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DEVELOPING APPROPRIATE TECHNOLOGY FOR COMMUNITY LEVEL PRODUCTION OF CHARCOAL AND ACTIVATED CARBON FROM COCONUT STEM WOOD AND SHELL FOR INDUSTRIAL USE

(Final Report of Project KFRI 470/'05)

(Project funded by Coconut Development Board)

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OUTLINE OF THE PROJECT PROPOSAL

1 Project Number : KFRI 470/'05

2 Title of Project : Developing appropriate technology for community level production of charcoal and activated carbon from coconut stem wood and shell for industrial use

3 Principal Investigator : Dr. T. K. Dhamodaran, (Wood Science & Technology)

4 Associate Investigator : Dr. R. Gnanaharan, Research Coordinator (Wood Science & Technology)

5 Objectives : (i) Develop appropriate method for community level production of charcoal and activated carbon from coconut shell and stem wood by designing, fabricating and installing pilot plants suitable for demonstration of the concept of community level production of charcoal and activated carbon from coconut shell and stem wood and transfer the technology to entrepreneurs for taking up commercialization.

: (ii) Assess the yield and quality of charcoal and activated carbon.

: (iii) Optimize reaction conditions for the production of desired quality products.

6 Funding Agency : Coconut Development Board, Kochi, Kerala.

7 Budget Outlay : Rs. 29,67,000/-

8 Duration : 3 Years

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PREFACE

Coconut by-product utilization through value addition should be an integral part of any coconut based industry for sustenance and better livelihood of the coconut farmers, members of coconut based agricultural cooperative societies, workers and industries. Utilization of coconut shells and stem wood is an area warranting much research inputs. In the context of implementing massive re-plantation programmes for wilt-diseased palms of different age groups, much timber unsuitable for structural applications is expected to be available. Conversion of waste stem wood and shells into charcoal is a promising area of value addition with low-energy inputs, but requiring intensive research for developing clean technologies. Conversion of shell charcoal into activated carbon is an area where still many-fold value addition potential exists; but this field being under the monopoly of large-scale industries, attempts for down-scaling the technologies or developing appropriate technologies become the need of the hour when cluster or community based organization level of operation are attracting much attention. Any attempt in this line will help to achieve livelihood improvement of the poor and marginalized coconut farmers and better profit to coconut based industries.

It was in this context, with the financial support from the Coconut Development Board, the Kerala Forest Research Institute took up a project for developing appropriate technologies for community level production of charcoal and activated carbon from coconut shells and stem wood for industrial use. The technologies developed through this project are of timely importance and are readily transferable to industrial entrepreneurs. Requests for transfer of technology for taking up commercialization will always be welcomed by the Institute.

Dr. K. V. Sankaran

DIRECTOR
KFRI

ABSTRACT

Coconut shell offers an excellent raw material for charcoal, which is again the raw material for industrial production of further value added product, activated granular carbon. Traditional shell charcoal production by the existing earth pit and drum methods is a highly air polluting due to ground level smoke spread. Charcoal production in the cluster or community level offers an additional livelihood to coconut farmers and the rural poor. It was in this context, an investigation was planned to develop an appropriate clean technology to produce charcoal at the cluster or community level. Production of activated carbon being limited to large scale industries, an attempt was planned to develop an appropriate clean technology to produce activated carbon in the cluster or community based organizations (CBOs). As the existing method of industrial scale production of activated carbon being the rotary kiln method which has very little scope for down-scaling due to techno-economic considerations, fluidized bed reactor (FBR) system was identified as the appropriate technology for small or community level production of active carbon.

Both the charcoal and activation plants were designed for continuous operation by way of operating three shifts per day. As pilot plants, a continuous vertical carbonizing plant with an input capacity of 3 tonnes raw material per day which can produce about one tonne charcoal per day and an FBR with an input capacity of 0.25 tonne charcoal per day which can produce 0.125 tonne of active carbon was successfully designed, fabricated and installed. Trial runs were conducted and the process was optimized for desired quality products. The quality of products was assessed for industrial use. The design drawings, description and operational details of the newly developed pilot plants are ready for commercialization. The quality of charcoal and the granular shell active carbon produced were found conforming to Indian standards. The details of the plants developed (1 tonne output capacity charcoal plant and 0.25 tone FBR activation plant) as well as yield and quality assessments are given in this report.

Economic analysis of the pilot plants developed showed that a minimum up-scaling of the plants to a level of a charcoal plant which can process 6 tonnes of shells per day is financially viable for self-sustaining. As far as technical viability is concerned, scope exists for further improvements for automation for both the plants. Further technical up gradation of the FBR such as developing a rotary FBR for better quality activated carbon suitable for vapour phase applications is suggested. Also, scope exists for further developing impregnated active carbon for speciality purposes (*e.g.* silver impregnated granular active shell carbon) from high grade active carbons.

As far as conversion of waste coconut stem wood is concerned, it was found that the plant can produce stem wood charcoal with moderate yield and quality. The inherent quality of stem wood charcoal, its poor hardness, makes it unsuitable for the manufacture of activated carbon. Stem wood charcoal is suggested for using as direct fuel or as an ingredient for fuel briquettes.

Both the plants developed are pollution-free and techno-economically suitable for cluster or community level production of charcoal and activated carbon after due up-scaling to the required capacity.

Key words: *Coconut shell utilization; coconut stem wood utilization; coconut shell charcoal, coconut stem wood charcoal; coconut shell activated carbon; Industrial plant for charcoal production; industrial plant and technology production of granulated activated shell carbon.*

1. INTRODUCTION

Coconut, the versatile tree crop is cultivated in an area of over 1.92 million hectares in India with an annual production of 14.00 billion nuts and it contributes over 70,000 million rupees to the country's GDP. India accounts for 22.34 per cent of the world's coconut production and is one of the major players in the world's coconut sector in terms of copra processing, coconut oil extraction and coir manufacturing. Coconut industry principally depends on the domestic market price of coconut oil which is highly fluctuating depending on the price of other vegetable oils. Owing to high cost of production, chiefly on account of labour cost, the domestic price of coconut oil is almost two to three folds higher than the international price. For instance, the domestic price of coconut oil was US$ 1261 per tonne as against the international price of US$ 467 during 2005. Though the domestic price is higher than the international price, the farmers are not fully benefited by this due to the threat of import of large quantities of coconut products to India from other countries. Thus the price situation is adversely affecting the economic viability of many coconut processing units in the country. The coconut sector has to be equipped to face these challenges by evolving ways and means to reduce cost of production and scaling up the production. Enterprise diversification, by-product utilization, and value addition are some viable options to assist the sustenance of the coconut processing industry.

1.1. Rationale of community level processing

The concept of community or cluster level processing of coconut received momentum following various women empowerment schemes. Economic viability of community level processing units in the coconut sector is realized from various programmes and schemes implemented by State and Central Government agencies. The efforts under various self help groups (SHGs) such as the women empowerment schemes for the below poverty line (BPL) groups; "Kudumbasree" of the State Poverty Alleviation Project of Government of Kerala; the "SUBICSHA" (Sustainable Business Development of Innovative Coconut Based Micro-enterprises for Holistic Growth and Poverty Alleviation) project in Perambra, Kozhikkode District, Kerala and many similar activities have one or more components of coconut processing in the community based organisation (CBO) level. Technology intervention support for processing by-products such as shells and waste stem wood are identified as the key issues that the Wood Science and Technology Division of the Kerala Forest Research Institute can attend to for livelihood improvement of the poor and marginalized coconut farmers and better profit to coconut based industries.

1.2. Community level processing of coconut by-products

Any coconut processing industry should have a plan for economic utilization of all the by-products. Otherwise it will lead to difficulties for storage space and environmental problems. In this regard, the community level processing of coconut assumes importance for easy local level management of by-products. This also leads to reduction in the cost of transportation of raw material, local employment generation, livelihood improvement, sustenance of industries through better/improved or value-added utilization of by-products, optimal utilization of wastes, product diversification, etc.

Conversion of the waste stem wood portions and shell into charcoal and its subsequent conversion into activated carbon open up an avenue for community level processing for value addition of these by-products. Activated carbon being a high value product from charcoal, scope exists for the cluster to take up the production of activated carbon for better economic returns.

1.2.1. Coconut stem wood

It is estimated that about 40% of the bearing palms in Kerala are affected by root wilt, a debilitating disease. About 14% of the non-bearing palms are in the advanced stages of the disease. Although the disease occurs in palms of all ages, young palms are more susceptible. The diseased palms may continue to give economic yield of nuts for some years even after the onset of the disease. Once the palm reaches the advanced stage of infection, it is not economical to retain it, as it is a phytosanitary hazard. Cutting down the wilt-diseased palms will help in controlling the disease spread. Also, clearing the land will facilitate systematic planting of new seedlings and permits the benefits of simplified inter-cropping. However, experience shows that it is extremely difficult to persuade farmers to fell the wilt-diseased and over-mature palms as long as they continue to yield. They will be persuaded if the value of coconut stem wood compensates for the expense of felling and replanting the area. Effective utilization of stem wood is not only an advantage in reducing the overall cost of replanting but also in reducing the pressure on forests or other tropical plantation species for wood requirement and thereby benefit in terms of environmental conservation.

As it is well known, the primary use of coconut stem wood is always, like any other timber, for structural applications. Due to its peculiar nature, it yields a significant quantity of waste wood (the outer and inner portion of stem wood of senile and mature palms as well as the whole stem wood of juvenile palms). Research carried out in the Wood Science and Technology Division of the Kerala Forest Research Institute has revealed that the average tree volume of a palm is about 0.4 m^3 and would yield about 0.1 m^3 sawn timber suitable for structural uses and the remaining 0.3 m^3 wood remains as waste (Gnanaharan *et al.,* 1985, Gnanaharan and Dhamodaran 1988). One rational way to utilize the portion not suitable for structural applications is to convert it into charcoal. Charcoal, as a domestic fuel, has many advantages over firewood in terms of energy and economy. Stem wood charcoal can also be used as an ingredient in fuel briquettes. A preliminary study made by the Kerala Forest Research Institute (Gnanaharan *et al.,* 1988) revealed that charcoal from coconut wood is of good quality, suitable for domestic purposes. They also reported that the volatile content of charcoal from young palms is in the range desirable for domestic purposes. This opens up an avenue for utilizing the entire wood from young palms and the waste wood from mature and over-aged palms for converting into charcoal for domestic purposes.

1.2.2. Shells

Considerable amount of shell, a by-product of kernel based (copra) processing units, is not properly utilized for value-addition at present. Charcoal is a major product from coconut shells presently produced at the rural level by the traditional earth pit method and at the community level by women SHGs by employing drum method. Coconut shells offer the best raw material for charcoal production. Shell charcoal is of high value both for domestic and industrial uses and of great demand. Shell charcoal forms the best raw material for the production of granular activated carbon, required for many industries.

Activated carbon, an industrial adsorbent, has enormous export potential; but the production is at present limited to or monopolized in large scale industrial units. World demand for activated carbon is forecasted to expand 5.0 per cent per year through 2010 to 1.2 million metric tonnes. Besides the demand from developed countries, greater growth opportunities will generally occur in developing markets, primarily the emerging industrial economies of Asia. It is possible to downsize the production of activated carbon from large scale industries suitable for operation at community level by designing appropriate carbonization and activation plants with less pollution.

Coconut shell and wood are used for the manufacture of charcoal in many coconut growing countries like the Philippines, Indonesia, Fiji, etc. In India, we are also producing shell charcoal; but still we are not utilizing the waste stem wood portions for charcoal. Hence, there exists a good scope for utilizing the waste stem wood portions for the production of charcoal.

1.3. Charcoal manufacturing - Issues

Traditional charcoal manufacturing is an ill-famed industry due to its inherent issue of smoke production environmental pollution. Bulk of the charcoal produced in the country is by the traditional earth pit method because of its simplicity requiring less skill and capital investment. But the great disadvantage of this method is the smoke spread in the ground level damaging the ambient air quality and leading to public health issues. Due to this reason, charcoal production sites are always restricted to remote village areas with low habitation. As land availability in Kerala is a problem, there is not much scope for continuing the production of charcoal by this method. This situation calls for looking into alternative safe and clean methods for charcoal production, preferably suitable to industrial scale operations.

1.4. Appropriate technology for cluster or community based organisations

Cluster or community based organisation (CBO) approach is popular now a days in the small scale industries. In clusters, charcoal is presently produced in small quantities by the drum method in homesteads. The drum method is also not a pollution-free. Attempting to add chimneys for the drum has not significantly helped in controlling the pollution.

The charcoal produced in a cluster is usually pooled for marketing or further processing. Shifting the charcoal production from the cluster members' homesteads to a community level production unit having a safe and clean production facility alone will help to solve the issue of environmental damage. Further, products of desired quality fetching higher prices or enhanced production can also be assured in such controlled systems.

Activated carbon manufacture is presently limited to the large scale industry sector. The technology available is also limited to the widely adapted rotary kilns of large scale industries. Rotary kilns are commercially available in large sizes only and hence are of not suitable for use in cluster based industries in a small scale. Down-scaling the rotary kiln into required size is also difficult and uneconomical due to its inherent issues of minimum length and diameter associated with the required minimum retention or residence time of charcoal for activation in the kiln and the non-suitability of such a system to process small quantity of charcoal. It is in this context, it was proposed to develop appropriate technology for community level production of activated carbon from charcoal as it forms a part of the integrated coconut utilization value chain. Further, this will provide the farmers' cluster an opportunity to get an enhanced income through local community or cluster level processing for further value-addition. Industries will also get benefited in terms of new technology for small scale production of activated carbon.

1.5. Existing traditional methods for charcoal production – Pollution issue

1.5.1. Earth pit methods

The **traditional earth pit method** employed by the local communities for the production of charcoal consists of piling the shells in a heap in a small pit made on the ground (see Fig.1) with a provision for air inlet and lighting the fire. The heap is slowly built up to the full and covered with leaves, over which a mud plaster is applied with a hole at the top for venting the smoke (Fig. 2). The charge is lighted and allowed to burn slowly. After six hours of burning with controlled air entry, the inlet and outlets are closed with mud plaster and allowed to cool overnight. The heap is opened on subsequent morning and charcoal is collected.

Fig. 1. Traditional earth pit method – the mud plastered heap of shells ready for igniting

Fig. 2. Smoke vent in the traditional charcoal making

In the **modified earth pit method**, a deep rectangular pit of required size is taken in the earth; shell is loaded and ignited (Fig. 3). Once the fire gets stabilized, the pit is slowly filled with shells; care is taken not to get the fire extinguished. Once the pit is full and fire is in a stabilized situation, the pit is closed with a rectangular metal sheet and plastered with mud and allowed to burn in the closed condition for overnight (Fig. 4). Due to poor control over the carbonization conditions, generally, there is not much scope for improving the yield and quality of product from the traditional earth pit method. Further, severe smoke spread at the ground level causes much air pollution.

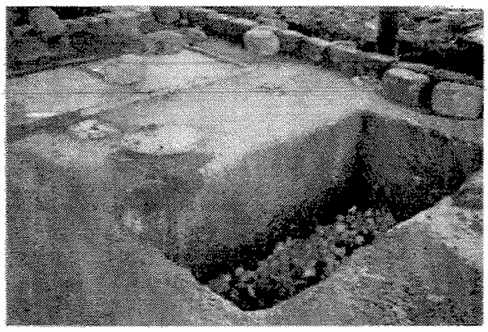


Fig. 3. Modified earth pit for charcoal making

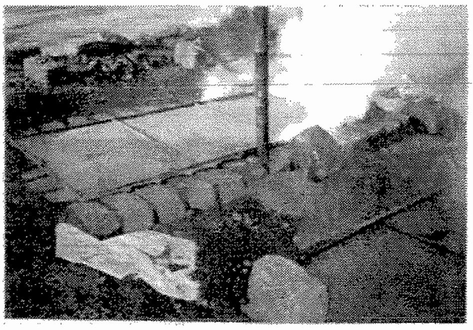


Fig. 4. Modified earth pit in closed condition; note the ground level spread of smoke

1.5.2. Drum method

Portable drums (empty oil or grease drums of 200 litre capacity) are employed in homesteads for the preparation of charcoal. The top lid of the drum is cut and removed; the drum is held vertically and partially filled with the material and ignited. Once the fire gets stabilized, the entire drum is slowly filled and closed with lid and plastered to limit the air supply and allowed to remain overnight (Fig. 5). Charcoal is collected in the next morning.

