of greenhouse gases into atmosphere due to the burning of fossil fuels like coal, furnace oil increases the global warming potential to greater concentration. Even natural wastes like biomass, cow dung, vegetable waste and food waste are utilized for producing biogas through anaerobic digestion process, methane is emitted into atmosphere which have 21 times global warming potential is higher than CO_2 . This also cause climate change by increasing the temperature by 4-6°C. But it can be used as a fuel which has reduced the CO_2 emission dramatically. Table 7 shows the CO_2 reduction occurred annually due the replacement of the biogas to the fossil fuels. The emission reductions are accounted in terms of the CO_2 equivalents.

Cost Analysis data for furnace oil, imported coal, energy consumptions and boiler feed is given in Table 8. These data indicates how far the biogas utilization results in economic and environmental aspects provide benefits.

Cumulative Emission Analysis

The obtained result of this project shows that switching to the waste biomass is proved to be beneficial in both economic and environmental basis. The biogas and briquettes are more comparatively low in emission and also in cost basis than biodiesel production. The extraction of raw material for biodiesel production is a tedious process and time consuming one. Even in the aspect of emission of NO_x it shows negative impact on global atmospheric scale about 40% increasing. Biodiesel on the whole, it is a good alternative fuel for automobile transportation which is obtained from green biomass of *Brassica juncea*. But it cannot be practiced as direct replacement, since it has to be blend with the Diesel in different proportions like B20, B50 to obtain maximum emission reduction.

Considering the biogas, it has the potential to get replaced directly as fuel in place of LPG in house hold applications, in industries for boilers, heat generation. Biogas is more economical and is obtained from the waste biomass. Hence biogas generation deals with the "waste to energy" concept. But only factor affecting it is the traces gases like CO_2 and H_2S reduces the calorific vale of the biogas. After the biogas generation the waste residue in the biogas reactor can be recovered, dried and can be easily used as bio-manure or as soil

enricher in agricultural sector, as boiler feed or as an alternative for the coal and firewood. Coming to the briquettes which is also generated from the waste biomass feeds like rice husk, bagasse, mustard stacks, no expenditure is required purchase raw materials. Instead the wastes from agricultural fields, sugar industry, paper industry, and saw dust etc., can be collected and used in Briquettes generation. Briquettes emission is not taken into account since the carbon is absorbed and stored in the plant biomass from the atmosphere during the photosynthesis process. Figure 14 shows the comparison between different emission parameters of Biodiesel, Biogas and diesel fuels. The red and violet dotted lines indicate the linear decrease in NO_x emission as well as the CO_2 emissions reduction.

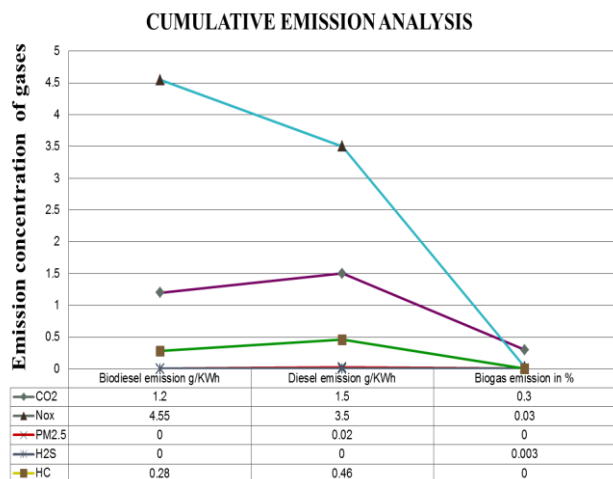


Fig.14 cumulative emission analysis between green fuels and diesel fuel

Even though CO_2 emissions have been reduced through the green biomass energy utilization, it is not enough to mitigate the global warming. Hence carbon sequestration and carbon neutrality comes in concern. To meet this uncertain goal catalyzed activated carbon scrubber should be implemented in CO_2 scrubbing and removal.

Testing of Activated Carbon Scrubber

The designed catalyzed activated carbon scrubber which could be implemented for biogas scrubbing, boiler exhausts emissions, in dye removal after the saturation of the scrubber, and can be used in the automobile emission control. The activated carbon used in this project is obtained as a by-product from the thermal conversion process of biomass in to green energy. Hence it is cost effective, regeneratable, and ecofriendly in disposing. The solid catalyst (soda lime) is also regeneratable once if it is saturated. Both activated carbon and catalyst can be done by simply back washing with continuous stream of water.

