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Production of Activated Carbon from Coconut Shells

Vanshika Poray[1], Sharvari Raut[2], Sudiksha Hegde[3] and Dr. S. J. Purohit[4]

Thadomal Shahani Engineering College, Mumbai – India[1-4]

Abstract: Apart from being natural and eco-friendly, we plan to manufacture activated carbon from coconut shells – energy saving process. Activated carbon is a form of carbon having low pore volume and good surface area imparting it great adsorptive properties. Its applications are abundant and hence the demand is high. The conventional method of producing activated carbon is Pyrolysis of coconut shells and the Activation of char. In our method of preparation, we plan on using a fluidized bed reactor due to its superlative mass and heat transfer properties compared to the other conventional reactors. In our paper we aim to give details about activated carbon from coconut shells and simulate some equipments with DWSIM. We plan to focus on the process' process flow diagram, equipment design, cost estimation, and applications of all the products and by-products. This method of manufacture promises high returns while being environmentally cautious.

Keywords: Activated Carbon, Pyrolysis, Activation

1. INTRODUCTION

Activated carbon (or Activated charcoal) is a crude form of graphite where the difference between the two is that the activated carbon has a random and defective structure which is extremely porous over a broad range of pore sizes from visible cracks and crevices to molecular dimensions. The graphite structure provides the abundant surface area to the activated carbon which allows the carbon to adsorb a wide range of compounds. Activated carbon is known to have the strongest physical adsorption forces, or the greatest volume of adsorbing porosity. Activated carbon can have a surface of greater than 1000m²/g. This implies that 3 grams of activated charcoal can have the surface area of a football field.
Activated charcoal is a powerful adsorbent used to purify a broad spectrum of pollutants in air, water and soil. It has odourless, tasteless and non-toxic characteristics and can be prepared from any carbonaceous material using physical or chemical activation methods. Typically, activated carbon is made from coal. But given the non-renewable nature of this material, manufacturers are looking for other resources of carbon, such as carbonaceous agricultural by-products, to prepare activated carbon. It can be made from many substances containing a high carbon content such as coal, coconut shells and wood. The raw material has a very large influence on the characteristics and performance of the activated carbon.
Activated carbon has around 100 different types, but the 3 main types that are most commonly seen are the following:

- **Powdered activated carbon**
- **Granular activated carbon**
- **Activated carbon rods**