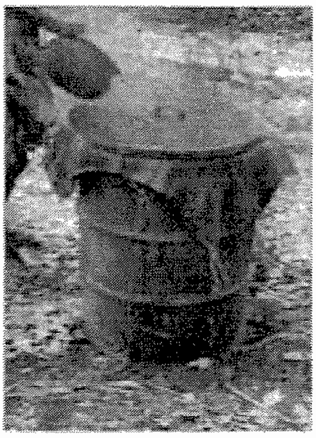


Fig. 5. Portable drum method for production of charcoal

Fig. 6. Tongan drum method for production of charcoal

In the **Tongan drum method**, the opening is along the side of the drum. The drum is held horizontally, loaded partially and the material is ignited (Fig. 6). Once the fire gets stabilized evenly, the drum is slowly filled and closed with the cut portion. After mud plastering, the drum allowed to remain overnight. The charcoal is collected in the next morning.

In the modified drum method, two drums are welded together to increase the capacity; and sufficient air vents are made on the sides of each cylinder (Fig. 7.1). A long pipe fitted to the top lid acts as a chimney to smoke vent. As before, material is added to the drum, ignited and when once the fire is stabilized, the drum is filled with the material and allowed to carbonize in controlled air supply (Fig. 7.2).

1.6. Continuous carbonization pilot plant appropriate to community level production of charcoal

Developing an industrial carbonization plant with pollution control facility is the only solution to overcome the problems of pollution, low yield and quality encountered in traditional methods. Batch process is not ideal for heat efficiency or recovery and for pollution control. For better pollution control, a continuous carbonization plant of limited capacity is more appropriate to community level operation and management. Introduction of tall chimney in such a system with a facility for flaring the volatile gas evolved (during the stabilized continuous carbonizing phase) in the chimney top can avoid the ground level spread of smoke or volatile vapours. In a continuous carbonization plant, smoke emission will always be limited to the starting stage; once the burning process stabilizes and continuous there will not be any smoke emission. Whatever volatile vapours emitted during the continuous carbonizing phase will get flared in the chimney top. Introduction of heat recovery system can facilitate the recovered heat for use in copra drying. Proper designing of the carbonization kiln can take care of the air inlet and out let controls for desired quality product. Control over the carbonization temperature can lead to better yield also. In the above context, it was planned to design a continuous carbonization pilot plant with an input capacity of 1 tonne shell per shift of 8 hours which can process 3 tonnes of shell per day.

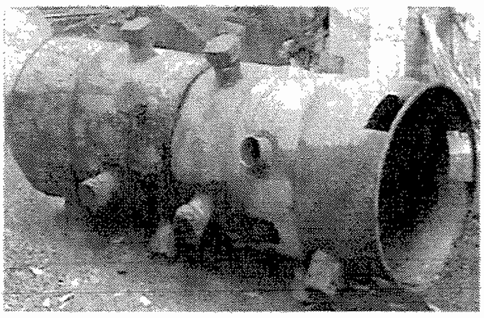


Fig. 7.1. The modified double drum with air vents in sides

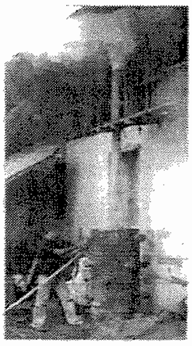
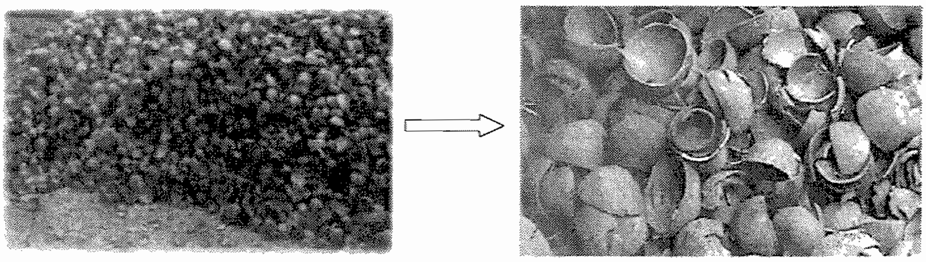


Fig. 7.2. The modified double drum with chimney pipe in working condition; note the smoke spread



1.7. Activated granular carbon from charcoal

Industrial production of granular carbon from shell charcoal is currently limited to employing rotary kilns. Physical activation is achieved using superheated steam at a pressure of around 3 kg/cm^2 and temperature around 900 ^{0}C. A quantity of steam of 1.5 times the weight of charcoal is required for effective activation. Industrial rotary kilns for activation of charcoal require the minimum size specifications of 12-18 metre length, 2.5 to 3 metre diameter and a shell thickness of 12-20 mm. The minimum cost of such a plant is estimated to be around Rs. 1.5 crores. Further, in the rotary kiln, activation takes a minimum residence time of 10-15 hours. These size specifications and proportionate minimum quantity of charcoal required for a charge being large and prolonged residence time required makes the system uneconomical to downscale for community level operation where only limited quantity is handled. Financial investment required for rotary kiln is unaffordable to community scale set up.

1.7.1. Appropriate technology for community level production of activated charcoal - Fluidized Bed Reactor (FBR)

Fluidized bed reactor (FBR) system is identified as an alternative cost-effective method for production of granular active carbon suitable for liquid phase applications. FBR are known for rapid heat transfer resulting in high conversion rates. Absence of moving parts in FBR contributes to low maintenance cost. The reactor is vertically placed in a furnace with three heating zones that can be operated up to 1100 ^{0}C. In a FBR, fine particle reactant is locally suspended in the fluidized bed by blowing a gas stream upward through the bed to ensure a good contact between solid and gas reactants. The fluidized bed consists of a fluid - solid mixture that exhibits fluid- like properties. The bed can be considered to be an inhomogeneous mixture of fluid and solid that can be represented by single bulk density.

The fluidized bed is formed when a quantity of solid particulate substance is placed under appropriate conditions to cause the solid / fluid mixture to behave as a fluid. This is usually achieved by the introduction of pressurized fluid through the particulate medium. This results the medium then acquiring properties and characteristics of normal fluids; such as the ability to free flow under gravity or to be pumped using fluid type technologies. The main application of the fluidized beds is in technical processes requiring high level of contact between gasses and solids. Area contact between fluid and solid per unit bed volume is extremely high in this system. Also, this system facilitates high level of intermixing of the particulate phase.

Uniform particle mixing and temperature gradients, ability to operate in continuous state are the main advantages of FBR. Current understanding of actual behaviour of materials in a fluidized bed is rather limited. It is very difficult to predict and calculate the complex mass and heat flow within the bed. Due to this lack of understanding, new processes require designing specific pilot plants and due to this reason, FBRs are seldom used in large scale active carbon industry, as the rotary kilns are time-proven.

An FBR pilot plant with an input capacity of 300 kg charcoal per day is planned to design, fabricate and install for trial pilot scale production of active carbon appropriate to community level operation.

2. REVIEW OF LITERATURE

2.1. Charcoal

Charcoal, the product of pyrolysis of ligno-cellulosic materials, is used as fuel or industrial raw material. Charcoal can be produced from ligno-cellulosic materials by controlled burning; burning in the absence of air or oxygen. Even though ligno-cellulosic materials itself are fuels, conversion to charcoal is preferred in terms of energy and economy. Charcoal is having more fuel value and is easy to transport (average calorific value of coconut shell charcoal is around 30140 kJ/kg). Charcoal is made from woody species or coconut shells that yield a dense, slow-burning product. Conversion of woody materials and coconut shells into charcoal is traditionally done in the homesteads or village level by employing simple technologies such as burning in earth pits, called the *pit method*. Portable metal drums such as the empty oil drums of 200 litre capacity which can hold 0.15-0.25 m^3 raw material depending on the size of material to be carbonized, are used for the production of charcoal in small or cottage level units. This method is called the *drum method*.

A number of methods are available for making charcoal depending on investment, skill, etc (Foley 1986); but majority of methods are batch processes.

Richolson and Alston (1977), by employing the drum method achieved a charcoal yield of 22.9 - 27.2% from coconut stem wood. Palomar (1979) by using a portable metal drum obtained a stem wood charcoal yield of 21%. Estudillo *et al.*, (1977) reported a yield of 25% coconut stem wood charcoal by employing a masonry block kiln. Paddon (1984) detailed the use of improved pit kiln having a capacity of about 8 m^3 of stacked wood. Gnanaharan *et al.*, (1988) employed the drum method for production of charcoal from coconut stem wood. The stem wood charcoal yield varied from 26 to 29%; the product was with volatile content from 20-30%, ash content 1-5%, and with fixed carbon content of 67-76% on oven dry basis.

The use of charcoal, the forerunner of modern activated carbon, dates back to 2000 BC for water purification and medical purposes by ancient Egyptians. Pyrolysed ligno-cellulosic materials replicate almost similar structure of the original raw material, but the charcoal possesses very low surface area (1-4 m^2/g) and thus is of poor adsorption capacity. To increase the adsorption capacity, charcoal needs to be activated so as to yield porous activated carbon with more surface area (around 1000 m^2/g) having wide applications as industrial adsorbents. The industrial use of active carbon was strengthened in the 1st World War period when its potential for poisonous gas adsorption and decolourization was utilized widely. The application of wood charcoal for gold recovery was reported by Gross and Scott (1927), Davis (1880) and Johnson (1984). Since then activated carbons found increased application in the field of hydro-metallurgy, particularly in the recovery of gold, silver, and to a lesser extent molybdenum (Cheremisinoff and Ellerbusch 1978, McDougall 1982, McDougall and Hancock 1980). In South Africa, it is reported that the gold-mining industry is the largest single consumer of activated carbon (McDougall 1991).

Today the world has truly recognized carbon as "Black Gold" because of its remarkable and diverse properties. It has wide range of applications from developing energy sources like fuel cells, primary batteries, super background capacitors and nuclear reactors to metallurgy and heavy industries, from electronics to automobile and aviation sector etc. Invention of activated carbon fibres (ACF) and nanotubes has made carbon a sought after material in almost all modern high performance industries which are affecting every aspect of mankind.

All batch methods of traditional charcoal production suffer from the major limitation of air pollution from smoke emission. Traditional methods such as the earth pit method are more polluting because of from the ground level smoke-spread. Improved earth pit and drum methods with tall chimney pipe in the traditional systems have not fully solved the smoke pollution issue as the method of production is of the batch type wherein the beginning hours of every batch are smoke emitting till the burning is stabilized. This will be repeated in every batch resulting intermittent smoke emission. **Continuous carbonization kilns** is the solution for this issue. But they are seldom used. Major quantity of charcoal production in the country is still in the village level. Most activated carbon industries do not produce charcoal, their raw material, in their units. They outsource charcoal production or buy the charcoal produced in the village level. Village level charcoal production in the country has not still reached the status of full fledged industry. The solution to this issue is developing appropriate technologies with better pollution control such as a continuous carbonizing plant suitable for cluster or community level production of charcoal.

2.2. Activated carbon

Activated carbon is a group of industrial adsorbent materials with highly developed internal surface area and porosity (microcrystalline porous carbon matrix with pore diameter range of <2 nm to > 50 nm with large internal surface area to the extent of 400-3000 m^2/g as measured by the nitrogen BET method and adsorption volumes of 0.2-0.8 cm^3/g depending on activation conditions), and hence having a large capacity for adsorbing chemicals from fluids. It is produced by pyrolysis and activation of carbonaceous natural as well as synthetic precursors.

Activated carbon has the strongest physical adsorption forces or the highest volume of adsorbing porosity of any material known to mankind. About 5 g of activated carbon can have the surface area of a football ground (McDougall, 1991).

Manocha (2003) and Clements (2002) gave a brief overview of the granular activated carbon (GAC) production and application technologies.

2.2.1. Applications

Activated carbons are used as adsorbents in **liquid phase** uses for removal of taste, odour, colour, haze, colloids, surfactants, pesticides, and other organics; whereas it has the adsorbent applications in **gas phase** such as separation of gases from gas mixtures, separation of vapours from gases, and as catalyst support.

Among specific applications, removal of odour, colour, taste and other undesirable organic impurities from potable water in the treatment of domestic and industrial waste water, solvent recovery, air purification in inhabited spaces such as restaurants, theatres, food processing and chemical industry, for removal of colour from various types of sugar syrups, in air pollution control, in purification of many chemicals, pharmaceuticals and food products, and a variety of gas phase applications, in gold recovery from mines, etc. are some important areas where active carbon finds applications. Activated carbon is widely used for adsorption of pollutants from gaseous and liquid streams. In the nuclear industry, activated carbon is used for adsorption of iodine and noble gases from gaseous effluents, removal of ruthenium and technetium from radioactive liquid wastes. About 190 process patents and various applications of activated carbon are summarized by Yehaskel (1978).

Use of porous carbons for automobile canisters to adsorb gasoline vapour and the use of ACF for energy applications such as adsorbed natural gas (ANG) storage containers as an alternative to compressed natural gas (CNG), ACF for more efficient electric double-layer capacitors in rechargeable batteries, etc are some of the recently developed applications of specialty grade active carbons (Manocha 2003).

Activated carbon is non-toxic and used in medical treatment to adsorb a wide variety of toxins; doses to the extent of 1g/body weight are routinely given in human poisoning cases. Activated carbon will not have any detrimental chemical interactions with any other chemical that would be used in organic food processing (Cooney, 1980).

2.2.2. Raw material

Activated carbon can be made from any substance containing high carbon content such as bituminous coal, lignite, petroleum coke, and biomass resources such as coconut shells, wood, saw dust, peat, bagasse (Ioannidou and Zabaniotou, 2006) and animal residues such as bone etc. The **moisture content of the raw material** is an important parameter; if it is high (>20%), the water driven off during the early stages of pyrolysis or carbonization, reacts with the off-gases or impedes their removal which allows the off-gases to crack and restrict micropore openings in the product (Stephen *et al.,* 1992). The **nature of the source material** has marked effect on properties such as hardness and pore-size distribution of the final product. The activated carbon production challenge is thus to make tailor made product to precisely suit each application or range of applications by optimizing production parameters to control the reactions for desired quality product.

2.2.3. Production

Even though a number of processes and a variety of industrial equipments such as rotary kilns, shaft kilns, moving gate strokers, multiple hearth furnaces, pile furnaces, vertically stacked and connected crucibles, spaced perforated plates, dual pulse jet combustion systems, and fluidized beds (Ioannidou and Zabaniotou 2006), **rotary kilns** are most widely employed for the industrial manufacture of activated carbon (Yehaskel, 1978). In India, rotary kiln technology is the well established technology for commercial scale production of activated carbon of any specification to suit all process applications. Down-scaled versions of rotary kiln plants suitable for small or community scale production are still to be developed.

Whether large or small scale, the **process selection** has to be based on **nature of raw material, desired physical form of the product**, and **characteristics required for intended applications.** As is true with any production process, **the starting raw material influences the quality of the final product.**

For the production of active carbon, firstly **the raw material has to be converted into a uniform particle size** (if required, the physical properties of the final product, such as granule size, particle size distribution, shape, roughness and hardness, etc can be managed by application of techniques like high-pressure extrusion, pelletization or agglomeration).

All carbohydrate or lingo-cellulosic raw materials such as coconut shells, wood, etc. **need to be carbonized or pyrolized** where the raw material is slowly charred (thermally decomposed) in the absence of air (practically with very limited quantity of air entry) at a temperature range below 600 ^{0}C to remove the volatile pyrolysis products from the starting material and to yield charcoal rich in fixed carbon. The charcoal thus obtained contains predominantly macropores and practically inactive. Heat can be recovered from the carbonizing system for use elsewhere (such as for copra drying, etc).

$$\text{Biomass} \longrightarrow \text{C (char/charcoal)} + \text{Volatiles } (C_X H_Y, CO, H_2, CO_S, O_2, \text{etc})$$

$$\text{Or,} \quad C_6H_{12}O_6 \longrightarrow 6\,C + 6\,H_2O.$$

For producing good quality charcoal the process control parameters are rate of heating and cooling, operating temperature, physical state and moisture content of the raw material, residence time, and operating pressure. Finally, the raw material (charcoal) is **activated physically** by the use of superheated steam at temperatures above 900 ^{0}C whereby an interlinked micro porous structure is created through selective breakdown of the carbon. This process is also called as

gas or steam activation (physical activation), since either steam or carbon dioxide is commonly used for activation in rotary kilns. The oxidizing agents selectively attack portions of the char and transform it to gaseous products. The physically activated product, **granular activated carbon (GAC)** is characterized with mixed pore size, high surface activity on the outer shell; whereas the agglomerated process produces activated carbon that is much denser and more resistant to abrasion.