Before the installation of the scrubber for CO_2 scrubbing and sequestering, the adsorbing capacity of the Activated carbon and the catalyst mixture should be tested. The gas scrubber is fixed to the engine exhaust of the petrol and diesel vehicles. The parameters like CO, CO_2 , and HC are considered for petrol engine. The percentage of the emission reduction is recorded for time interval of three minutes using Multi-gas analyzer. The multi gas analyzer consist of two filters, both filters are AROMATIC WATER FILTER TYPE. These filters prevent moisture and dust particles if present in the gas sample. The smoke density test was conducted for the diesel engine emission using the Smoke analyzer. The smoke analyzer is for diesel engines. It consists of a peizo sensor and oil temperature measuring sensor. It also has an RPM analyzer. This analyzer takes more time than the Total gas analyzer. At different time

intervals the values will be noted. Both analyzers have a nozzle connected to the tube from the meters.

For diesel emissions the samples will be collected for several times for different speeds. Then the sample is analyzed in the smoke analyzer in which the peizo sensor will sense the smoke calculate the density value. Meanwhile the oil temperature of the vehicle and the speed of the engine are recorded by the other sensors and average hartidge units are calculated. For diesel engines the along with these parameters oil temperature -60°C and the RPM rate depending on the design of the engine is noted. The results obtained for petrol engine and diesel engine are given in the APPENDICES (4 to 11). Figure 15 shows total gas analyzer and Smoke analyzer used for the emission measurement. These tests are conducted for both fuels without fixing the scrubber initially and then test conducted with the scrubber being installed. Figure 16 shows experimental arrangement of the scrubber to the exhaust port of the vehicle with the smoke analyzer probe fixed to one end.



Fig.15 Total gas analyzer and smoke analyzer setup



Fig.16 Experimental arrangement of the fabricated scrubber for testing

Efficiency Analysis of Catalyzed Activated Carbon Scrubber

The emission testing for both petrol and diesel fuels are conducted as explained in the section 4.4. Emission criteria for petrol vehicles are based on the Carbon monoxide and Hydro carbon emissions. Regulations for CO and HC are 3.5 ppm and 6000 ppm. Before the scrubber is being installed the emission of CO and HC are recorded as 3.264 ppm and 2952 ppm. After the scrubber is installed the rate of CO emission decreased to 1.819 ppm and nearly upto HC to 1688 ppm and after 3 minutes time interval it decrease to 1.305 ppm and HC to 1448 ppm. Apart from this results CO_2 emission has increased slightly which indicated that conversion reaction has occurred inside the scrubber. Thus carbon monoxide reacts with oxygen and converted into CO_2 at the initial point of installing the scrubber and then gradually decreases.

Hence the CO_2 emission is about 12.54 ppm without scrubber and after fixing scrubber it increases to 13.32 ppm, after 3minutes time interval reduces to 12.48 ppm. The oxygen data shoes the entire working of the scrubber is at optimum value with increase in time and temperature. The emission

testing results are given in APPENDICES (4 to 6). Figure 17 shows the graphical representation on the emission analysis result plotted for Carbon monoxide emission reduction due to installation of the scrubber.

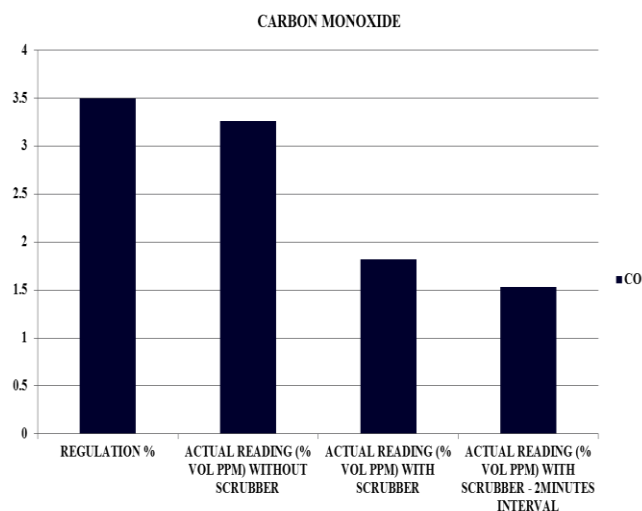


Fig.17 CO reduction due to catalyzed carbon scrubber

Figure 18 shows the graphical representation of the Hydro Carbon emission variation with presence of the scrubber and in the absence of the scrubber. The CO and HC emissions are considered for the petroleum fuels. The value of HC is given in parts per million.