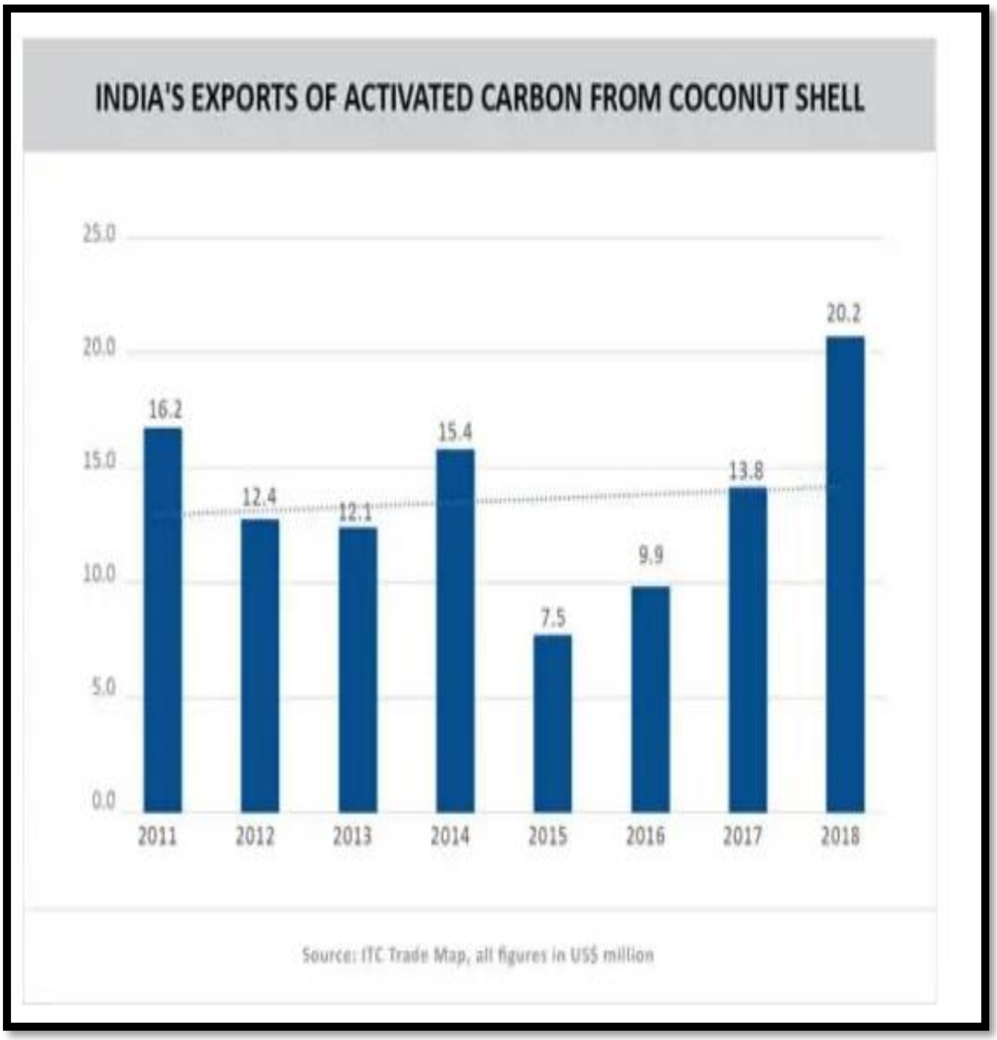
2. MARKET RESEARCH

Recently, Markets and Markets, a renowned market research firm, announced the publication of a comprehensive global report on the Activated Carbon market. The global activated carbon market is estimated to be USD 5.7 billion in 2021 and is projected to reach USD 8.9 billion by 2026, at a compound annual growth rate of 9.3% from 2021 to 2026, fueled mostly by the predicted surge in demand for activated carbon in the United States. The activated carbon market is dominated by a few globally established players, such as Osaka Gas Co., Ltd. (Japan), Cabot Corporation (US), Kuraray Co. Ltd. (Japan), Haycarb Plc (Sri Lanka), and Kureha Corporation (Japan) among others.
Activated carbon is in significant demand in the United States, the United Kingdom, Germany, Japan, and South Korea, where it is mostly used to purify gold, water, and air. Activated carbon imports are predicted to surpass US$ 3 billion by 2022, owing to its effectiveness as a purifier. The focus will gradually shift to developing markets in the future, driven by China and India in Asia, Latin America, and the Middle East. Activated carbon is widely employed in the refining and bleaching of vegetable oils and chemical solutions, as well as in water purification, solvent and other vapour recovery, gold recovery, and gas masks. for hazardous gas protection, in filters to provide suitable protection against war gases/nuclear fallouts, and so on. India's activated carbon export was 16.2 in 2011 and rose to 20.2 million US$ in 2018.

3. PROCESS SELECTION PARAMETERS

Activated carbon has high demand predominantly due to its high adsorptive properties which aid to purify water and air. It is used to absorb several unwanted components. The adsorptive property of activated carbon is mainly due to its pore size and volume; hence this factor plays a vital role. Activated carbon can be manufactured using various raw materials like bituminous coal, wood or coconut shells. The type of raw material used to produce activated carbon has a major impact upon its pore size characteristics.
There are chiefly three types of pore sizes:
i. micropores- pore size of less than 2 nanometre
ii. mesopore- pore size between 2 to 50 nm
iii. macropore- pore size more than 50 nm

Activated carbon produced from bituminous coal has few micropores and mainly mesopores and macropores, thus reducing its ability to strain out smaller particles. Activated carbon produced from wood also mainly has mesopores and macropores. Though it has better adsorptive index compared to coal-based activated carbon, it is still restricted for its usage in adsorbing larger particulates. It is less ideal for higher-grade filtration. Activated carbon produced from coconut shells has a high density of micropores and fewer mesopores and macropores, therefore it is more efficient to filter out finer contaminants. These also have a tight structure and minimal ash content.
Moreover, coconut shells are green raw materials, which are easily and abundantly available as waste products from other industries. Their disposal is costly and may cause environmental problems, hence they are excellent raw materials. Wood is a renewable commodity, but not easily available (since one tree takes years to grow). Coal is the most unfavorable out of the three, as it is a non-renewable source and is very expensive. Hence, we choose coconut shell-based production of activated carbon as it has the best adsorptive index and is a very cheap raw material.