Chemical activation is used for non-charred raw material such as saw dust and peat to produce **powder activated carbon (PAC)**. Here, the raw material (in the form of saw dust) is treated with dehydrating chemicals such as zinc chloride, phosphoric acid, sulphuric acid, K_2S, KSNS, alkali metal hydroxides, carbonates or chlorides of Ca, Mg or Fe (Bansal 1988, Derbyshier, 1995) and calcined at comparatively low temperatures (400-600 °C) in the absence of air in order to obtain a uniform micro porous carbon (the dehydrating chemicals inhibit formation of tar and decrease the formation of acetic acid, methanol, etc while the pyrolytic decomposition enhance the yield of carbon). The chemically activated product needs to be washed to remove the activating chemical and calcined. Chemical activation (employing alkali metal hydroxides) is claimed to be offering route to tailoring porosity in carbons and provides better control of the pore-size distribution and structure (Andrews, 2003).

Pulverization of the cooled final product (physically activated or chemically activated) yields the product of desired uniform particle size.

Apart from the raw material, the **activation process parameters** (such as **volatile content of the raw material, activation temperature, steam temperature and pressure, air pressure, residence time, etc**) also have strong influence on the characteristics and performance of activated carbons. In general, the challenge is that this is a group of products with distinct characteristics obtained from a single raw material by varying the process condition.

The following chemical reactions occur during activation process:

$C + H_2O \longrightarrow CO + H_2$ (- 29 kcal) (Water Gas or Syn Gas Reaction)

The reaction being endothermic, temperature is maintained by partial burning of the CO and H_2 formed.

$2CO + O_2 \longrightarrow 2CO_2 + \text{Heat}$

$2H_2 + O_2 \longrightarrow 2H_2O + \text{Heat}$

Gasification of the carbonized material with suitable oxidizing agents such as steam (H_2O) and CO_2 occurs during the endothermic reactions. The H_2O molecule being smaller than the CO_2 molecule, steam diffuses faster into the pores of charcoal and consequently reaction of charcoal with steam is faster than that with CO_2. H_2O in activation is responsible for micropores, mesopores and macropores.

$C + CO_2 \longrightarrow 2\,CO \quad (-\,39\text{ kcal})$

$CO + H_2O \longrightarrow CO_2 + H_2 \; (-\,10\text{ kcal})$

Activation with CO_2 promotes external oxidation and development of larger pores as compared to steam and hence CO_2 is responsible for development of micropores with enlargement of surface pores. Active carbon produced by CO_2 activation has lower total pore volume (0.49 cm^3/g) than those of corresponding samples obtained by activation with steam. However, the effective surface area in both cases will almost be the same due to the contribution of micropores to the surface area (Manocha, 2003).

In the case of activation with air (oxygen), both the following exothermic reactions take place:

$C + O_2 \longrightarrow CO_2 \quad (+\,92.4\text{ kcal})$

$2C + O_2 \longrightarrow 2\,CO\;(+\,53.96\text{ kcal})$ (Producer Gas or Suction Gas Reaction)

Since both the reactions are exothermic, there will be excessive burning (burn-off /surface erosion) which is difficult to control. This could lead to local heating and the product obtained will not be uniform. As the reaction is aggressive, burning is not restricted and also occurs on the surface of the charcoal grains, causing excessive weight loss. The role of O_2 is to develop more micropores. Since activation is associated with weight loss of charcoal, the extent of burn-off of the carbon material is considered as a measure of activation (Manocha *et al.*, 2002). Activation with 50-70% burn-off causes an increase in the total adsorption volume from 0.6-0.83 cm^3/g (Rodriguez, 1995).

The reaction rate control essential for getting desired quality product is achieved by diffusion control by the activating gas. Heat from the flue gas (water gas) mixture can be recovered to utilize in a heat recovery boiler to produce the steam required for activation.

2.2.4. Coconut Shell Activated Carbon - Characteristics

Coconut shell activated carbons have the advantages over carbons made from other materials because of its high density, high purity, and virtually dust free nature. These carbons are harder and more resistant to attrition; besides being amorphous that can absorb many gases, vapours, liquid impurities and colloidal solids. The most important characteristic of activated coconut shell carbon is that it is extremely microporous, around pore diameter of 20 Angstrom. For this reason, coconut shell active carbon is ideal for the adsorption of small gaseous molecules that fit snugly into the micropores, and are therefore extensively employed in gas-phase and solvent recovery applications. The extremely good impact hardness and wet abrasion resistance of coconut shell active carbon combined with their high adsorptive capacity for the small gold dicyanoaurate complex, makes these carbons ideal for applications in gold recovery.

The structure of pores and the pore-size distribution are predetermined to a large extent by the source material, if it is of ligno-cellulosic origin, which is apparent from the photomicrographs of the pore structure of activated carbons manufactured from coconut shells (McDougall and Hancock, 1980). This indicates that the structure of the original source material, *viz.*, the cellular structure of the coconut shell is still present in the carbon skeleton of the final product. Therefore, the inherent cellular structure of raw materials of vegetable origin imposes a constraint on the extent to which the properties of the product can be modified for special applications. For example, the micropores of the cellular structure of coconut shell can be converted into macropores by burning-away the cell walls, thus changing the adsorption properties of the final product. But, unfortunately this type of modification is always accompanied by a loss in the structural integrity and, hence, the strength of the product as well as a decrease in product yield.

Surface area of granular active carbon from coconut shell, as measured by the N_2 BET adsorption, is proportional to the degree of burn-off to a certain point (around 50%), and this point corresponds to the formation of microporosity in the product. The point after which further burn-off results in reduction of BET surface area represents the conversion of micropores into mesopores and macropores by the burning-away of the pore walls. This will be usually associated with a loss in the structural strength of the product (McDougall 1991). Laine *et al.,* (1991) prepared coconut shell activated carbon in a small scale rotary kiln at 800 ^{0}C and found that the product surface area increased with increasing the water input concentration from about 0.5 to 5.0 g/g of feed, resulting surface area values up to 1,400 m^2/g. The use of nitrogen instead of air during activation did not significantly change product surface area.

Laine *et al.,* (1991) also demonstrated that both carbonization and activation of coconut shell can be carried out together in a single heating step (**one-step process**), resulting in a higher overall yield than in the usual two step procedure. Nithechan (1994) reported that an optimum volatile content of around 20-30% in charcoal is desirable to obtain high surface area in the steam activated product. In the one-step process, as no control over the volatile content in the raw material before steam activation is possible, activated carbon with low surface area and adsorption capacity is obtained. Even though the one-step process is advantageous in terms of energy and economy, the low product quality due to lack of control over the volatile content of raw material remains to be the major constraint in the one-step process.

Laine and Yunes (1992) studied the effect of preparation method on the pore size and distribution of activated carbon from coconut shell. Physical activation with CO_2 at 800 ^{0}C resulted in a bimodal pore size distribution featuring both the widest macropores and the narrowest micropores. Introduction of potassium phosphate as a catalyst during the CO_2 activation led to a decrease in macropore volume and diameter and to a slight increase in micropore diameter. Wider micropores and significant mesoporosity resulted when employing chemical activation with phosphoric acid at 500 ^{0}C. Surface area was found to increase with increasing median micropore diameter between about 7-15 Angstrom.

Recently, Li *et al.,* (2009) successfully demonstrated the feasibility of employing **microwave heating** for the preparation of steam activated coconut shell active carbon. Microwave energy is found capable to decrease the reaction time and temperature thereby saving energy remarkably compared to conventional heating, owing to its internal and volumetric heating effects, and could achieve product with iodine number 1070 – 1085 mg/g after 30 minutes activation. A BET surface area of 891 m^2/g is achieved for a sample with iodine number 1073, corresponding to a total pore volume of 0.7233 ml/g. The isotherm indicated that the sample was of mesoporous structure which contained plenty of mesopores, micropores and few macropores; with a broad pore size distribution. Unbelievably high yield, to the tune of 70%, is reported from the experiment.

2.2.4.1. Fluidized bed reactor (FBR) for the production of active carbon

Though widely employed, rotary kilns are costly, energy intensive, with poor gas-liquid contact and less amenable to down-scaling due to techno-economic reasons. In spite of the advantages of the fluidized bed reactor (FBR) system such as cost effectiveness, excellent gas - solid contact, and high heat and mass transfer rates (Kunil and Levenspiel 1969), FBRs have not received much attention for activated carbon production and are not in use in India for commercial scale production of active carbon. Rather than in production, FBRs were mainly used in West Germany till 1970 for the re-activation of used or spent active carbons in water treatment plants (Clements 2002). FBR system offers an alternative cost-effective and appropriate technology for the production of active carbon, for small scale operation in community based organisations (CBOs). Only limited information is available in the literature regarding the engineering design details and operating conditions of FBR system for producing active carbon (Edwards *et al.,* 1963).

In an attempt to activate coconut shell charcoal of particle size 1.1 mm at 850 °C in batches of 30 g, using steam, by employing a small FBR of 36 mm inside diameter; Hashimoto *et al.,* (1979) achieved product with maximum BET surface area of about 890 m^2/g for burn-off of 0.476; but this study was limited to a narrow range of operating parameters using a small charge.

Kirubakaran (1990) and Kirubakaran *et al.,* (1991) employed a laboratory-scale FBR of 50 mm internal diameter and 330mm length for **chemical activation of coconut shells** with zinc chloride and phosphoric acid as activating agents and nitrogen and carbon dioxide as fluidizing media. The effect of process variables such as time of activation, particle size, temperature, chemical reagent for activation, impregnation ratio, and fluidizing medium on the production and quality of activated carbon was studied. This study established the superiority of fluidized bed process over fixed bed for chemical activation. However, the yield from static bed was higher than that from the FBR. High activation and greater yield are reported to be possible with nitrogen and carbon dioxide compared to air as the medium of activation. Kirubakaran *et al.,* (1991) obtained chemically activated coconut shell carbon with maximum iodine number of about 1100 corresponding to 2000 m^2 /g of BET surface area for an optimal reaction time of 2.0 hours, temperature of 500 ^{0}C, particle size of 0.515 mm with zinc chloride as the activating agent with an impregnation ratio of 25% and nitrogen as the fluidizing medium, which is suggested as the ideal reaction condition for good quality product. However, the limitation was that it was on a small laboratory scale FBR.

Later, Satya Sai *et al.,* (1997) continued the study on production of **physically activated coconut shell carbon** employing an FBR of 100 mm internal diameter and 1250 mm length. The physically activated product obtained by employing FBR was reported to be much superior in quality to that produced by conventional processes. Increase in reaction time, fluidizing velocity, particle size and temperature resulted in better activation. However, at higher reaction times, a decrease in iodine number was observed, which is due to coalescence or widening of already formed pores. Static bed heights greater than the diameter of the column gave lower iodine numbers due to poor gas – solid contact, because of slugging. Steam as the activating gas enhanced the activation compared to a mixture of steam and CO_2. They achieved a maximum iodine number of 1328 mg/g corresponding to a BET surface area of 4300 m^2/g for a reaction time of 1.5 hours for a processing condition of 24.7 cm/s fluidization velocity; 1.5 mm particle size; 100 mm static bed height; 850 ^{0}C temperature and steam as the fluidizing medium for coconut shell charcoal as the raw material.

The change in macropore volume with burn-off at 850 ^{0}C in physically activated (using CO_2 as the activating gas) coconut shell active carbon production by employing an experimental FBR was reported to be negligible, but the absolute macropore volume decreased with burn-off (Wan Mohd. Ashri and Wan Shabuddin, 2004). Satya Sai and Krishnaiah (2005) characterized the **acid washed physically activated coconut shell active carbon** prepared by employing an FBR, in terms of pore-size distribution, micropore volume, external surface area and average pore size. The effects of various parameters such as reaction time, fluidizing velocity, particle size, and temperature of activation, using steam and CO_2 as activating gases on the above-mentioned characteristics of activated carbon were evaluated. The reaction time, temperature, and fluidizing conditions showed significant effects. Formation of micropores is more at 1.5 hours of reaction time and large pores beyond 150 Angstrom developed for a reaction time of 2.0 hours. Between 800-850 °C the pore volume doubled with corresponding pore-size distribution. High fluidizing velocities and large particles are found required for the formation of meso and micropores. Activating gases also had considerable effects on the characteristics of activated carbon produced in FBR. Steam promoted smaller pore size compared to CO_2. This showed the possibility of producing tailor-made carbons by properly choosing the activating gases.

2.2.5. Important parameters for activation – Developing optimum production parameter schedules

The nature of the lingo-cellulosic starting material or quality of the charcoal (moisture content, volatile content, ash content, fixed carbon content, hardness, etc), the composition and flow rate of the activating gas (steam, air, flue gas or mixtures of these), the temperature of activation, and the duration of activation or the burn-off period (residence time) are the important factors that can affect the surface area and pore-size distribution of the product and hence the adsorptive and other properties deciding the quality of active carbon product.

Like in most production processes, the production of quality active carbon involves balancing the production conditions to get the desired characteristics of the output. This balancing becomes complicated as there are more than one characteristic that has to be considered. Further, the desirable characteristics not only refer to the requirements of the end-uses such as high surface area, appropriate porosity, and high bulk density; but also refer to the raw material characteristics. As active carbon from bio-material resources will have the finger-print structure of the raw material, raw material - process – product quality correlation become extremely complex to control. Due to this reason, developing optimum production parameter schedules is of prime importance as far as active carbon manufacturing is concerned.

Activation temperature has a significant role in getting the product of desired quality. The desired optimum activation temperature varies depending on the process (physical or chemical activation and the reagents in chemical activation) and raw material. The optimum activation temperature for higher surface area was found to be 450 °C for coconut shell charcoal chemically activated with phosphoric acid

(Laine *et al.,* 1989), whereas for physical activation, the desired activation temperature is in the range of 900 ºC. An activation temperature range of 800-900 ºC is found not significantly influencing the development of micropore volume in oil palm shell activated carbon prepared by physical activation using steam and nitrogen as activating agents, employing FBR (Wan Mohd Ashri *et al.,* 2004). The porosity development in active carbon is found inter-dependent on the nature of raw material and the activation temperature employed (Srinivasakannan and Abu Bakar, 2004; Lafi, 2001; Diao *et al.,* 2002; Vernersson *et al.,* 2002).

The extent of **microporosity development** is another factor that needs to be taken care of for getting active carbon product of desired quality. Mesopores to macropores are found to have insignificant contribution to surface area compared to micropore development (Lazaro *et al.,* 2007).

The **chemical impregnation ratio**, the ratio of the weights of the chemical reagent and the dry raw material, is another factor having critical role on the characteristics of the carbon produced in chemical activation process. The chemicals employed being dehydrating agents, penetrate into the structure causing tiny pores to develop; thus affecting the pore size and surface area of the product. Generally, smaller pores of large number will result in larger surface area.