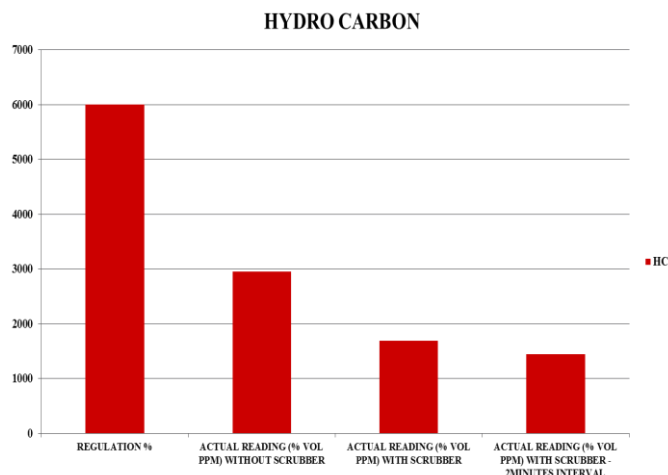


Fig.18 Hydrocarbon emission reduction due to catalyzed carbon scrubber

Figure 19 shows the graphical representation of the CO₂ emission resulted while burning the Petroleum based fuels. The variations in the CO₂ level shows that the carbon monoxide has been converted into CO₂ by combining the oxygen molecule in the air with CO due to the internal reaction in the scrubber.

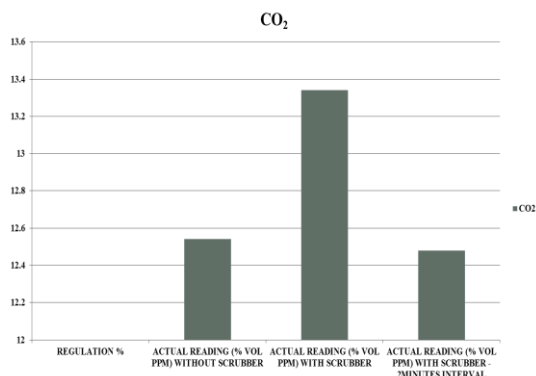


Fig.19 CO₂ emission variation due to scrubber

Figure 20 shows the O₂ utilization in the scrubber by the catalyst for reducing the carbon emission. The graph is plotted for O₂ concentration in the ppm and reading recorded at time interval of 3 minutes.

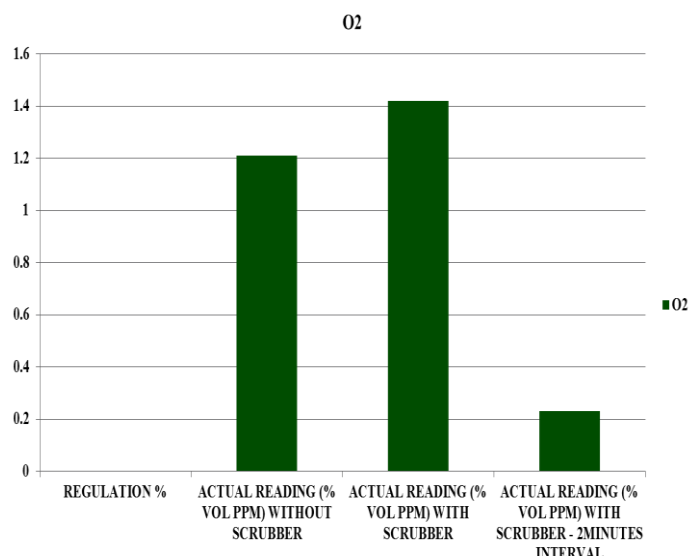


Fig.20 Oxygen utilization in emission reduction by the catalyst

The graphical figures show the emission reduction factor and carbon adsorbing capacity of the activated carbon scrubber. When testing for Diesel engine emission, smoke density reduction is measured in terms of the light absorbing coefficient (L/M) value and Hartidge units. Figure 21 shows the graph plotted between L/M value and range of rpm. Figure 22 shows the graphical representation of the Smoke density reduction at different rpms with the installation of the activated carbon scrubber. The brown bar represents the smoke density measured before the installation of the scrubber. Smoke density varies depending on varying rpm rates. The overall efficiency of the scrubber to adsorb carbon is given in the table 12. The efficiency of the scrubber for CO and HC efficiency is at optimum of 75.86% and 56.28% respectively which are based on the regulation values set by pollution control board. The efficiency of the scrubber tends to increase on each trail. Table 13 shows the efficiency of scrubber to reduce the smoke density for diesel emission. The efficiency is estimated to be 19.84% at optimum value. Test results are conducted at five different rpm rates.



Fig.21 Light absorbing coefficient vs. rpm rates

Table 1
Composition of mustard oil

FATTY ACIDS	MASS FRACTION, %
Myristic	0.063
Palmitic	2.377
Palmitoleic	0.180
Heptadecanoic	0.018
Heptadecanoic	0.043
Stearic	1.253
Oleic	25.156
Linoleic	14.459
Arachidic	1.338
Eicosenoic	0.423
Heneicosanoic	0.838
Docosadienoic	0.286

Table 2
Comparison of properties of biodiesel with diesel fuel

Properties	Diesel	FAME
Density @ 15°C, kg/m ³	831.9	882
Viscosity @40°C, cSt	3.348	5.63
Sulphur, % mass	0.45	0.054
Acid number, mg KOH/g	-	0.35
Flash point	65.0	154
Pour point [degree]C	-6	-11
Cloud point[degree]C	NA	+5
Cetane number	55	49