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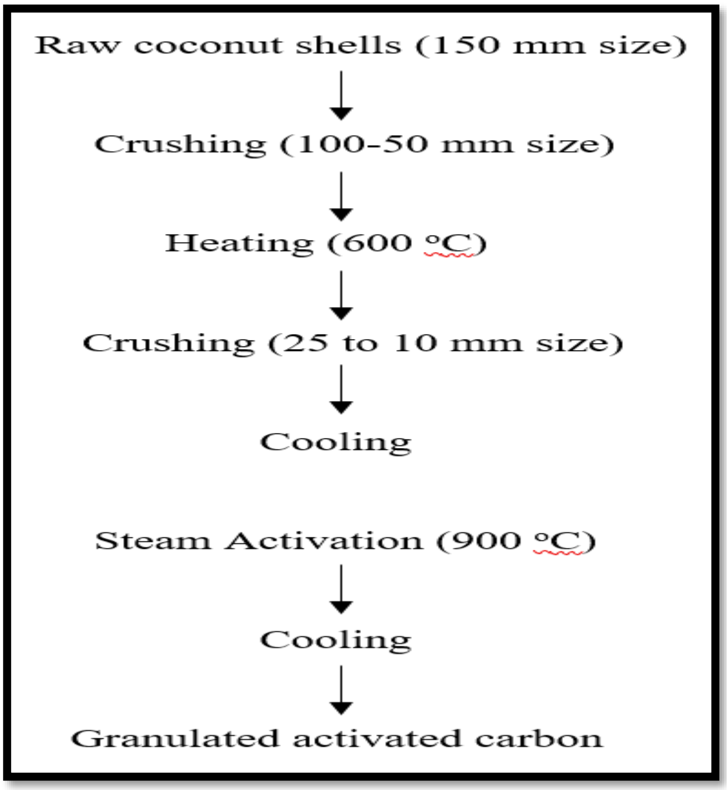
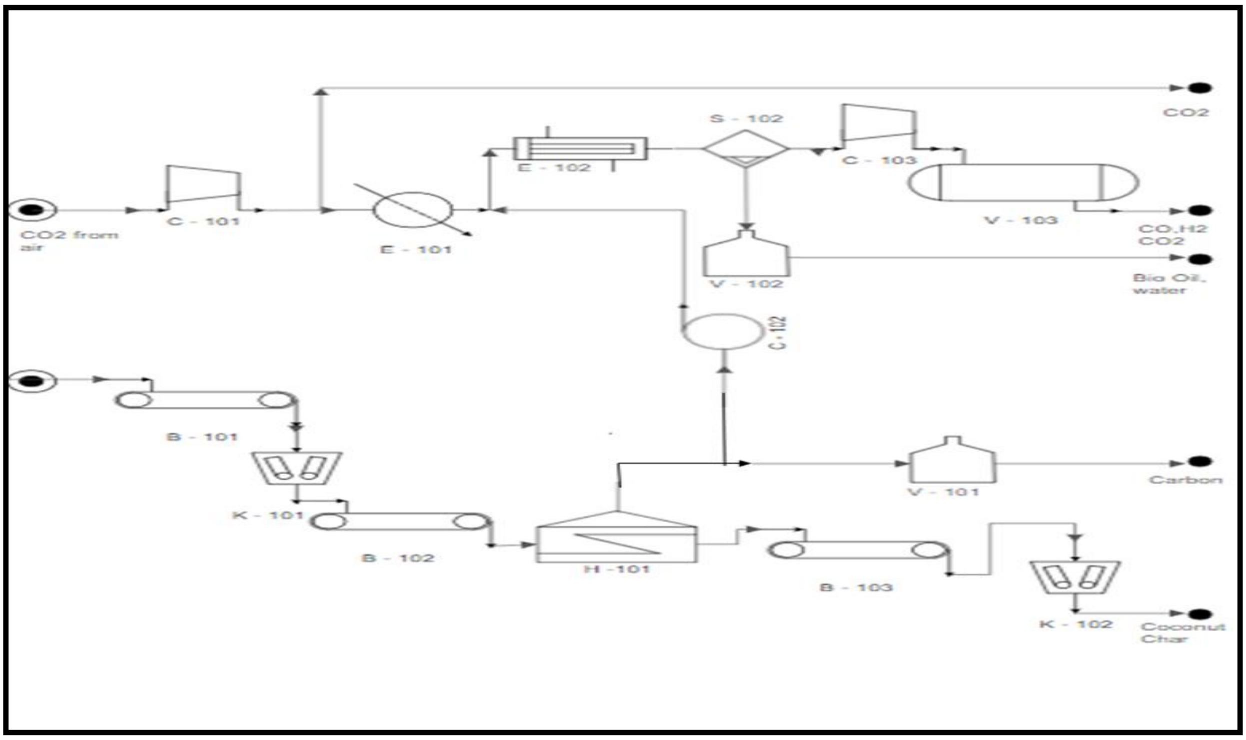
Process Flow Chart