2.2.6. Mechanism of activation/pore development

Activation of carbon occurs in a series of processes. During carbonization, most of the non-carbon elements such as hydrogen and oxygen are first removed in gaseous form by pyrolytic decomposition of the starting material. Carbon atoms differ from each other in their reactivity depending on their spatial arrangement. Activation eliminates the disorganised carbon, exposing the aromatic sheets to the action of activating reagents and leads to development of microporous structure. The freed atoms of elementary carbon are grouped into sheets of condensed aromatic ring systems with a degree of planar structure (Bansal *et al.,* 1988). The mutual arrangement of these aromatic sheets is irregular and leaves free interstices between them, which may become filled with tarry matter or the products of deposition or blocked partially by the disorganized carbon. In the first stage of activation, when burn-off is not higher than 10% (which occurs at low reaction times), this disorganized carbon is burnt out preferentially and the closed and clogged pores between the sheets are freed. In the course of further activation at the second stage, carbon of the aromatic sheets is burnt. When the burn-off is less than 50%, a microporous activated carbon is obtained; when the burn-off is larger than 75% (which occurs at high reaction times), a macroporous product is obtained; and when the burn-off is between 50 and 75%, the product is of mixed structure and contains both micro and macro pores. Development of macropores due to coalescence or widening of micropores under fast reaction conditions results in a reduction in iodine numbers at higher reaction times (Satya Sai *et al.,* 1997). The micropores contribute only 33% towards total pore volume and 63% towards surface area in the case of steam-activated carbon. The carbon atoms which are localised at the edges and the periphery of the aromatic sheets or those located at defect position and dislocations or discontinuities are associated with unpaired electron or have residual valancies, rich in potential energy. Consequently, these carbon atoms are more reactive and have a tendency to form surface oxygen complexes during oxidative activation. These surface chemical groups promote adsorption. Alternatively, these surface oxygen complexes break down and peel off the oxidised carbon from the surfaces as gaseous oxides leaving behind new unsaturated carbon atoms for further reaction with an activating agent. In brief, activation mechanism can be visualised as an interaction between the activating agent and the carbon atoms which form the structure of intermediate carbonized product resulting in large internal surface area with interconnected pores of desired dimension and surface chemical groups (Manocha, 2003).

2.2.7. Structure

Activated carbon (AC) is characterized with micropores (diameter < 2 nm; pore volume 0.6-0.8 cm^3/g; pores of diameter 0.7-2.0 nm are classified as super-micropores and <0.7 nm as ultra-micropores), mesopores (transitional) (diameter 2-50 nm) and macropores (diameter >50 nm). The macropores open directly to the external surface of the particle; mesopores branch off from macropores; and micropores branch off from the mesopores. The specific area of the micropores usually amounts to at least 90% of the total surface area. The amount of each of these pores is very important to the type of particle being adsorbed. For example, the different sized molecules will fill different size spaces in the structure. Macropores contribute very little to the total internal surface area of the product and functions to serve as transport arteries that make the internal parts of the carbon granules readily accessible to the molecules being adsorbed. Mesopores account for about 5%, and the micropores for about 95%, of the total internal surface area.

X-ray diffraction studies have shown that the structure of thermally activated carbon is similar to that of graphite, slipping layers (Bockris, 1969, Mattson and Mark, 1971). Here, the carbon is believed to be composed of tiny graphite-like platelets, only few carbon atoms thick and 20-100 Angstrom in diameters, which form the walls of open cavities of molecular dimensions, *i. e.*, the pore system. The overall structure is very disordered and the separation between the layers is greater than that found in graphite.

The pore structure and pore size distribution of activated carbon is largely determined by the nature of the starting material (Gergova *et al.*, 1993 and 1994). In comparison between coconut shell active carbon and wood-based active carbon, the coconut shell active carbon was shown to have a fine pore distribution with a major portion of its pore volume being represented by pores of diameter of less than 2 nm; whereas wood-based active carbon contained comparatively significant amounts of mesopores and macropores (McDougall, 1991). Rodriguez and Solano (1989) reported that the botanical family of the raw material influences the pore size distribution. The shape of the pore is determined by the nature of raw material; coconut shell active carbon is known to have slit-like macropore shape, whereas for coal-based carbon the shape of macropore is tortuous (McDougall, 1991). One of the parameters which differentiates between materials being their chemical composition. Gergova *et al.*, (1994) attributed the predominately mesopore and macropore structure of the activated carbon produced from grape seed and cherry stone to the high lignin content in the raw material. This revealed the possibility of selecting raw materials to produce activated carbon with certain pore-size distribution by recognizing their differences in material composition. If an activated carbon with significant amount of mesopores and macropores is required, it may be produced from lingo-cellulosic materials that contain comparatively large percentage of lignin content (Wan Mohd. Ashri and Wan Shabuddin, 2004).

2.2.8. Properties, Specifications and Tests

Adsorption, the prime characteristic feature of activated carbon, is the formation of a gaseous or liquid layer by molecules in a fluid phase on the surface of a solid by the week molecular attraction forces of the *van der Waals* type. Atoms at the surface of porous solids like active carbons have imbalanced forces as compared to those within the solids and consequently foreign molecules in a bid to satisfy this imbalance get attracted to the surface. Such foreign molecules (adsorbates) form a monolayer on the surface of the porous solid (adsorbent). Therefore, adsorptive capacity of the adsorbent material depends on the total surface area available for adsorption and on the pore size; hence, determined by the quantity and nature (number and size distribution) of the various pores present in the specific type of the carbon. Consequently, the more porous the material, the better its adsorption capacity and is the reason for the excellent adsorption capacity of porous active carbons.

Adsorption is a dynamic process in which some adsorbate molecules are transferred from the fluid phase on to the solid surface while some are released again to the fluid state. These processes are functions of partial pressures. When the rates of the two processes become equal, an adsorption equilibrium or so-called *adsorption isotherm* is obtained. This expresses the amount of adsorbate adsorbed as a function of gas phase concentration measured by equilibrium partial pressures p/p_0 at constant temperature. Adsorption isotherms are used to estimate surface area, pore volume in various porosity regimes, assessments of the surface chemistry of the adsorbent, and fundamental information on the efficiency of industrial carbon employed in separation or purification techniques.

The particle size distribution, pore size, surface area, surface chemistry, density and hardness (dry impact hardness), wet abrasion resistance, etc are the major product qualities that govern the suitability of a specific active carbon product for a specific end-use. From the chemical point of view, comparisons are based on the ability of the different products to adsorb various selected representative adsorbates from the gaseous phase such as benzene, carbon tetrachloride (CTC), and nitrogen; as well as from the aqueous phase such as iodine, molasses, phenol, methylene blue, and tannin. The American Society of Testing and Materials (ASTM) specifies majority of the methods of testing these properties (Appendix II).

2.2.9. Types of active carbons

Different types of active carbons include: Powder activated carbon (PAC) (particle diameter 15-25 nm or < 0.18 mm – US mesh 80), granulated activated carbon (GAC) (0.2 to 5 mm), pelleted activated carbon (extruded and cylindrical or spherical shaped with diameter 0.8-5 mm), impregnated carbons (impregnated with iodine, silver, cations such as Al, Mn, Zn, Fe, Li, Ca, etc.), polymer coated activated carbon, advanced active carbons such as the active carbon molecular sieves, fullerenes, activated carbon fibres (ACF) with very high surface area (around 2000 m^2/g), etc.

2.2.10. Packaging

Because of the adsorptive properties of activated carbon, it is important that the product should be sealed from the atmosphere. Activated carbon is therefore usually packed directly into polyethylene bags and sealed before being placed in a second, stronger bag made of material such as woven polypropylene.

2.2.11. Industrial Experience

NORIT Americas Inc., the world famous multi-national, company in activated carbon manufacturing, suggested conducting isotherm testing with specific active carbon product can only be reliable in deciding the applicability of the active carbon developed for specific end-uses. They rather cautioned that the usual laboratory analytical tests such as the iodine number, phenol value or surface area could be misleading as a predictor of carbon performance. For example, they say, carbon with the highest iodine number value is frequently not the best choice for colour removal in food processing or for taste and odour removal from potable water. The physical and chemical properties such as carbon particle size, pH, temperature, impurity concentration and viscosity can affect adsorption and must be duplicated in the laboratory isotherm testing. They also suggest the specific method for isotherm testing (NORIT, 2000).

Babu and Ramakrishna (2002) reported that the activated carbon prepared from various raw materials being examined and reported for more characteristics than prescribed under the relevant Indian Standard Codes, IS 8366 for powder activated carbons and IS 2752 for granular activated carbons (BIS, 1989 and 1995); some of the characteristics prescribed by the Indian Standards are not being examined by many investigators. They found that many products are not complying fully the IS codes; rather the IS codes need revision as they are found incompetent to include and categorize many of the reported properties of active carbon prepared from varied raw materials for suitable end uses. They suggested for developing a separate IS code for defining the suitability of activated carbon for waste water treatment; a possible re-examination of the characteristics selected and prescribed under IS 2752 and 8366; identification of characteristics for the activated carbon prepared from a specific raw material category; and prescription of standard method for the preparation of activated carbon for commercial purposes. Majority of published literature on activated carbon are confined to laboratory scale preparation and theoretical dealings on adsorption, and very little on pilot scale production technology and practically none on commercial scale production, design of plants, etc.

Response Surface Methodology (RSM) technique has been reported to be an ideal tool for the industrial process optimization in industries. Gratuito *et al.,* (2008) attempted to determine the optimum conditions for the production of chemically (phosphoric acid) activated coconut shell active carbon (8 mesh – 2.4 mm diameter) employing the RSM analysis of output characteristics such as yield, bulk density, average pore diameter, small pore diameter, and number of pores per unit area and analysed the data on fifteen combinations of the three variables; phosphoric acid impregnation ratio (1.0, 1.5 and 2.0), activation time (10, 20 and 30 minutes), and activation temperature (400, 450 and 500 ^{0}C). The optimum points reported are 1.75, 19.5 minutes, and 416 ^{0}C for impregnation ratio, activation time and activation temperature respectively. Upon validation, the correlations developed were found able to predict the values of the responses quite well as evidenced by the generally acceptable values of the percentage errors. Direct characterization of the pores using scanning electron microscopy (SEM) is reported to be a good technique to actually see the pores and get actual measurements that can be then be used to analyze and the optimum production process.

The manufacture of high-quality activated carbon products from lingo-cellulosic origin is a difficult task because of the number of variables involved in the manufacturing process and the complex interrelationship between those variables. The prime objective in the manufacture of granular active carbon from coconut shell is the development of an optimum pore structure associated with a high surface area – with minimum loss of the carbon content through carbonization and oxidation – and of a product with sufficient structural strength to withstand normal usage without excessive attrition of the particles. This warrants the serious attention towards employing scientific methods based on latest developments in the field.

3. MATERIALS AND METHODS

3.1. Continuous vertical carbonization plant for charcoal production

A continuous vertical carbonization pilot plant of 1 tonne input capacity per shift of 8 hours (*i.e.*, 3 tonnes input capacity per day) is designed fabricated (Fig. 8).

3.1.1. Description of the carbonizing plant

The carbonizer (Fig. 8) designed is a continuous vertical type kiln lined with refractory bricks. A furnace is attached with the chimney for burning the volatile matter let out to the atmosphere through the chimney of 0.4 m diameter and 4.65 m height from the ground level. The carbonizer is an assemblage of three different chambers. The top chamber (Fig. 9) is cylindrical in shape and a feeding hopper is provided on it. The top (first) chamber is 1.3 m in height and 1.2 m internal diameter. Middle chamber (Fig. 10) is conical in shape and having 1.8 m in vertical height and 1.2 m internal diameter at top to 0.6 m at bottom. Bottom chamber (Fig. 11) is also conical in shape with 0.45 m in height; 0.60 m at top to 0.40 m at bottom as internal diameter. All the chambers are made out of 6 mm MS sheets. The entire unit is externally lined with cold refractory bricks and internally with hot refractory bricks of 150 mm thickness (Fig. 12 & 13). The gaps between the linings are filled with castable clay (special type of cement used in refractory work). A hopper of diameter 1.05 m and 1.025 m height made up of 6 mm SS sheet is provided at the top of the plant (Fig. 14) to feed the raw material. Top conical shaped cover of the plant is also made with SS. Thermometer wells and viewing glass frames pushing bars and shafts are also made with SS. All other supporting materials and accessories like chimney, lift, etc are made with MS/GI sheets/pipes.

To lift the raw material from the ground to the hopper a lift mechanism with 1 hp motor is provided (Fig. 15). For withdrawal of product, the outlet pipe (Fig. 16) is fitted at the bottom portion of the plant; a gear and belt drive shaft and rotating arm mechanism with 1 hp motor (Fig. 17) is provided to push out the charcoal produced. The volatile substances from the carbonizer are taken through a pipeline insulated with refractory bricks, to a furnace (Fig. 18) where they get burnt and let away to the atmosphere through a chimney (Fig. 19). Heat recovery option is provided in the furnace for taking the waste heat, if required. Inside the plant the material is burned with limited access to air , controlled by equidistantly placed air vents, 12 numbers in the middle chamber (provided as two rows; distance between the rows is around 0.8 m) and four in the bottom chamber (Fig. 10, 11 & 20) (as single row). Digital thermometers (pyrometer type with range 0-1500 °C; one in each chamber) are provided to record the working temperature of the plant (Fig. 21).

For charcoal collection from the outlet pipe, withdrawal cans having water seal in its mouth portion to prevent entry of air through the product pipe and thereby to the plant are provided (Fig. 22). The same water sealed collection cans are used for the collection of activated carbon from the outlet pipe of the activation plant too.

A pulverizer (Fig 23) with 2 HP motor is used to crush the charcoal to desired sizes for activation. Sieves of appropriate meshes are used for sieving the crushed charcoal (Fig 24). Sieving is done manually.

Fig. 8. Carbonizing pilot plant: An overall view

Fig. 9.Top chamber

Fig. 10. Middle chamber

Fig. 11.Bottom chamber

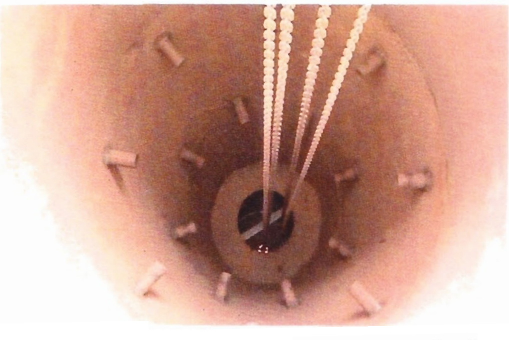


Fig. 12. Interior view of carbonizer, before giving fire brick lining

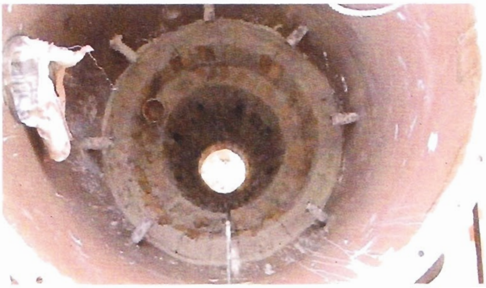


Fig. 13. Interior view of carbonizer, after giving fire brick lining

Fig. 14. Feeding hopper

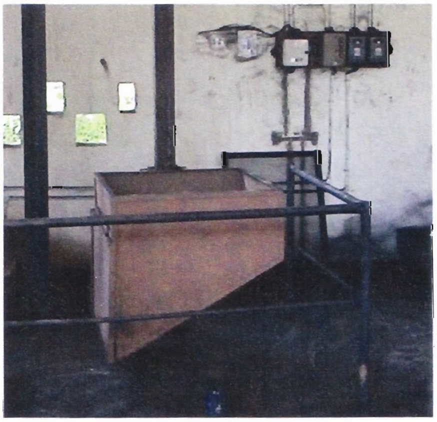


Fig 15.Lift mechanism

Fig 16.Outlet pipe

Fig 17.Outlet pipe fitted to the product withdrawal cane & motor assembly to push out the charcoal

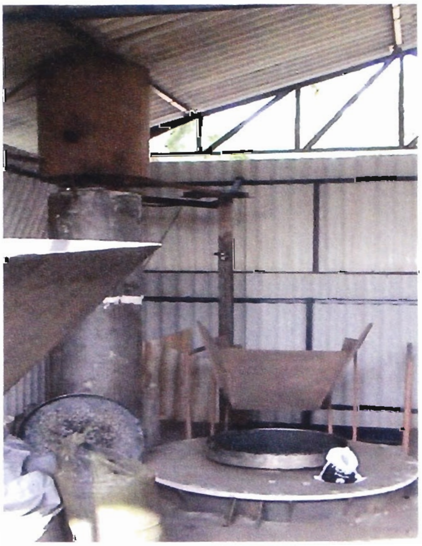


Fig 18. Flue gas burning furnace , attached to the chimney; and feeding hopper

Fig. 19. Chimney of the plants

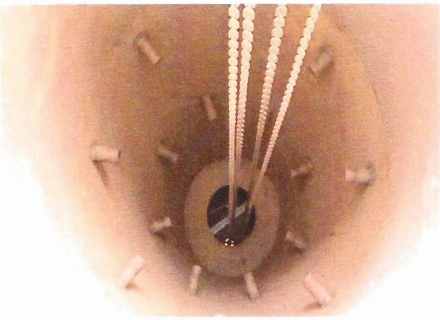


Fig. 20 Air vents in all the chambers

Fig. 23. Pulveriser

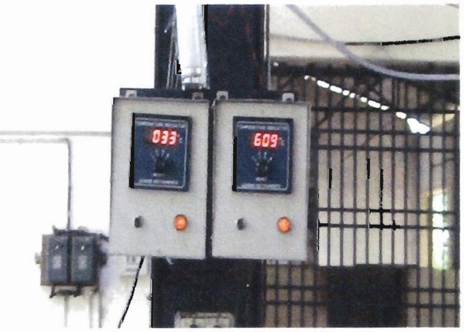


Fig. 21. Digital display of temperature

Fig. 24. Sieving and packing of charcoal

Fig. 22. Charcoal collection can; (note the water jacket portion in the neck of the can)

3.1.2. Operation of the Carbonizing Plant

The holding capacity of the carbonizing plant is about 350 kg coconut shells. About 35 kg of coconut shells are introduced into the plant for ignition. As excessive air is not good for the partial combustion, all the air vents are closed tightly while igniting (the top of the plant, i.e., the hopper portion is always opened). Usually the ignition is started either with kerosene or diesel. Around 1 litre of kerosene and waste cotton are required for igniting the shells in the plant. A piece of cotton waste dipped in kerosene is fired externally and dropped into the plant through the hopper. The coconut shells may take 20 to 30 minutes to get ignited and this will lead to the formation of a stable fire bed of coconut shells. After such a stabilized burning fire bed formation, rest of the load in batches of about 70 kg is added to the plant. In case the fire is extinguished during addition of shells all the air vents in the middle storey are opened and firing is done again externally by inserting a piece of burning kerosene soaked cotton through air vents of both the rows of the middle storey.