Table 3
Emission standards and reduction level

Parameter	Diesel	Biodiesel B50	% Difference
CO	1.5 g/kWh	1.2 g/kWh	Decreased By 20%
HC	0.46 g/kWh	0.28 g/kWh	Decreased By 40%
NO _x	3.5 g/kWh	4.55 g/kWh	Increased By 30%
PM10	0.02 g/kWh	Negligible	Decreased By 65%

Table 4
Cumulative gas production and utilization on day 1

PARAMETERS	VALUES	UNITS
Raw effluent	244198	m ³
Gas production	421167	m ³
Gas to kiln	421167	m ³
Lime in	71.82	Mt
Recirculation	1484	m ³ /day
Reactor inlet	53694	kg COD/day
Reduced	46285	kg COD/day
Reactor O/L	7409	kg COD/day
Gas production factor	0.5	--

Table 5
Optimum loading rates loading rates

PARAMETERS	DAY 1(%)	DAY (2%)
HLR	95.88	91.84
OLR	93.22	83.67
VLR	5.6	5.0
COD	86.29	86.05

Table 6
Cumulative gas production and utilization on day 2

PARAMETERS	VALUES	UNITS
Raw effluent	255217	m ³
Gas production	441905	m ³
Gas to kiln	441905	m ³
Lime in	75.81	mT
Recirculation	1997	m ³ /day
Reactor inlet	49925	kg COD/day
Reduced	43259	kg COD/day
Reactor O/L	6723	kg COD/day
Gas production factor	0.49	--

Table 7
Emission reduction due to biogas substitution and design standards

PARTICULARS		VALUES	PARAMETERS	STANDARD VALUES
Bio gas generation per year	m ³	5797777		
savings of furnace oil per year	KL	3479		
Emission reduction of GHG / year due to CH ₄ avoidance	MT CO _{2e}	65062	FLOW RATE m ³ /d INLET COD mg/l OUTLET COD mg/l COD reduction % Gas production m ³ /d	12000 6000 750 85 23000
Emission reduction due to furnace Oil savings	MT CO _{2e}	11281		

Table 8
cost analysis for bagasse and biogas

Cost Of Fuel Per Ton	5183 RS
Total Running Days Of Boiler	330 DAYS
Fuel Saving Per Hour	139 kg/hr.
Fuel Saving Per Day	0.1392 x 2 = 3.36 ton/day
Fuel Savings Per Annum	1100 TON
Amount Saved	55 LAKHS
Feed For Boiler	1000 TONS / DAY
Furnace Oil Saved	12 KL
Bagasse Pith Used	300 TON/DAY
Biogas generation rate	25860 m ³ /day

Table 12: Efficiency of scrubber for Carbon emission reduction

Parameter For Diesel Fuel	Regulation - In Hartidge Units	T 1	T 2	T 3	T 4	T 5
Rpm Rates	Free Acceleration- 3500 Rpm	3200	3300	4500	2600	2300
Hartidge Units	65	58.9	55.8	56.4	51.7	52.1
Efficiency Of Scrubber For Smoke Density Reduction	Efficiency= (Regulation - Actual Reading / Regulation)X 1000	9.38 %	14.15%	13.23 %	20.46%	19.84 %

Table 13: Efficiency of scrubber for Smoke reduction

PARAMETERS FOR PETROL FUEL	Regulation IN ppm	TRIAL 1	TRIAL 2	TRIAL 3
HC Emission In PPM	6000	2952	1688	1448
CO Emission In PPM	3.5	3.264	1.819	1.53
EFFICIENCY OF SCRUBBER FOR CO EMISSION	Efficiency = (regulation - actual reading / regulation)x 1000	50.80%	71.86%	75.86%
EFFICIENCY OF SCRUBBER FOR HC EMISSION		6.74%	48.02%	56.28%

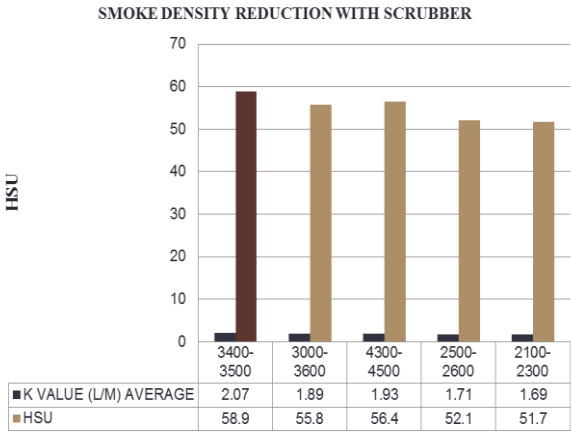


Fig.22 Smoke density reduction with scrubber

Conclusion

Typically cost of biomass plays a role in effective green energy production. As far as India is concerned, it is the major source of biomass like sugarcane waste bagasse, rice husk, and other agricultural residues. Based the results obtained in this project the Biogas production and Briquettes production are more cost effective than Biodiesel obtained from fresh biomass, because the other two methods utilizes the waste biomass residue to convert into enrgy. Biodiesel obtained form mustatd oil is comparatively similar to the properties of petroleum based fuel in all aspects. But it could be used only as blend with the diesel which comparatively increase the emission of NO_x.