4. PROCESS FLOW DIAGRAM

Pyrolysis



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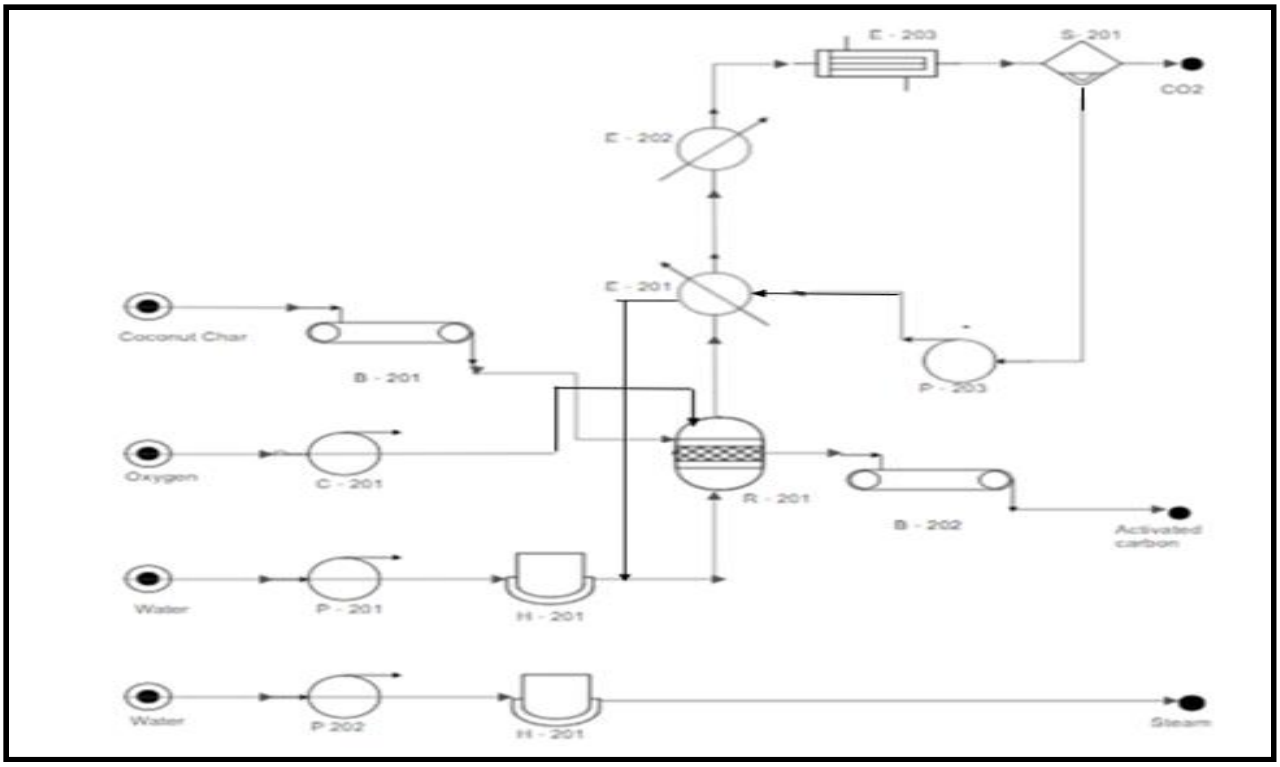
Activation