After the fire bed formation, coconut shells are added continuously with careful monitoring of the temperature readings in all the zones of the carbonizer so as to avoid excessive burning since it is important for restoring adequate volatile material in the charcoal. The temperature is maintained below 400^0 C in the middle zone where the combustion process occurs. When the temperature increases, some charcoal is withdrawn until the temperature gets reduced. It takes about an hour between filling the charge and first time collection of charcoal. Care should be taken while withdrawing charcoal, as withdrawing more quantity of charcoal in a single attempt will lead to excessive loss of temperature in the middle and top zones of the plant. Being a continuous process, regular time gap should be maintained for every product withdrawal in such a way as to prevent heat loss and maintain the optimal temperature. A withdrawal schedule of 1 to 3 minutes charcoal collection within a regular time interval of 10-20 minutes depending upon the temperature readings is suggested.

Once the temperature is stabilized to the desired level, air vents should not be closed too tightly; vents should be kept in such a way so as to facilitate easy opening when temperature falls. Within two hours, a fire can be lightened up in the furnace attached to the chimney to burn the volatile substances completely before reaching the atmosphere.

The water sealed product withdrawal can is placed below the output pipe for collecting the charcoal. Once withdrawal can is filled up with charcoal, it is removed from the output pipe and closed with its lid for few minutes to avoid any further open burning by direct exposure to air. The withdrawn charcoal should be spread over the dry floor for cooling. The hot charcoal has to be checked thoroughly for any fire or sparks remaining. If any fire/spark is found, it was extinguished with a water spray. The cooled charcoal may be packed in sacks and weighed for determining the yield.

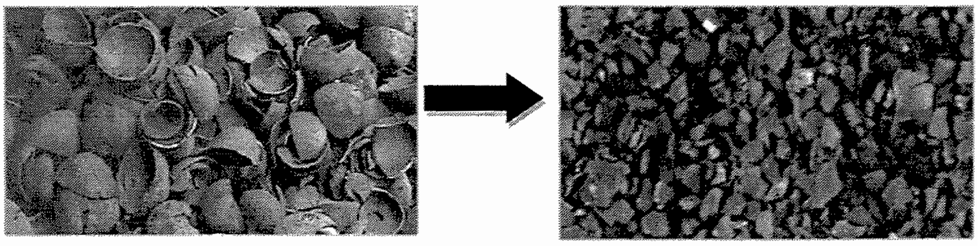
One person is required to withdraw the charcoal and one for loading the input materials on the lift. It is always recommended to run the carbonizer continuously forming three shifts per day.

Adequate stock of the raw material (shells) should be ensured. Completely dried raw materials should be used in order to avoid heavy smoke problem at the initial stage of process which in turn can affect the yield too. Raw materials should be placed near the lift and a weighing balance (platform balance) adjacent to the lift. All the input shell loadings and output charcoal should be weighed for quantifying the yield.

Care should be given to the working condition of the plant. It should be ensured before igniting the plant that all motors and lift is in working condition, as once the charge gets ignited the process can't be stopped.

3.2. Crushing the charcoal

The charcoal needs to be pulverized into desired particle size. The raw material for activation should be pulverized charcoal of size that can pass through IS sieve 4 and retained in IS sieve 8. Charcoal should be loaded into the pulverizer/crusher (Fig. 23 & 24) immediately after switching it on; loading before switching on can lead to getting struck with the crushing blades. All the openings in the crusher box need to be closed to avoid dust spreading. IS sieves 4 and 8 may be used for sieving the pulverized or crushed charcoal. On health point of view, it is suggested to wear nose strips to prevent inhalation of carbon dust produced while crushing and sieving the charcoal.



3.3. Activation Plant - Fluidized Bed Reactor (FBR) for community level production of activated carbon

An FBR with an input capacity of 0.25 tonne charcoal per day is conceptualized designed and fabricated (Fig. 25).

3.3.1. Description of the FBR

The fluidized bed reactor (Fig. 25) is a refractory-brick lined kiln structure comprising four different chambers (Fig. 26). All the chambers are made out of 6mm MS sheets, cylindrical in shape from outside, but conical inside. One inch thick cast iron plates with pipe flanges are provided in between for isolation of each chamber. The top (first) and second chambers are with dimensions 0.9 m height and 0.75 m diameter (Fig. 27 & 28). The top chamber is for pre-heating the charcoal fed into the plant and the second chamber is for stabilizing the pre-heated charcoal. The third chamber, 0.8 m in height and 0.75 m in diameter (Fig. 29) is the reaction zone or real fluidized bed reactor where the actual reaction takes place. The bottom most furnace (fourth chamber) is 0.45 m in height and 0.75 m in diameter (Fig. 30) and is the place through which the super heated steam, air and LPG (if necessary) is supplied for the reactions. Separate thermometer wells (Fig. 31), view glasses (to see the reaction from outside) (Fig. 32) and digital temperature displays (Fig. 33) are provided for the first, second and third chambers. Air supply arrangements (air rings, one each) are provided to the first, second and fourth chambers (Fig. 34). The forth chamber is provided with another two separate rings (Fig. 35), one for steam and another one for LPG, if necessary, to use as an additional heat source. The entire plant is lined with refractory bricks. A rotary valve mechanism with 1 HP motor is provided at the bottom to withdraw the product, activated carbon through the outlet pipe. An air compressor (Fig. 36) (3 HP) is used to blow air into the system. Three air rings from the air compressor are separately connected to the first, second and fourth chambers. The volatile substance from the second chamber is burned in an attached furnace (Fig.37) and the waste heat recovered is used for the boiler (Fig.38) for the production of super heated steam by using a super heater (Fig.39). Superheated steam is admitted through a steam ring to the fourth chamber. One more ring is connected to the fourth chamber (bottom most) for admitting LPG, in situations where an additional heat source is required. A 0.5 HP motor is provided to pump water to the tank. Water tank is connected to the boiler. In case of a failure in keeping the desired water level in the boiler, a non-returnable valve (NRV) fitted between the water tank and boiler prevents the return of steam from boiler to the pipeline and water tank and thereby safeguarding the collapse of pipeline, tank and the boiler itself. The NRV necessitates another motor (0.5 HP) to pump water from the tank to the boiler. Thermometer wells, pushing bars, shafts and viewing glass frames are made with SS. Air flow pipes and other pipes inside activated carbon plant are made with SS. All other supporting materials and accessories like chimney, lift etc. are made with MS/GI sheets/pipes.

3.3.2. Operation of the FBR

The water sealed product withdrawal can is placed (Fig. 40) below the outlet pipe of the plant before starting the process.

The activation plant is loaded with the pulverized charcoal of desired size through the feeding hopper (Fig.41) till it reaches the level of the first air ring (*see Fig.41*, a thread with a weight tied in one end can be used to identify the charcoal level in the plant). The air compressor (*see Fig.36*) is switched on and air is allowed at a pressure of 1 to 2 kg/cm^2 to pass through the activation plant for half an hour before starting the ignition and the same air pressure is maintained in all the three air rings (*see Fig.34*) attached to the first, second and fourth chambers during this period. The ***steam inlet valve*** of the reactor (Fig. 42) is closed. The ***steam bypass valve*** provided below the steam pressure gauge (Fig.43) is kept in open position for facilitating the indication of steam production (steam production will be indicated by the upcoming steam through the opened valve mentioned above).

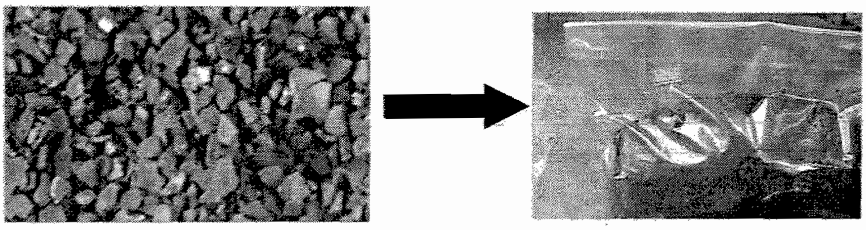
The charcoal is now ignited in the top chamber of the plant. This can be done by putting some externally ignited burning crushed shells into the first chamber through the feeding hopper. The viewer glass (*see Fig.32*) can be used to ascertain that the fire has reached in the top of the first chamber. Now, the air pressure is increased in the top (first) air ring (*see Fig.34*) to around 1 to 2 kg/cm^2 by operating the respective control valve (*see Fig. 42*) attached to the flow meters (Fig. 44) connected in order to get adequate fire in the first chamber. The temperature in the first chamber is watched by observing the digital display of the respective thermometer. Simultaneously, the spread of the fire is kept under observation in the chamber through the viewer glass to ensure that the fire gets stabilized in the first chamber. It can be observed that the temperature in the first chamber (as indicated by digital thermometer display) is slowly increasing from room temperature to around 100 ^{0}C.

In order to raise the temperature of the other lower stabilizer chambers, some charcoal is withdrawn through the outlet pipe to the withdrawal can for ten seconds and the same is followed at regular intervals of 5 minutes till the temperature of the third chamber reaches around 800 ^{0}C. During all the operations in the plant, it should be always ensured that the charcoal level in the plant is up to the first air ring and the feeding hopper is full. For this, the withdrawn charcoal as well as fresh charcoal may be added as and when found necessary. The temperatures of the second and third chambers should be monitored. Due to the heat exchanger connected from the first chamber to the third chamber (activation zone or activator), it can be seen that the temperature of the third chamber is getting raised comparatively faster than the second zone. When the temperature of the third chamber reaches above 200 ^{0}C, the quantity of air in the first and second air rings is reduced to about 1 to 2 m^3/hr and increase the air in the third ring to about 3 m^3/hr. Because of the high quantity air flow to the third chamber, the temperature of the third chamber now slowly gets raised to above 800 ^{0}C (as indicated by the respective digital thermometer display, *see Fig.33*) within around three hours. It should be noted that charcoal withdrawal and addition should be continued as before during all these operations.

It can be seen that steam is getting produced sufficiently in the heat recovery boiler when the temperature of the third chamber is reaching around 800 ^{0}C, as indicated by the steam bypass valve mentioned above. Now, the steam bypass valve is closed and the steam inlet valve is opened to allow the steam to enter into the fourth chamber first and then into the third reaction chamber. It can be observed that due to steam entry, the temperature of the third chamber slowly falls down. Now, by regulating the steam entry by adjusting the steam inlet valve, the system is adjusted by trials in such a way that the steam entry is equilibrated against the maximum temperature attainable in the third chamber. At this stage, the steam pressure can be around 0.5 to 1 kg/cm^2 and temperature around 850 °C. This is the stage where activation process is stabilized. Within a time of five hours after ignition, the system will get stabilized. The product withdrawn from this stage onwards is activated carbon; and should not be used for loading into the plant as before.

The product withdrawal system involves opening the outlet pipe for a specified or pre-determined duration and repeating the same within regular time intervals. Application of an appropriate withdrawal schedule is important (refer also 'Results and Discussion' sections for details for ideal product withdrawal schedule). Short schedules are preferred over long schedules as they are likely to affect adversely the reaction temperature and thereby the quality of product.

Once the withdrawal can is filled up with activated carbon, then it is removed from the outlet pipe and closed it with its lid for few minutes. It is then spread over the dried floor, checked for any fire or sparks, cooled to room temperature and packed. The product is weighed for assessing the yield. The activated carbon can now be packed and stored for marketing.



It should be ensured that adequate water level is always maintained in the boiler. The water level in the boiler can be checked through the view glass provided in the boiler (Fig.45). In case of a water level fall, the motor provided can be switched on for pumping water into the boiler. In case of negligence in keeping the water level and failure of the NRV, the potential risk of return of high pressure steam to the water pipes and tank and the resultant collapse of the structure can be prevented by immediately opening all the steam relieving valves.

3.4. Trial production of charcoal and activated carbon

Charcoal from coconut shells and stem wood was produced by employing traditional pit and drum methods as well as the newly developed pilot scale carbonizing plant. Yield and quality of charcoal were assessed and compared with the product from the new carbonization plant.

In order to develop optimized reaction conditions for desired quality product, shell charcoal was produced in the carbonization plant employing different temperature ranges; *viz.*, low temperature range of 300-350 ^{0}C and 350-450 ^{0}C, medium temperature range of 400-650 ^{0}C and high temperature range of 500-800 ^{0}C. The temperature control was effected by controlling the air entry into the plant by regulating the air vents provided. The yield and quality of product from each trial were assessed for revealing the effect of temperature of production on quality of the product.

Charcoal thus produced was crushed using the crusher, graded using IS sieves 4 and 8 and fed to the activation plant (FBR). Charcoal with low (6%), medium (8-9%), and high (13%) volatile content obtained from the newly developed charcoal plant were separately activated in the FBR; the maximum temperature attained while using charcoal with different volatile contents was recorded. The yield and quality (iodine number) of the granular active carbon obtained were assessed to determine the effect of volatile content and temperature on yield and quality of product. An air pressure of 4 kg/m^2 was employed in activating charcoal of low, medium and high volatile contents. The effect of application of slightly elevated air pressures (5 kg/m^2 for charcoal with low volatile content and 6 kg/m^2 for charcoal with medium volatile contents) on the activation process was also observed (by assessing the yield and quality of product). In general, the steam pressure employed was 1 kg/cm^2; effect of an increased steam pressure (2 kg/m^2) was assessed while activating charcoal with medium volatile content. In order to reveal the effect of retention/product withdrawal schedules on the quality of product (iodine number), the following schedules were employed in the trial runs: product (granular active carbon) withdrawal for 1 minute within a retention period of 7.5 minutes (denoted by *1/7.5*), *1/10*, and *2/10* for charcoal with all (small, medium and large) volatile contents; *0.1/5* (product withdrawal for 0.1

minute within a retention period of 5 minutes) for charcoal with small and medium volatile contents.

3.5. Assessment of Yield and quality of products

Yield of charcoal and activated carbon were determined on oven dry (OD) basis by weighing the raw material and products after correcting for moisture content (MC, %) at test condition. Moisture content was determined by oven dry method.