Biogas ingeneral effective in utilizing for heat generation process like cooking, boilers, and co-generation plants instead of coal, LPG and wood. As the Biogas is generated from waste biomass, environmental friendly waste disposal and cleaner development environment is enhanced. Briquettes production on other hand, they are effective in waste utilization and emission reduction. It could possibly enhance rural employment as it requires less cost and low man power.

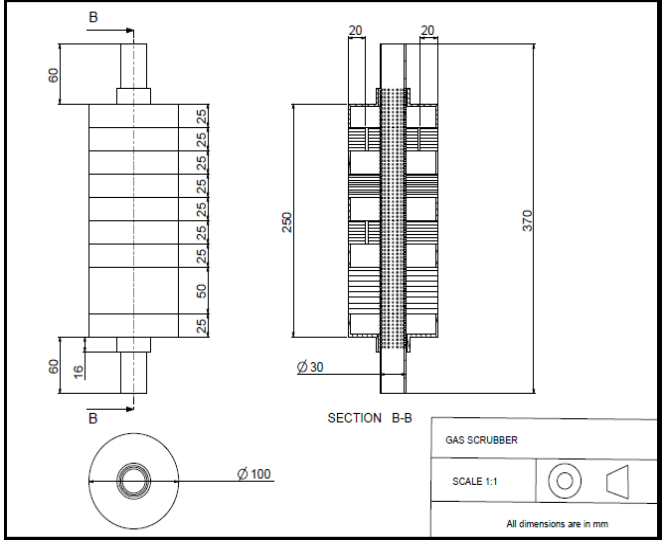
In overall the green biomass fuels in three different states ar good sustitute for the fossil fuels and their by-products. Hence in emission aspect also they are far superior to the biodiesel extraction through trans-esterification process. But producing green fuel alone wont help in reducing the global carbon emission. In order to reqach ulimate emission reduction, the scrubbing of the exhaust gas to reduce the major contributing GHG gases.

The efficiency of the scrubber is recorded as the 75.86% for Carbon adsorbance factor. Hence implementing the Activated carbon scrubber with catalyst for scrubbing of biogas to obtain 99% pure Bio-methane or the mathane content can be increased to 75-80% from 60-70% which could imprope the heating value of the Biogas. Even if this scrubber is used at the Biogas flaring to reduce the escaping of the GHG gas with high concentration. This scrubber made of Activated carbon and Soda lime catalyst can also be used in boilers to control emissions and reduce Black carbon emission from thermal power plants due to the high capacity of the Carbon capturing capacity. This scrubber can also be installed for odour removal in houses, industries by placing at ventilating ducts, re-breathers in under sea respiration equipments and after the scrubbers get completely saturated they can be installed for pH reduction and water treatment process before neutralization process.

Appendices

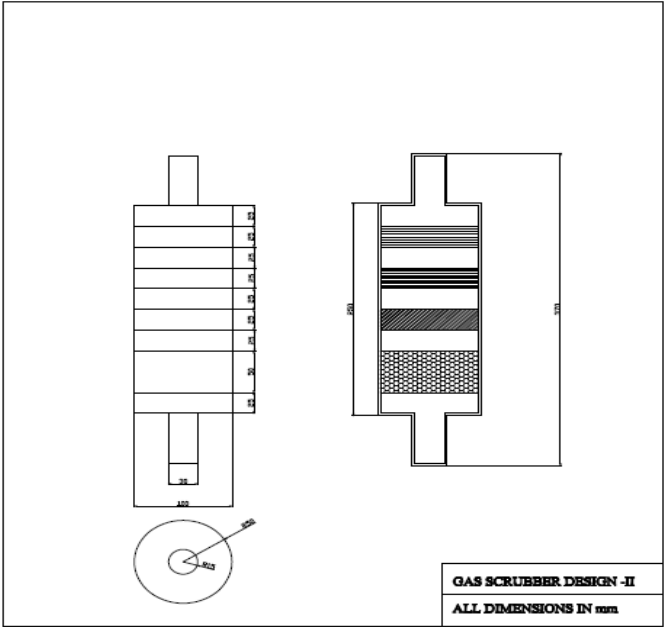
Appendix 1

2-d representation of proposed desing of the catalyzed activated carbon scrubber



Appendix 2

2-d representation of fabricated design of the catalyzed activated carbon scrubber