5. PROCESS DESCRIPTION

There are two main processes involved namely carbonization and chemical activation. Carbonization is the process of converting biomass into char using pyrolysis and chemical activation is conversion of char into activated carbon with more pores. Our main raw material for the process is coconut shells. In the first step coconut shells are degraded, i.e, de-polymerization after which the monomers rearrange forming biochar.

The process of pyrolysis of coconut shells consists of two operations occurring simultaneously.

In the pyrolysis stage, the coconut shells are initially brought in through a conveyor belt and passed on to the jaw crusher to reduce the size of the shells to about 100- 50mm shards. Then another conveyor belt transports these bits to a heating furnace and heating is done at 600°C increasing the temperature gradually.

It is then kept in the furnace for two hours for pyrolysis at a constant temperature of 600°C.

In the second section, a physical activation process converts the char to activated carbon. When the pyrolysis reaction is completed, the char is transferred to a crusher to reduce its size. The reduced char is then transported to the fluidized bed reactor which is the main activation stage of the plant. The coconut char is heated to 900°C. The char then reacts with steam to produce activated carbon. At this point, the coconut char consists entirely of elemental carbon, and some of the carbon reacts with water to produce carbon monoxide and hydrogen gas. The gas escapes from the solid char, leaving behind pores in the carbon solid. The endothermic carbon-steam reaction takes place in the reactor.

6. EQUIPMENT DESIGN

Heat Exchangers E-101 and E-202 were simulated on DWSIM to find their area as well as other factors such as equipment design data and heat load. Both the heat exchangers are shell and tube type heat exchangers

E- 101

E- 202

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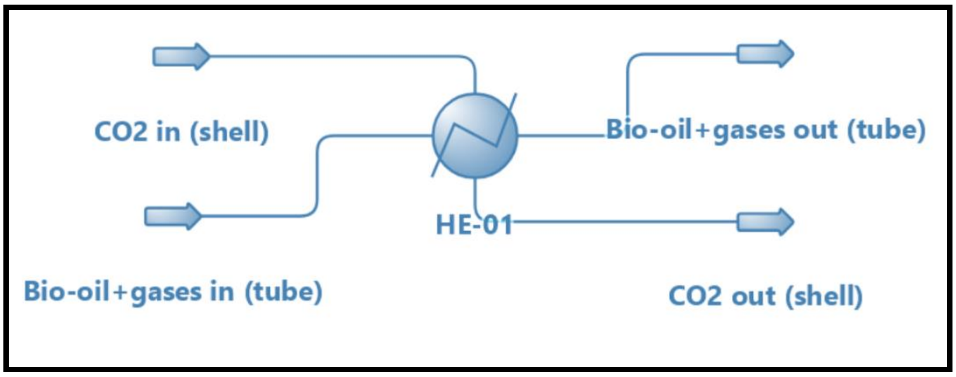
Heat Exchange Area (A)	44.2847	m2
Heat Load	260.552	kW
Cold fluid outlet temperature	30	C
Hot fluid outlet temperature	110.586	C
[Shell and Tube] Internal Shell Diameter	500000	mm
[Shell and Tube] Baffle Cut	20	%
[Shell and Tube] Baffle Spacing	250000	mm
[Shell and Tube] Internal Tube Diameter	50000	mm
[Shell and Tube] External Tube Diameter	60000	mm
[Shell and Tube] Tube Length	5	m
[Shell and Tube] Number of Tubes	50	
[Shell and Tube] Tube Pitch	70000	mm
Logarithmic mean temperature difference LMTD	98.0594	C.