Quality parameters of charcoal and activated carbon were determined as per standard procedures. Quality parameters such as moisture content, volatile content, ash content, fixed carbon content, iodine value, etc were determined by chemical analysis (BIS, 1984, 1989, 1992, 1995, 2002, ASTM 1977).

The method essentially consists of oven drying (at 105 ^{0} C) pre-weighed air dried (AD) charcoal dust that passed through of 850 micron IS sieve and recording the oven dry weight of the sample, from which moisture content is calculated. Volatile content is determined on the oven dried sample by using a muffle furnace at a temperature of 300-500 ^{0}C and weighing the cooled sample. Ash content is determined on the same sample used for volatile content determination by igniting the sample in a muffle furnace at 750 ^{0}C for 6 hours and weighing the cooled ash. Fixed carbon content is calculated by subtracting the sum of volatile content and ash content of the OD sample from 100.

Iodine number test being easier to run than the BET (m^2/g) test, it is commonly used in industries as a quality indicator of the active carbon product. Iodine value is determined on 0.2 g finely powdered samples that pass through a 75 micron IS sieve. The carbon powder is introduced into an iodine flask and 40 ml of 0.1 N iodine solutions is added. The contents are shaken for exactly 4 minutes and filtered through a Whatman No. 1 filter paper. 10 ml of the filtrate is taken and titrated against standard (0.05 N) sodium thiosulphate solution (Exactly 0.1 N potassium iodate solution is used for the standardization of sodium thiosulphate solution using starch indicator; the iodine solution is standardised against the standardized sodium thiosulphate solution using starch indicator; and the quantity of iodine adsorbed is calculated from the quantity of iodine mg/gm in the original solution and the quantity of iodine in the filtrate by taking difference). Iodine value of commercial laboratory grade active carbon from BDH is also determined for comparison purpose.

In order to determine the metal ion adsorption capability of active carbon produced in the FBR by employing the optimized or ideal production parameters tests were conducted for their ability to remove nickel and iron ions from respective solutions of 100 ppm strength. Spectrophotometric method employing colorimeter was used for the experiment. One gram active carbon dust that passes through 75 micron IS sieve was agitated with 50 ml of metal ion solutions of Ni^{2+} and Fe^{2+} for 1 hr, filtered and analysed for the metal ion concentration. The difference between the initial and final concentrations of metal ions was estimated to assess the capability of the active carbon for metal ion removal from solutions. This will give an indication to the ability of the product for use in water or liquid purification, pollution control, etc.

Performance of the plants against smoke pollution was monitored visually by observing the smoke emission from the chimney and testing the ambient air quality using Envirotech APM 460 BL Portable Respirable Dust Sampler. SO_2, NO_2, CO, suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM) were tested as per Indian Standards and other standard procedures (BIS, 1969, 1973, 1975; Lodge, 1988).

Fig. 25. Side views of the FBR

Fig. 27. First (Top) chamber of FBR

Fig. 26. The four chambers of the FBR

Fig. 28. Second chamber of FBR

Fig. 29. Third chamber (activation zone) of FBR

Fig. 30. Bottom chamber of FBR

Fig. 31. Thermometer wells

Fig. 32. View glass

Fig. 33. Digital display unit of the pyrometer

Fig 34. Air supply arrangements (air rings)

Fig. 35. Bottom (4th) chamber with three rings (note the overall view of bottom chamber with three rings for air, steam and LPG as well as the heat exchanger between 2nd & 4th chambers)

Fig. 36. Air compressor with pressure gauge

Fig. 37. Flue gas burning furnace attached to the FBR

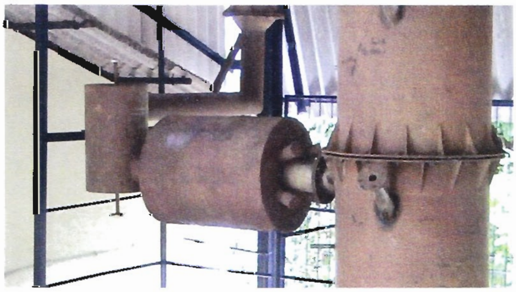


Fig. 39. Internal view of the super heater

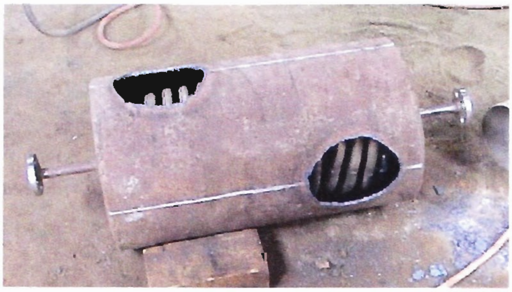


Fig. 38. Waste heat recovery boiler attached to the FBR

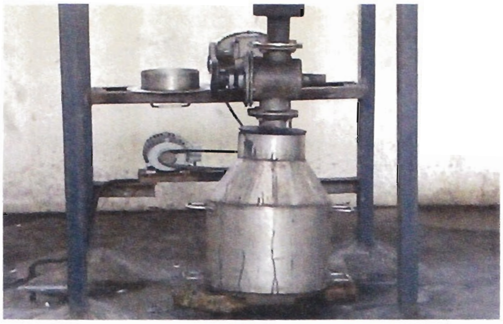


Fig. 40. Product output pipe and withdrawal can

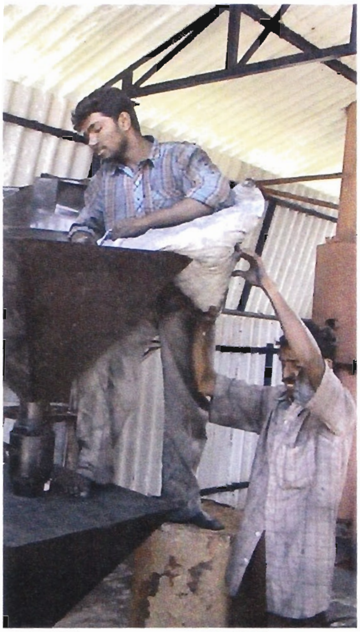


Fig. 41. Feeding hopper

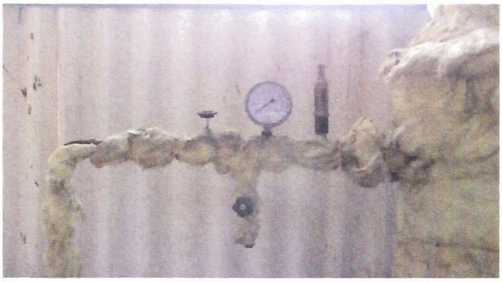


Fig. 42. Steam inlet and bypass valves

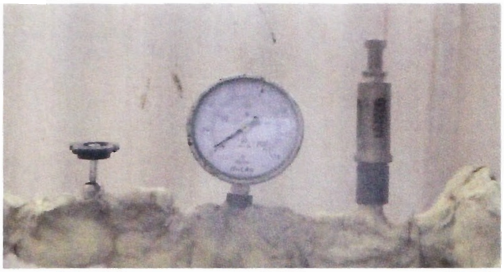


Fig. 43. Steam pressure gauge

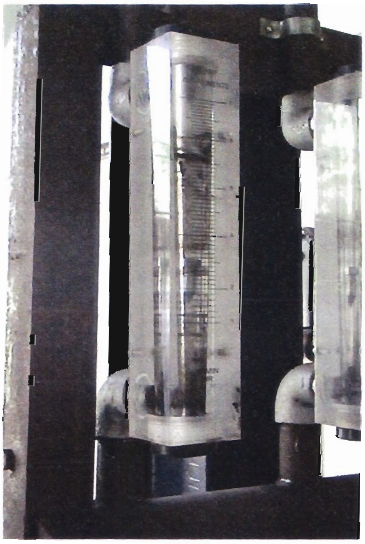


Fig. 44. Air pressure gauge for three air rings

Fig. 45. Water level view glass in the boiler

4. RESULTS AND DISCUSSION

4.1. Charcoal

4.1.1. Performance of traditional methods of production *vs.* the newly developed carbonizing pilot plant

Table 1 shows the results on yield and quality of charcoal produced by the traditional methods *versus* that produced by employing the newly developed carbonization pilot plant. Traditional methods yield an average of 27-28% of coconut shell charcoal. As the observed difference in yield between the traditional methods being less than 1%, yield is not appreciably different between the pit and drum methods. As far as coconut stem wood charcoal is concerned, traditional (drum) method yielded 24% charcoal. Low temperature carbonization in the newly developed pilot plant yielded an appreciably higher quantity of charcoal. On an oven-dry basis, 32% yield is achieved for shell carbon; for stem wood charcoal, the yield was 26% (Table 1). This result showed that the newly developed carbonization plant is capable to produce higher yield compared to the traditional methods.

The input output details recorded while conducting trial runs showed that after firing the charge, carbonization is stabilized within the first 1.5 hours and collection of charcoal can be started at this point. As far as quality of charcoal is concerned, charcoal from traditional methods yielded higher volatile content (914.7-15.7% for shell charcoal and 22.6% for stem wood charcoal). Between the pit and drum methods the difference in volatile content was not appreciably high, there was only a difference of 1%.

Use of the carbonization plant yielded charcoal with significantly lower volatile content (13.0 % for shell charcoal and 19.9% for stem wood charcoal). As charcoal with lower volatile content is preferred for industrial use, the newly developed carbonization plant is a success in this regard too.

Ash content, another quality parameter of charcoal is mainly raw material dependent; for shell charcoal the ash content was between 1.0-1.5% whereas for stem wood charcoal it was in the range of 2.2-3.2%.

The fixed carbon content of shell charcoal from traditional methods was found to be in the range of 83-84%, whereas the product from the carbonization plant yielded shell charcoal with 86% fixed carbon. For stem wood charcoal also, the newly developed carbonization plant yielded product with high fixed carbon (78%) compared with the product from traditional (drum) method (74%). So, the newly developed plant was found to be capable to produce charcoal with higher fixed carbon also, a feature desirable for industrial use.

Table 1. Comparison of yield quality of charcoal produced by traditional methods and the carbonizing pilot plant

Method of production	**Yield***	**Volatile content ***	**Ash content ***	**Fixed Carbon content ***
Coconut shell charcoal				
Earth-Pit method	27.1	14.7	1.5	83.8
Portable Drum method	27.9	15.7	1.1	83.2
Carbonizing Pilot Plant (Low temperature; 350-450 ⁰C)	32.0	13.0	1.0	86.0
Coconut stem wood charcoal				
Portable Drum method	24	22.6	3.2	74.2
Carbonizing Pilot Plant (Low temperature; 350-450 ⁰C)	26	19.9	2.2	77.9

*=OD Basis, %

4.1.2. Trial runs for optimization of reaction conditions in the newly developed carbonization pilot plant for desired quality product

Table 2 reveals the effect of temperature of production on the yield and quality of charcoal while employing the newly developed carbonization plant. It is understood that lower the carbonization temperature, higher the yield (Fig. 46). Charcoal yield was 34% while employing low temperature for carbonization (300-450 ⁰C); medium carbonization temperature (400-650 ⁰C) yielded 29% and high temperature carbonization (500-800 ⁰C) yielded 27% charcoal.

As far as quality of charcoal produced from the different carbonization temperatures is concerned, the ash content was not found varying much (1-2%); volatile content of charcoal was found inversely related to the temperature of production. Fig. 47 shows the relationship between yield and volatile content. Fig. 47 shows the relationship between volatile content and fixed carbon content of the charcoal produced. High carbonization temperature (800 ^{0}C) yielded charcoal with low volatile content (6.2%); medium carbonization temperature (300-450 ^{0}C) was found yielding charcoal with moderate volatile content (8-9%), whereas low temperatures of carbonization yielded charcoal with high volatile content (13%) (Fig. 48). Proportionate to the volatile content, charcoal with high fixed carbon (92%) can be produced by employing high carbonization temperature (500-800 ^{0}C); charcoal with 89-90% fixed carbon can be produced by employing medium carbonization temperatures (350-650 ^{0}C). Charcoal from low carbonization temperature yielded around 86% fixed carbon.

Table 2. Effect of temperature of production on yield and quality of coconut shell charcoal produced by the carbonizing pilot plant.

Temperature range	**Yield (%) (OD Basis)**	**Volatile content (%)**	**Ash content (%)**	**Fixed Carbon content (%)**
Low temperature; 300-350 ^{0}C	34	13.0	1.0	86.0
Low temperature; 350-450 ^{0}C	32	9.4	2.0	88.6
Medium temperature; 400-650 ^{0}C	29	8.1	2.1	89.8
High temperature; 500-800 ^{0}C	27	6.2	1.8	92.0

Charcoal of different qualities is in demand for various end uses. For domestic (cooking) fuel, charcoal with relatively high volatile content is preferred, charcoal with high fixed carbon (low volatile content) is preferred for industrial uses such as in metallurgy, explosives and pyrotechnic compositions (BIS 1992), alternative to coke, etc. Coconut shell charcoal as a raw material for granular active carbon industries prefer material with moderate volatile content for effective burning in the rotary kiln.

These results showed the effectiveness of the newly developed carbonization plant for producing charcoal with the desired quality. As the plant permits application of varied temperatures by controlling the air entry, the newly developed carbonization plant is found capable to produce charcoal of varying qualities as per demand. Application of still higher temperatures above 800 ^{0}C can lead to the production of charcoal with still lower volatile content (below 6%) which may have innovative applications such as substitute for coke; even there is possibility to develop products such as "Bio-coke" or "Coco-coke"!

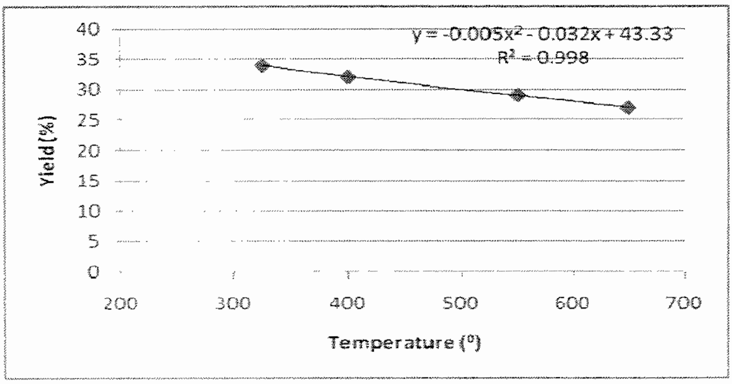


Fig. 46. Effect of carbonization temperature on yield of charcoal produced in the carbonization plant.

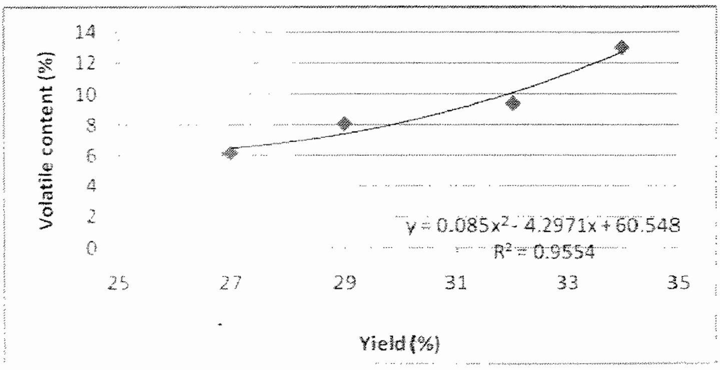


Fig. 47. Relationship between yield and volatile content of charcoal produced in the carbonizing plant

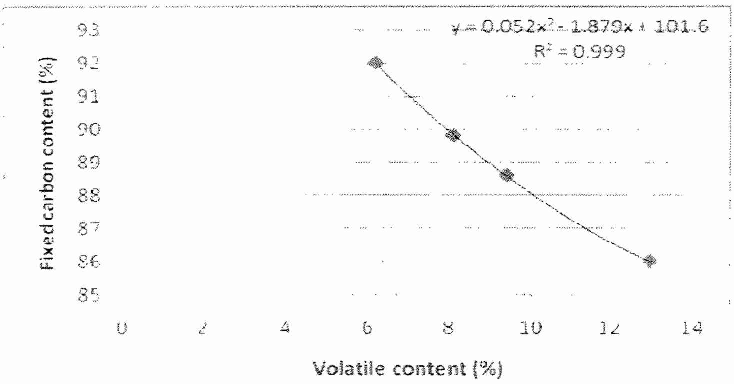


Fig. 48. Correlation between volatile content and fixed carbon content (%) of charcoal produced in the carbonizing plant.