Appendix 3

Formula for loading rate calculation

PARAMETER	FORMULA
HLR	$\frac{\text{TOTAL RAW FLOW} \times 100}{\text{DAY}}$
OLR	$\frac{\text{TOTAL RAW FLOW} \times \text{avg INLET COD}}{57600}$
GPF	$\frac{\text{GAS PRODUCTION}}{\text{Kg OF COD REDUCED}}$
Kg OF COD	$\frac{\text{INLET kg COD} - \text{OUTLET kg COD}}{\text{INLET COD}}$
COD REDUCTION	$\frac{\text{INLET COD} - \text{OUTLET COD}}{\text{INLET COD}} \%$
VLR	$\frac{\text{TOTAL kg COD}}{10000}$

Appendix 4

Emission testing report for petrol engine without scrubber

Form (Computerised Pollution Under Control Certificate (Petrol))
RULE 116 (B) (10) (C) (Authorised by the Transport Department Govt. of Tamilnadu)

SUPER AUTO SERVICE
Vehicle Emission Testing Centre
C/o. HP Petrol Bunk
Mettupalayam Road, Near TVS Benz Show Room, Coimbatore - 641 043.
Cell : 98433 60980, 91501 14296

Serial No.: 1044

Centre Code: TN-38-009
I.D. Number: TN38AW2326
Vehicle Registration No.: 0
Month & Year of Registration: 10-Oct-2010
Speedometer Reading (Kms): 0
Test Result: 3.5 IDLNG 3.4

Type Of Vehicle: 2 Stroke
Type Of Engine: TVS
Vehicle Make: XL SUPER
Vehicle Model: AW 2326
Bharat Stage: Stage II

Authorisation Number & Validity: 21/CBE/99 & 12-12-2014
Date: 02-Mar-2013 5:13:29 PM
Fuel: PETROL/CNG/LPG
Oil Temperature: 73

ALLOWABLE RPM LIMITS: 300 +/- 3347 RPM

Free acceleration	K-Value (1/m)	ACTUAL RPM
T1	1.91	3400
T2	1.91	3500
T3	2.32	3400
T4	2.04	3420
T5	2.01	3400
T6	---	---
T7	---	---
T8	---	---
T9	---	---
T10	---	---

HSU Average: 58.9 K-Average: 2.67

Permission Limits at the back of the Form

Validity: 6 Months

MR ANANTHAMOORTHY
Seal of Testing Station: Code: TN-38-009
Signature of the Driver/Owner: Signature of the Licence / Testing Person

01-Sep-2013

Appendix 7

Emission testing report for diesel engine without scrubber

COMPUTERISED POLLUTION UNDER CONTROL CERTIFICATE
RULE 116 (B) (10) (C) (Authorised by the Transport Department)

BRIGHT STAR
VEHICLE EMISSION MONITORING CENTRE
525-A, Avinashi Road, Opp. Raja Raja Garden, Peelamedu, Coimbatore - 641 004.
Authorisation Number & Validity: 11/CBE/99 & 26-09-2014

Cell No.: 98432 60116

Centre Code: TN-37-004
I.D. Number: DP201300384
Vehicle Number: TN38AE040
Type Of Vehicle: 4W
Month & Year Of manufacture: 02/2006
Makers Name: TATA
Makers Class: INDICA
Odometer Reading (Kms): 0
Oil Temperature: 73

S.N.O.: 26041
Fuel: DIESEL
Date: 02/Mar/2013
Time: 5:30:48 PM

Photo of Vehicle

Valid upto: 01/Sep/2013
Testing Charges: Centre Code: TN37004

HSU Average: 58.9 K-Average: 2.67

Permission Limits at the back of the Form

Validity: 6 Months

MR ANANTHAMOORTHY
Seal of Testing Station: Name of the Driver/Owner: Signature of the Driver/Owner: Signature of the Licence / Testing Person

Appendix 5

Emission testing report for petrol engine with scrubber - trial 1

Form (Computerised Pollution Under Control Certificate (Petrol))
RULE 116 (B) (10) (C) (Authorised by the Transport Department Govt. of Tamilnadu)

SUPER AUTO SERVICE
Vehicle Emission Testing Centre
C/o. HP Petrol Bunk
Mettupalayam Road, Near TVS Benz Show Room, Coimbatore - 641 043.
Cell : 98433 60980, 91501 14296

Serial No.: 1045

Centre Code: TN-38-009
I.D. Number: TN38AW2326
Vehicle Registration No.: 0
Month & Year of Registration: 10-Oct-2010
Speedometer Reading (Kms): 0
Test Result: 3.5 IDLNG 3.9