Heat Exchange Area (A)	64.0113	m2
Heat Load	396.635	kW
Cold fluid outlet temperature	600	C
Hot fluid outlet temperature	567.678	C
[Shell and Tube] Internal Shell Diameter	500000	mm
[Shell and Tube] Baffle Cut	20	%
[Shell and Tube] Baffle Spacing	250000	mm
[Shell and Tube] Internal Tube Diameter	50000	mm
[Shell and Tube] External Tube Diameter	60000	mm
[Shell and Tube] Tube Length	5	m
[Shell and Tube] Tube Passes Per Shell	2	
[Shell and Tube] Number of Tubes	50	
[Shell and Tube] Tube Pitch	70000	mm
Logarithmic mean temperature difference LMTD	206.544	C.
Thermal Efficiency	90.3219	%
Maximum Theoretical Heat Exchange	439.134	kW

Fired Heater

The fired heater is utilized in the pyrolysis process to burn the coconut shells at 600 C and char them to obtain our inactivated carbon char. It is made out of stainless steel to account for the corrosive nature of the gases. The fired heater is horizontal cyclindrical in shape and has a big rotating mixer inside it to ensure that all the coconut shards recieve uniform heat to pyrolyze and form char.



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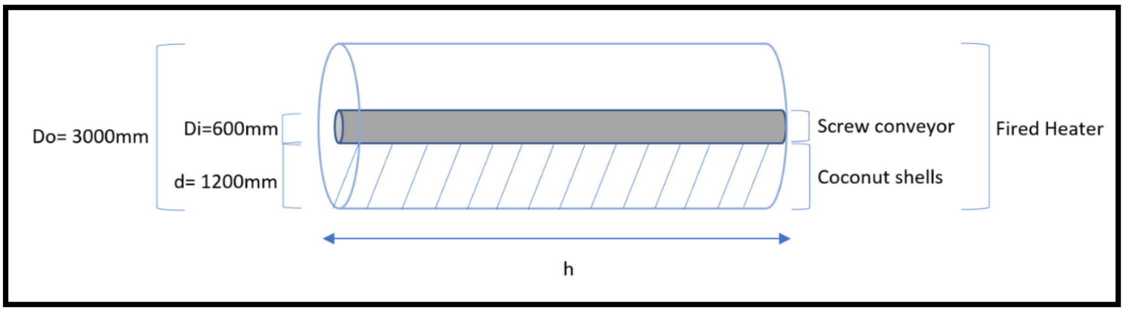

The following data is obtained and assumed to calculate the dimensions of the equipment. To find length of fired heater according to volume of coconut shells processed:

V = 9.54375 m3, r = 0.6 m h = ?

Using volume of cylinder: V= pi*r^2*h h = 8.443 m ≈ 8.5 m

Density of coconut shell	1600 kg/m^3
Mass of coconut shells/batch	15270 kg/batch
1 batch consists of	2.5 hours
Volume of coconut shells/batch	9.54375 m^3

Dimensions:		
Outer diameter, D_o	3000 mm (Assumed)	3 m
Inner diameter, D_i	600 mm (screw conveyor diameter)	0.6 m
D_o-D_i	2400 mm	2.4 m
Diameter of section where coconut shells process, d	1200 mm (refer above diagram)	1.2 m
Radius of section where coconut shells process, d/2	600 mm	0.6 m

Equipment Cost

Equipment costs are calculated with reference to theory from Seider. Below values are obtained from literature. Refer PFD for equipment codes.

Sr. No.	Code	Description	Seider ($)	Conversion to Rs
1	B – 101	Crusher Conveyor Belt	13413	41312.04
2	K – 101	Crusher	11723	36106.84
3	B -102	Furnace Screw Conveyor	1341	4130.28
4	H – 101	Furnace	4520058	13921778.64
5	B – 103	Char Screw Conveyor	13778	42436.24
6	E – 101	Bio-Oil Cooler	176882	544796.56
7	V – 101	Carbon Vessel	523128	1611234.24
8	E – 102	Bio-Oil Condenser	122446	377133.68
9	K – 102	Ball Mill	2815	8670.2
10	V – 102	Bio-Oil Storage Vessel	995377	3065761.16
11	C – 102	Volatiles Blower	1985435	6115139.8
12	S – 101	Gravity Separator	7531	23195.48