4.2. Activated Carbon – Trial runs for optimization of process parameters

Table 3 details the yield and properties of the activated carbon produced in the preliminary trial. In this trial the raw material was coconut shell charcoal with 9.4% volatile content (on moisture free basis; produced at a low temperature range, 350-450 °C). A yield of 50% on oven dry (OD) basis was recorded. An average of 9 samples on chemical analysis showed 3% moisture content (MC). The volatile content, on OD basis, was 1.0% and ash 1.4%. An iodine value of 900 mg/g is recorded. This indicates that the product conforms to the Indian Standard Specification is 2752: 1995 for activated granular carbons (MC <5%, ash content <5-6%, iodine value 450-900) (BIS 1995). According to this specification, the product from the present trial is of 'Type 1', a superior grade active carbon approved for the use as a base for respirator carbons and solvent recovery. As the properties of Type 1 are superior to the 'Type 2' for use in water treatment, the product has potential in applications in water purification too. The preliminary trial itself showed the capability of the newly developed fluidized bed reactor (FBR) for producing high grade active carbon. Results of chemical analysis of commercial laboratory grade active carbon (BDH) as given in Table 3 showed that the active carbon from the newly developed FBR is of equal quality to that is available in market.

As part of optimization of production parameters, 4 more trials were conducted with shell charcoal of differing volatile contents (Table 4). The yield varied from 39 to 54% on OD basis. Table 4 shows an increasing trend of the yield of activated carbon with decreasing volatile content; i. e., with increasing fixed carbon content of the raw material, shell charcoal. Charcoal with the highest volatile content (13%) yielded product with the lowest yield (39%). Charcoal with moderate volatile content (8.1 – 9.4%) yielded product with 50% yield. Charcoal with the lowest volatile content gave product with the highest yield (54%). This trend shows that charcoal with lower volatile content is better for more yield of activated carbon. As the fixed carbon content of charcoal is found inversely related with volatile content, the yield of activated carbon can be more meaningfully correlated with the fixed carbon (FC) content of charcoal. Figs. 49 and 50 illustrate the variation of the yield of activated carbon with the quality of raw material; volatile content and fixed carbon content of charcoal. But this result needs to be cross verified in terms of the adsorption capability of product (iodine number). As the average value of ash content of coconut shell charcoal being 1.7% (Table 2) and its variation is not much (1-2%), ash content of raw material need not have a role in the yield of activated carbon.

The principal quality of activated carbon is its adsorption capability, measured in terms of iodine value (mg/g). The iodine number is defined as the milligrams of iodine that are adsorbed per gram of carbon when the equilibrium concentration of the bulk saturation is 0.02 N and provides an indication of the amount of micropores (down to 10 Angstrom in diameter) in carbon. Because iodine is a small molecule, it provides an indication of a particular carbon's capacity to adsorb smaller molecules and is a good indication of the carbon for water purification purposes. Activated carbons with iodine number (mg/g) ranges 500, 800, 900, 1000 -1100 are generally specified for various end uses. As is evident from Table 4, the highest iodine value (875-900 mg/g) is obtained for the product from the charge which attained activation temperatures in the range 750-850 ^{0}C. Generally, all traditional rotary kiln units producing commercial quantities of activated carbon are employing activation temperature near 900 ^{0}C resulting product with iodine value around 900 mg/g. This shows that activation temperature is an important factor in getting product with desired iodine value. Active carbon produced from the present trials with activation temperature below the range 750-850 ^{0}C achieved iodine values below 875-900 mg/g only. Even though there was no clear trend in the achieved activation temperature achieved with the volatile content of the raw material used; may be an effect due to the interaction of the other parameters employed (use of a higher air and steam pressure), it is clear from Table 4 that out of the various trials, only the trial with the charge having moderate volatile content (9.4%) yielded the desired activation temperature (750-850 ^{0}C) automatically, yielding product with higher iodine value. This showed the necessity of a moderate volatile content in the charcoal to be used as the raw material for achieving the maximum activation temperature as well as employing an air pressure of around 6 kg/cm^2 and steam (superheated) pressure of around 1-2 kg/cm^2 for yielding product with desired iodine value of around 900 mg/g when an FBR is used for producing active carbon.

Table 3. Yield and quality of activated carbon produced by the fluidized bed reactor

Raw material quality	**Reaction condition***	**Yield***	**Volatile content***	**Ash content ***	**Fixed carbon content***	**Iodine value (mg/g)**
Coconut shell charcoal with volatile content 9.4%, produced at low temperature range (350-450 ^{0}C)	Activation temperature around 750^0 C, activated with 2 kg/cm^2 steam.	50	1.0	1.4	97.6	900
Commercial laboratory grade active carbon from BDH						
	--	--	0.9	1.6	97.5	925

*=on OD Basis & %

The various trials conducted for optimization of production parameters showed that for producing granular shell active carbon by employing the newly developed FBR, the minimum activation temperature should be around 850 ^{0}C and the raw material (charcoal) should have a moderate volatile content in the range of 9% on OD basis. According to the Indian Standard Specification for granular activated carbons, the minimum requirement of iodine value is 450mg/g for the 'Type 2' active granular carbons for the use in water treatment (BIS 1995). Almost all the products from the different trials achieved this minimum iodine value requirement (Table 3). This clearly shows that the newly developed FBR is capable to produce granular active carbon of varied or desired quality.

The retention or residence time of charcoal in the reactor and the product withdrawal frequency (duration) are also factors which decide the efficacy of activation. Table 4 details the various retention/product withdrawal conditions employed. A retention time of 5-10 minutes is allowed in the various trials employed. As product with high iodine value is the target and this is achieved satisfactorily from the use of charcoal produced at low temperature (350-450 ^{0}C) having moderate volatile content (9.4%); the product withdrawal condition employed, withdrawal for 0.1 minute within a retention period of 5 minutes is found satisfactory. The manual product withdrawal system can be modified into an automatic system later.

It is interesting to note a particular observation that the product from a particular batch of activation in the FBR where the desired high temperature and optimum air pressure was given, but the charge was not supplied with steam and happened to discontinue and stop the process, also gave 50% yield with an iodine value of around 860 mg/g (Table 4). Theoretically, the product from this particular batch could be again charcoal only. But the high iodine value obtained for the product showed the possibility of charcoal itself produced at high temperature (750 ^{0}C) from the newly developed plant possess excellent adsorption capability and is suitable for use in water treatment; this could act as an alternative to active carbon for water treatment. This again validates the earlier mentioned scope that shell charcoal produced at high temperatures from the newly developed carbonizer can be considered as an alternative to coke; possibility to develop products such as "Bio-coke" or "Coco-coke"!

Table 4. Optimization of activation process conditions in the FBR.

Sl. No.	Raw material quality	Reaction condition	Retention/product withdrawal condition	Yield (%) (on OD Basis)	Quality (Iodine value, mg/g)
1	Coconut shell charcoal with volatile content 13% produced at low temperature range (300-350 ^{0}C)	Air pressure of 4 kg/cm^2 in the activation chamber; Activation temperature around 650 ^{0}C; activated with 1 kg/cm^2 steam.	Withdrawal for 1 minute within a retention period of 7.5 minutes	39	420
2	Shell charcoal with volatile content 13% produced at low temperature range (300-350 ^{0}C)	Air pressure of 4 kg/cm^2 in the activation chamber; Activation temperature around 650 ^{0}C; activated with 1 kg/cm^2 steam.	Withdrawal for 1 minute within a retention period of 10 minutes		510
3	Shell charcoal with volatile content 13% produced at low temperature range (300-350 ^{0}C)	Air pressure of 4 kg/cm^2 in the activation chamber; Activation temperature around 650 ^{0}C; activated with 1 kg/cm^2 steam.	Withdrawal for 2 minute within a retention period of 10 minutes		430
4	Shell charcoal with volatile content 8.1% produced at medium temperature range (400-650 ^{0}C)	Air pressure of 4 kg/cm^2 in the activation chamber; Activation temperature around 650 ^{0}C; activated with 1 kg/cm^2 steam.	Withdrawal for 1 minute within a retention period of 7.5 minutes	50	450
5	Shell charcoal with volatile content 8.1%	Air pressure of 4 kg/cm^2 in the activation	Withdrawal for 1 minute within a		460

	produced at medium temperature range (450-650 °C)	chamber; Activation temperature around 650 °C; activated with 1 kg/cm² steam.	retention period of 10 minutes		
6	Shell charcoal with volatile content 8.1 %, produced at medium temperature range (450-650 °C)	Air pressure of 4 kg/cm² in the activation chamber; Activation temperature around 650 °C; activated with 1 kg/cm² steam.	Withdrawal for 2 minute within a retention period of 10 minutes		485
7	Shell charcoal with volatile content 6.2 % produced at high temperature range (500-800 °C)	Air pressure of 4 kg/cm² in the activation chamber; Activation temperature around 650 °C; activated with 1 kg/cm² steam.	Withdrawal for 1 minute within a retention period of 7.5 minutes	54	615
8	Shell charcoal with volatile content 6.2 % produced at high temperature range (500-800 °C)	Air pressure of 4 kg/cm² in the activation chamber; Activation temperature around 650 °C; activated with 1 kg/cm² steam.	Withdrawal for 1 minute within a retention period of 10 minutes		535
9	Shell charcoal with volatile content 6.2 % produced at high temperature range (500-800 °C)	Air pressure of 4 kg/cm² in the activation chamber; Activation temperature around 650 °C; activated with 1 kg/cm² steam.	Withdrawal for 2 minute within a retention period of 10 minutes		570
10	Shell charcoal with volatile content 6.2 % produced at high temperature range (450-650 °C)	Air pressure of 5 kg/cm² in the activation chamber; Activation temperature around 720 °C; activated with 1 kg/cm² steam.	Withdrawal for 0.1 minute within a retention period of 5 minutes		570
11	Coconut shell charcoal with volatile content 9.4%, produced at low temperature range (350-450 °C)	Air pressure of 6 kg/cm² in the activation chamber; Activation temperature around 850 °C; activated with 1 kg/cm² steam.	Withdrawal for 0.1 minute within a retention period of 5 minutes	50	875
12	Coconut shell charcoal with volatile content 9.4%, produced at low temperature range (350-450 °C)	Air pressure of 6 kg/cm² in the activation chamber; Activation temperature around 750 °C; activated with 2 kg/cm² steam.	Withdrawal for 0.1 minute within a retention period of 5 minutes		900

The potential of the active carbon prepared by employing the newly developed FBR for metal ion removal from solutions is reflected from the study of Ni^{2+} and Fe^{2+} ion removal from their respective solutions (Table 5). All the samples with iodine value range of >400 mg/g showed capability of metal ion removal >98% and compares quite well with that of the commercial sample from market. This shows the activated carbon from the newly developed FBR is having enough potential to use in water and liquid purification, pollution control, etc.

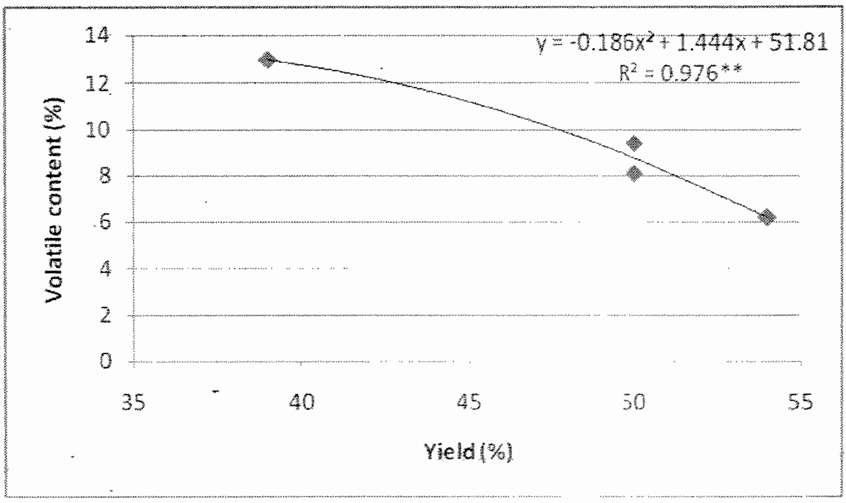


Fig 49. Variation of yield (%) of activated carbon with the volatile content (%) of charcoal

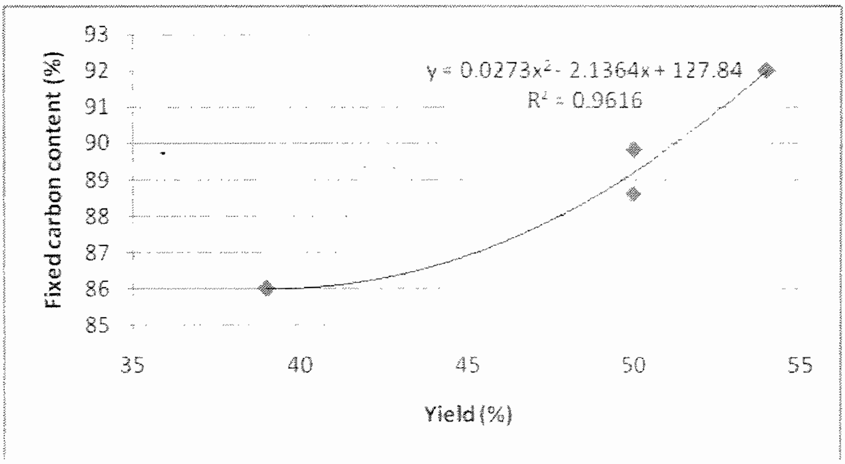


Fig. 50. Variation of yield (%) of activated carbon with fixed carbon content (%) of charcoal

Table. 5. Metal ion removal capability of active carbon produced from the FBR

Sl. No.	**Description of sample**	**Metal ions removed from solution (%)**	
		Ni^{2+}	Fe^{2+}
1	Active carbon with iodine value 900 mg/g	98.1	98.1
2	Active carbon with iodine value 615 mg/g	97.8	98.0
3	Active carbon with iodine value 420 mg/g	97.2	98.0
4	Commercial laboratory grade active carbon (BDH) with iodine value 925 mg/g	99.9	99.9

Table. 6. Yield and quality of high quality (activated?) charcoal produced without steam supply in the activation plant.

Raw material quality	Reaction condition	Retention/product withdrawal condition	Yield (%) (on OD Basis)	Quality (Iodine value, mg/g)
Coconut shell charcoal with volatile content 9.4%, produced at low temperature range (350-450 °C)	Air pressure of 6 kg/cm² in the activation chamber; temperature of activation zone around 750 °C	Withdrawal for 0.1 minute within a retention period of 5 minutes	50	860

4.2.1. Scope of coconut stem wood charcoal for producing active carbon

The coconut stem wood charcoal was not hard enough to withstand crushing into desired size grade for activation. It is getting crumbled and a major portion is getting powdered while crushing in the crusher. Due to this reason, technically it cannot be used as a raw material for activated carbon production. Even if it is suggested for use as a raw material for powder active carbon production, the present FBR technology is not the right one for dealing with powder charcoal for activation. Active powder charcoal technology is employing the chemical activation method, which is beyond the scope of community level operation, as it involves high temperature heating of the powder with activating chemicals and continued washing and drying processes, disposal of polluted waste liquor, etc. Further, the traditional raw material for powder active carbon production being saw dust and conversion of coconut stem wood into sawdust on a massive scale is not a viable proposition. In this context, coconut stem wood charcoal is proposed to be used as fuel or ingredient in fuel briquettes.