Type Of Vehicle: 2 Stroke
Type Of Engine: TVS
Vehicle Make: XL SUPER
Vehicle Model: AW 2326
Bharat Stage: Stage II

Authorisation Number & Validity: 21/CBE/99 & 12-12-2014
Date: 02-Mar-2013 5:17:11 PM
Fuel: PETROL/CNG/LPG
Oil Temperature: 73

ALLOWABLE RPM LIMITS: 300 +/- 3287 RPM

Free acceleration	K-Value (1/m)	ACTUAL RPM
T1	1.88	3160
T2	1.88	3560
T3	1.91	3050
T4	1.91	3170
T5	---	---
T6	---	---
T7	---	---
T8	---	---
T9	---	---
T10	---	---

HSU Average: 55.8 K-Average: 1.89

Permission Limits at the back of the Form

Validity: 6 Months

MR ANANTHAMOORTHY
Seal of Testing Station: Code: TN-38-009
Signature of the Driver/Owner: Signature of the Licence / Testing Person

01-Sep-2013

Appendix 8

Emission testing report for diesel engine with scrubber - trial 1

COMPUTERISED POLLUTION UNDER CONTROL CERTIFICATE
RULE 116 (B) (10) (C) (Authorised by the Transport Department)

BRIGHT STAR
VEHICLE EMISSION MONITORING CENTRE
525-A, Avinashi Road, Opp. Raja Raja Garden, Peelamedu, Coimbatore - 641 004.
Authorisation Number & Validity: 11/CBE/99 & 26-09-2014

Cell No.: 98432 60116

Centre Code: TN-37-004
I.D. Number: DP201300385
Vehicle Number: TN38AE9040
Type Of Vehicle: 4W
Month & Year Of manufacture: 02/2006
Makers Name: TATA
Makers Class: INDICA
Odometer Reading (Kms): 0
Oil Temperature: 73

S.N.O.: 26042
Fuel: DIESEL
Date: 02/Mar/2013
Time: 5:33:22 PM

Photo of Vehicle

Valid upto: 01/Sep/2013
Testing Charges: Centre Code: TN37004

HSU Average: 55.8 K-Average: 1.89

Permission Limits at the back of the Form

Validity: 6 Months

MR ANANTHAMOORTHY
Seal of Testing Station: Name of the Driver/Owner: Signature of the Driver/Owner: Signature of the Licence / Testing Person

Appendix 9

Emission testing report for diesel engine with scrubber - trial 2

COMPUTERISED POLLUTION UNDER CONTROL CERTIFICATE
RULE 116 (B) (10) (C) (Authorised by the Transport Department)

BRIGHT STAR
VEHICLE EMISSION MONITORING CENTRE
525-A, Avinashi Road, Opp. Raja Raja Garden, Peelamedu, Coimbatore - 641 004.
Authorisation Number & Validity: 11/CBE/99 & 26-09-2014

Cell No.: 98432 60116

Centre Code: TN-37-004
I.D. Number: DP201300386
Vehicle Number: TN38AE9040
Type Of Vehicle: 4W
Month & Year Of manufacture: 02/2006
Makers Name: TATA
Makers Class: INDICA
Odometer Reading (Kms): 0
Oil Temperature: 97

S.N.O.: 26043
Fuel: DIESEL
Date: 02/Mar/2013
Time: 5:35:54 PM

Photo of Vehicle

Valid upto: 01/Sep/2013
Testing Charges: Centre Code: TN37004

HSU Average: 58.4 K-Average: 1.93

Permission Limits at the back of the Form

Validity: 6 Months

MR ANANTHAMOORTHY
Seal of Testing Station: Name of the Driver/Owner: Signature of the Driver/Owner: Signature of the Licence / Testing Person

Appendix 6

Emission testing report for petrol engine with scrubber - trial 2

Form (Computerised Pollution Under Control Certificate (Petrol))
RULE 116 (B) (10) (C) (Authorised by the Transport Department Govt. of Tamilnadu)

SUPER AUTO SERVICE
Vehicle Emission Testing Centre
C/o. HP Petrol Bunk
Mettupalayam Road, Near TVS Benz Show Room, Coimbatore - 641 043.
Cell : 98433 60980, 91501 14296

Serial No.: 1046

Centre Code: TN-38-009
I.D. Number: TN38AW2326
Vehicle Registration No.: 0
Month & Year of Registration: 10-Oct-2010
Speedometer Reading (Kms): 0
Test Result: 3.5 IDLNG 3.9

Type Of Vehicle: 2 Stroke
Type Of Engine: TVS
Vehicle Make: XL SUPER
Vehicle Model: AW 2326
Bharat Stage: Stage II

Authorisation Number & Validity: 21/CBE/99 & 12-12-2014
Date: 02-Mar-2013 5:21:02 PM
Fuel: PETROL/CNG/LPG
Oil Temperature: 73

ALLOWABLE RPM LIMITS: 300 +/- 4412 RPM

Free acceleration	K-Value (1/m)	ACTUAL RPM
T1	1.93	4430
T2	1.93	4380
T3	1.93	4470
T4	1.93	4420
T5	---	---
T6	---	---
T7	---	---
T8	---	---
T9	---	---
T10	---	---

HSU Average: 58.4 K-Average: 1.93

Permission Limits at the back of the Form

Validity: 6 Months

MR ANANTHAMOORTHY
Seal of Testing Station: Code: TN-38-009
Signature of the Driver/Owner: Signature of the Licence / Testing Person

01-Sep-2013

Appendix 10

Emission testing report for diesel engine with scrubber – trial 3

COMPUTERISED POLLUTION UNDER CONTROL CERTIFICATE
 RULE 11(B) (10) (C) (Authorised by the Transport Department)
BRIGHT STAR Cell No. : 98432 60116

VEHICLE EMISSION MONITORING CENTRE
 525-A, Avinashi Road, Opp. Raja Raja Garden, Peelamedu, Coimbatore - 641 004.
 Authorisation Number & Validity : 11/CBE/99 & 26-09-2014

Centre Code : TN-37-004
 I.D. Number : DP201300387
 Vehicle Number : TN38AE040
 Type Of Vehicle : 4W
 Fuel : DIESEL
 Month & Year Of manufacture : 02/2006
 Makers Name : TATA
 Date : 02/Mar/2013
 Odometer Reading (Kms) : 0
 Makers Class : INDICA
 Time : 5:37:45 PM
 Oil Temperature : 99
 Photo of Vehicle

ALLOWABLE RPM LIMITS : 300 +/- 2500 RPM

Free acceleration	K-Value (1/m)	ACTUAL RPM
T1	1.71	2560
T2	1.71	2510
T3	1.65	2540
T4	1.69	2590
T5	---	---
T6	---	---
T7	---	---
T8	---	---
T9	---	---
T10	---	---

HSU Average : 51.7 K-Average : 1.69

Valid upto : 01/Sep/2013
 Testing Charges :
 Centre Code : TN37004

Signature of the Licence / Testing Person

MR ANANTHAMOORTHY
 Name of the Driver/Owner :
 Signature of the Driver/Owner :

Appendix 11

Emission testing report for diesel engine with scrubber – trial 4

COMPUTERISED POLLUTION UNDER CONTROL CERTIFICATE
 RULE 11(B) (10) (C) (Authorised by the Transport Department)
BRIGHT STAR Cell No. : 98432 60116

VEHICLE EMISSION MONITORING CENTRE
 525-A, Avinashi Road, Opp. Raja Raja Garden, Peelamedu, Coimbatore - 641 004.
 Authorisation Number & Validity : 11/CBE/99 & 26-09-2014

Centre Code : TN-37-004
 I.D. Number : DP201300388
 Vehicle Number : TN38AE040
 Type Of Vehicle : 4W
 Fuel : DIESEL
 Month & Year Of manufacture : 02/2006
 Makers Name : TATA
 Date : 02/Mar/2013
 Odometer Reading (Kms) : 0
 Makers Class : INDICA
 Time : 5:39:53 PM
 Oil Temperature : 74
 Photo of Vehicle

ALLOWABLE RPM LIMITS : 300 +/- 2240 RPM

Free acceleration	K-Value (1/m)	ACTUAL RPM
T1	1.85	2210
T2	1.71	2120
T3	1.67	2240
T4	1.81	2250
T5	---	---
T6	---	---
T7	---	---
T8	---	---
T9	---	---
T10	---	---

HSU Average : 52.1 K-Average : 1.71

Valid upto : 01/Sep/2013
 Testing Charges :
 Centre Code : TN37004

Signature of the Licence / Testing Person

MR ANANTHAMOORTHY
 Name of the Driver/Owner :
 Signature of the Driver/Owner :

Appendix 12

Project certificate issued at tnpl, karur

Tamil Nadu Newsprint and Papers Ltd.
 Karthikeyapuram-639 136, Karur Dt., Tamilnadu.

CERTIFICATE

HR/31/23/Envr./08/01 September 15, 2012

Name : Mr. U. ANANTHAMOORTHY
 Department : B.E. (Environmental Engineering)
 Name of the Institution : Park College of Technology, Coimbatore
 Department in Which Undergone Training : Environment
 Project Title : Energy Audit in Bio-methanation Plant and Co-generation Unit
 Project Duration : From: 16.08.2012 To: 14.09.2012

Training Centre
 Tamil Nadu News Print and Papers Ltd.
 Karthikeyapuram, Karur - 639 136
 Ph: 94324-277051, Extn. 2715

AUTHORISED SIGNATORY
 (TRAINING CENTRE - TNPL)

TNPL

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