4.3. Pollution control

Table 7. Results of ambient air quality analysis

Parameter	4 Hourly reading						24 Hour average
	1	2	3	4	5	6	
SO_2	BDL	BDL	BDL	BDL	BDL	BDL	BDL
NO_x	2.5	3.5	3.0	3.7	3.7	2.5	3.15
	8 Hourly reading						24 Hour average
	1		2		3		
SPM	31.08		28.2		34.4		31.22
RSPM	9.6		10.4		12.8		10.93

SPM = Suspended particulate matter; RSPM = Respirable suspended particulate matter

Smoke production from the carbonizing and activation plants is visually recorded as minimum. The use of chimney with 15 metres height prevents any ground level smoke spread. As the plant is designed for continuous operation, once the carbonization kiln attained the burning condition, it continues to burn and there was no visible smoke production at all. Smoke is produced only when burning is affected due to clogging of raw material, which again can be rectified by allowing enough air entry by operating the air inlets provided in the plant. Pollution from the emission of volatiles or deposition of suspended particulate matter (wood tar) is controlled by igniting the same over the chimney. In this way there is no possibility of carbon monoxide (CO) production. Table 7 gives the results of the ambient air quality testing. All the values are found well below the National Standards laid down as expected. As the entire area is well covered with vegetation, the possibility of air pollution is further reduced, which may be another reason for getting the low values for the pollutants. This suggests facilitating vegetation cover around such locations.

4.4. Economics of charcoal and active carbon production potential in community level

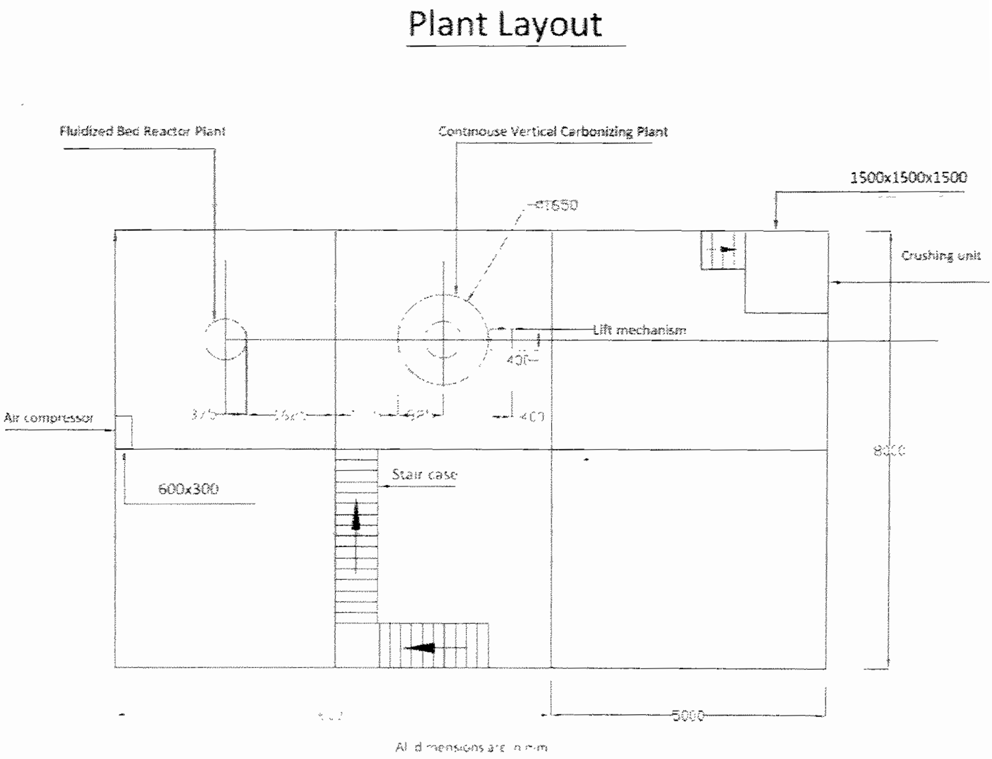
Table. 8. Project Economics.

Parameters	**Charcoal production alone**	**Activated carbon production**
Raw material cost per day (A), (Rs)	18,000	18,000
Labour cost per day (B), (Rs)	2,250	2,250
Other miscellaneous costs per day (C), (Rs)	400	400
Total variable costs per day, (D), (A+B+C), Rs	20,650	20,650
Annual income from sale, (Rs)	72,00,000	1,27,20,000
Contribution/day, (Rs)	3,350	21,750
Contribution per Tone, (Rs)	558.33	3,625
Capital Expenditure (Plant, Machineries & work shed), (Rs)	15,00,000	40,00,000
Working Capital (For 15 Days), (Rs)	2,70,000	2,70,000
Total Capital Outlay, (Rs)	17,70,000	42,70,000
Total Fixed Overheads, (Rs)	5,72,400	13,32,400
BEP , in terms of shell input capacity per year, (Tone/year)	1025	367
BEP in terms of shell input capacity/day, (Tones)	3.42	1.23
Total Cash expenses/year, (Rs)	65,42,400	69,27,400
Annual Net Cash Inflow, (Rs)	6,57,600	57,93,000
Payback period (BEP, in terms of years)	2.28	0.70
Annual Profit, (Rs)	4,32,600	51,92,600

Number of working days per year = 300; Number of shifts (8 hours) per day = 3.

The economic layout designed for saving space in the available land for installing the charcoal and activation plants is given in Fig. 51. Economics of community or cluster or small scale production of coconut shell charcoal alone showed that a plant with a minimum input capacity of above 3 tonnes will be profitable and will reach a pay back period within 2.3 years. Utilizing the shell charcoal produced for activated carbon production is-found extremely profitable (1200%) than directly selling the charcoal (Table 8). Such an active carbon plant is found reaching its payback period within a year. Detailed project economics of establishing a 6 tonne per day shell input capacity charcoal plant and utilizing the charcoal thus produced for activated carbon production by employing the newly developed FBR is detailed in Appendix II (Tables 9-14). It has been convincingly found that small scale production of coconut shell charcoal and activated carbon at the community or cluster level is extremely profitable and worth promotion for improved livelihood of the poor and marginalized coconut farmers.

Fig. 51. Layout of the charcoal and activation plant



5. CONCLUSION

Coconut shell has the potential for value addition in two ways; by converting it into charcoal and then to activated carbon. Even though charcoal production is going on mainly in the rural industry level and to some extent in the community or cluster level by employing traditional earth pit method with the associated ground level smoke spread air pollution problem, commercial scale production of activated carbon is limited to large scale industries by employing the physical steam action technology using rotary kiln. An attempt was made to develop an appropriate clean technology for production of charcoal in the community or cluster level followed by its activation by identifying and developing appropriate alternative technology that can be operated in community based organization (CBO) level. Strengthening CBOs in coconut processing sector for better sustenance and livelihood improvement of the coconut farmers, industry, and workers are the other indirect benefit that may follow the project undertaken.

The ill-fame of traditional charcoal production due to its associated pollution issue is tackled by developing a pollution controlled design of a continuous vertical carbonization plant. The pilot plant designed, fabricated, installed and trial runs conducted have shown its capability to produce charcoal in better yield and desired quality for industrial use. The plant can also be used for producing coconut stem wood charcoal; but the quality of the stem wood charcoal (especially, its poor hardness; an inherent quality of coconut stem wood charcoal) is found not suitable to use it as a raw material for activated carbon. Stem wood charcoal is suggested for use as fuel or as an ingredient in fuel briquettes. The design of the plant and technology are documented and ready for commercialization.

Fluidized bed reactor (FBR) system has been identified as the alternative clean technology for small scale production of active carbon appropriate to CBO level. A pollution free pilot plant is successfully designed, fabricated and installed; trial runs conducted, product quality analysed have shown its capability to produce granular active shell carbon in good yield, suitable for liquid phase industrial uses as per Indian Standards. The design and technology of the FBR are documented and ready for commercialization. Analysis of economic feasibility has shown that community level operated activated carbon production plant of input capacity of 3-6 tonnes shells per day is reaching its pay-back period within the first year itself, which indicates the strong potential of the up-scaled versions of the present pilot plants developed for commercial adoption.

The pilot plants developed were installed at the SUBICSHA Coconut Producer Company Limited, Perambra, Kozhikode District, Kerala for technology demonstration, trial production and training to potential entrepreneurs. The plant will be utilized by the SUBICSHA project under the control of the Coconut Development Board. M/s. Green Earth Technologies, Udumalpet, Coimbatore District, Tamil Nadu is the suggested expert firm for fabrication of the up-scaled versions of the plants.

In the light of the results of study undertaken, it is recommended to take follow-up steps for further up-scaling of the plants to increase the capacity as well as to further refine the technology by introducing required level of automation. Establishing more community level operated shell carbon production units is recommended in the context of its proven techno-economic feasibility.

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7. APPENDICES

Appendix. I. ASTM* Standards on Activated Carbon

Sl. No.	Parameter & Unit	Test Method
1	Bulk density (g/l)	ASTM D 2854
2	Hardness (%)	ASTM D 3802
3	Attrition (Abrasion)	ASTM D 5159
4	Particle size of GAC	ASTM D 2862
5	Particle size of PAC – Air jet sieving	ASTM D 5158
6	Ignition temperature	ASTM D 3466
7	Moisture content (%)	ASTM D 2867
8	Volatile content (%)	ASTM D 5832
9	Ash content (%)	ASTM D 2866
10	pH	ASTM D 3838
11	Water solubles (mg/g)	ASTM D 5029
12	Acid solubles (mg/g)	ASTM D 6385 Or, JISK 1474
13	Acid soluble iron - by AAS	ASTM D 6647
14	Iodine value (mg/g)	ASTM D 4607
15	CTC value (%)	ASTM D 3467
16	Butane working capacity	ASTM D 5228
17	Butane activity	ASTM D 5742
18	H_2S Breaking capacity	ASTM D 6646
19	Adsorptive capacity – Adsorption isotherm technique	ASTM D 3860
20	Adsorptive capacity – Micro-adsorption isotherm technique for adsorbates at ppb concentrations	ASTM D 5919
21	Gas phase adsorption testing	ASTM D 5160
22	Prediction of contaminant adsorption on GAC in aqueous systems using rapid small-scale column test	ASTM D 6586
23	Specifications for Impregnated activated carbon used to remove gaseous radio-iodine from gas streams	ASTM D 4069
24	Standard test methods for nuclear grade activated carbon	ASTM D 3803
25	Standard terminology relating to activated carbon	ASTM D 2652

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Appendix II: Economics of community level coconut shell charcoal and activated carbon production

Table 9. Arriving Income over expenditure (*contribution*) for a 6 tonne shell input capacity charcoal plant.

Expenditure (Variable cost)	**Amount (Rs)**	**Income (Selling price)**	**Amount (Rs)**
Raw material (Coconut shells @ Rs. 3000/Tone; 6 Tones/.day)	18,000	Charcoal, 2 Tone, @ Rs.12,000/Tone	24,000
Labour @ Rs. 250/ head x 3persons/shift x 3 shifts/day	2,250	Total income per day	**24,000**
Other costs	400		
Total variable costs	**20,650**		
Contribution/day (Selling price – Variable cost)			**3,350**
Contribution per Tone = Contribution per day/6			**558.33**

Table 10. Arriving Income over expenditure (*contribution*) for a 6 tonne shell input capacity activation plant.

Expenditure (Variable cost)	**Amount (Rs)**	**Income (Selling price)**	**Amount (Rs)**
Raw material (Coconut shells @ Rs. 3000/Tone; 6 Tones/.day)	18,000	Granular Active Shell Carbon, 0.8 Tone; @ Rs. 50,000/- Tone	40,000
Labour @ Rs. 250/ head x 3persons/shift x 3 shifts/day	2,250	Charcoal Powder, 0.4 Tone/day; @ Rs 6000/- Tone	2,400
Other costs	400	Total income per day	42,400
Total variable costs	**20,650**		
		Contribution/day (Selling price – Variable cost)	**21,750**
		Contribution per Tone (Contribution per day/6)	**3,625**

Table 11. Arriving fixed costs and breakeven point (BEP) for a 6 tonne shell input capacity charcoal plant.

Capital Outlay (Rs)			Fixed Overheads (Direct Expenses) (Rs)					BEP , in terms of shell input capacity per year, I (Tone/year) = Fixed OH/ Contribution per tone	**BEP in terms of input/day, J (Tones) = I/300 ***
Capital Expenditure (Plant & Machineries, Building, etc.(A)	Working Capital (For 15 Days) (B)	Total C=(A+B)	Interest @ 12% of C = D	Insurance @ 1% of A =E	Depreciation @ 15% of A=F	Administrative Expenses , G	Total Fixed Overheads H = (H+D=		
15,00,000	2,70,00	17,70,000	2,12,400	15,000	2,25,000	1,20,000	5,72,400	1025	3.42

* Number of working days/year = 300.

Table 12. Arriving fixed costs and break-even point (BEP) for a 6 tonne shell input capacity activation plant.

Capital Outlay (Rs)			Fixed Overheads (Direct Expenses) (Rs)					BEP , in terms of shell input capacity per year, I (Tone/year) = Fixed OH/ Contribution per tone	BEP in terms of input/day, J (Tones) = I/300 *
Capital Expenditure (Plant & Machineries, Building, etc.(A)	Working Capital (For 15 Days) (B)	Total C=(A+B)	Interest @ 12% of C = D	Insurance @ 1% of A =E	Depreciation @ 15% of A=F	Administrative Expenses , G	Total Fixed Overheads H = (H+D=		
40,00,000	2,70,00	42,70,000	5,12,400	40,000	6,00,000	1,80,000	13,32,400	367	1.23

* Number of working days/year = 300.

Table. 13. Arriving Payback period and profitability for a 6 tonne shell input capacity charcoal plant.

Description	**Quantity**
Annual income from sale (Rs) = Per day income from sales x Number of working days	24,000 x 300 = Rs. 72,00,000/-
Cash Expenses: (a) Variable Costs per year (Variable cost/day x Number of working days) (b) Cash Fixed Overheads (Fixed Overheads – Depreciation)	 20,650 x 300 = 61,95,000/- 5,72,400 – 2,25,000 = 3,47,400/-
Total Cash expenses = Variable costs (a) + Cash Fixed Overheads (b)	61,95,000 + 3,47,400 = 65,42,400/-
Annual Net Cash Inflow = Annual income from sale - Total cash expenses	72,00,000 – 65,42,400 = 6,57,600
Payback period = Capital Expenditure/Annual Net Cash Inflow	15, 00,000/6, 57,600= 2.28 Years.
Profitability	
Annual Input = Per day input x Number of working days/year	6 x 300 = 1,800 Tone shell/Year
Annual contribution = Contribution per day x Number of working days	3,350 x 300 = Rs. 10,05,000
Fixed Overheads	5,72,400/-
Annual Profit = Annual contribution - Fixed Overheads	10,05,000 - 5,72,400 = Rs. 4,32,600/-

Table. 14. Arriving Payback period and profitability for a 6 tonne shell input capacity activation plant.

Description	**Quantity**
Annual income from sale (Rs) = Per day income from sales x Number of working days	42,400 x 300 = Rs. 1,27,20,000/-
Cash Expenses: (a) Variable Costs per year 9 Variable cost/day x Number of working days) (b) Cash Fixed Overheads (Fixed Overheads – Depreciation)	 20,650 x 300 = 61,95,000/- 13,32,400 – 6,00,000 = 7,32,400/-
Total Cash expenses = Variable costs (a) + Cash Fixed Overheads (b)	61,95,000 + 7,32,400 = 69,27,400/-
Annual Net Cash Inflow = Annual income from sale - Total cash expenses	1,27,20,000 - 69,27,400 = 57,92,600/-
Payback period = Capital Expenditure/Annual Net Cash Inflow	40, 00,000/57, 92,600= 0.69 Years.
Profitability	
Annual Input = Per day input x Number of working days/year	6 x 300 = 1,800 Tone shell/Year
Annual contribution = Contribution per day x Number of working days	21,750 x 300 = Rs 65,25,000/-
Fixed Overheads	13,32,400/-
Annual Profit = Annual contribution - Fixed Overheads	65,25,000 - 13,32,400 = Rs. 51,92,600/-

Appendix III: Approximate cost of the pilot plants

In 2006: for a 3 tonnes per day shell input capacity charcoal plant: Rs 6.5 Lakhs

FBR Activation plant, 0.25 tonne per day charcoal input capacity; Rs. 12.0 Lakhs

In 2009: for a 6 tonnes per day shell input capacity charcoal plant: Rs 9.0 Lakhs

FBR Activation plant, 2.0 tonnes per day charcoal input capacity; Rs. 13.0 Lakhs.