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13	P-201, P-202, P-203	Water Pump	20989	64646.12
14	B – 201	FBR Conveyor Belt	13778	42436.24
15	H – 201	FBR Boiler	114194	351717.52
16	H – 202	FBR Cooling Jacket	941903	2901061.24
17	R – 201	Fluidized Bed Reactor (FBR)	2552341	7861210.28
18	E – 201	Boiler	233785	720057.8
19	E – 202	Cooler	45434	139936.72
20	E – 203	Water Condenser	56872	175165.76
21	B – 202	AC Conveyor Belt	8612	26524.96
22	S – 201	Gravity Separator	402631	1240103.48

Total = Rs. 3.93 crores

Cost & Investment
Direct Plant Cost

Component	% of purchased equipment	Cost (Rs.)
Purchased equipment	E	39314555.28
Purchased equipment instalation	40%	15725822.11
Instrumentation and control	50%	19657277.64
Piping	30%	11794366.58
Electrical system	10%	3931455.528
Land	6%	2358873.317
Yard improvement	10%	3931455.528
	Total=	**Rs. 9.67 crores**

Indirect Plant Cost

Component	% of purchased equipment	Cost (Rs.)
Engineering Supervision	10%	69693984.36
Construction Expenses	10%	69693984.36
	Total =	**Rs. 13.93 crores**

Total Direct and Indirect Cost(D+I) = 96713805.9 + 139387968.7
= Rs 10.45 crores

Contractor’s fee	5%(D+I)	5228835.852
Contingency	10%(D+I)	10457671.7
	Total=	Rs. 1.56 crores

Fixed Capital Investment
FCI = Total direct plant cost + Total indirect plant cost
= 15686507.56 + 104576717
= Rs 12.02 crores

Working Capital Investment
WCI = 0.15 × FCI

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= 0.15 × 120263224.6
= Rs. 1.80 crores

Total Capital Investment
TCI = FCI +WCI
=120263224.6 + 18039483.69
= Rs. 13.83 crores

Total Production Cost
Direct Production Cost

MATERIAL	QUANTITY (ton)	RATE (Rs.)	Cost (Rs.)
cocunut Shells	13742871	6	8.24 crores

Manufacturing Cost
Operating Labour Cost

Position	No. of	Salary per person	total salary (Rs.)
General Manager	1	420000	420000
Engineer	3	15000	45000
Supervisor	4	12000	48000
Skilled workers	5	8000	40000
Unskilled workers	6	4000	24000
Clerks	4	4000	16000
		Total	Rs. 5,93,000

Total labour cost = Rs. 5,93,000

Component	% of FCI	Cost (Rs.)
Total labour cost	TLC	593000
Supervision charge	5	6013161.23
R&D & laboratory	25	30065806.15
Maintenance & repair	5	6013161.23
Utility	10	12026322.46
TOTAL		5.47 crores

Direct Production Cost
Direct product cost = Total raw material cost+ Total mfg. cost
= 8245726 + 54711451.07
= **Rs 13.71 crores**

Fixed Charges
Depreciation
On building & civil structure (5%FCI) = Rs. 60.13 lakhs
On plant and machinery(5%FCI) = Rs. 60.13 lakhs

Taxes (1.5 % FCI) = Rs. 18.03 lakhs
Insurance (1 % FCI) = Rs. 12.02 lakhs

Total fixed charges = Rs. 1.50 crores
Distribution & marketing cost (10% FCI) = Rs. 1.20 crores
Total production cost = Direct production cost +Total fixed charges +Distribution and marketing cost

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=137168677.1 + 15032903.08 + 12026322.46
= **Rs. 16.4 crores**

Estimation of Profit and Payback Period
Product = Activated Carbon
Quantity product = 20,40,816 Kg
Price / Kg = 140
Cost of product / year = Rs 28.57 crores

Product = Bio-oil
Quantity product = 8,70,300
Price / kg = 70
Cost of product / year = Rs 6.09 crores

Total Annual Sales = 285714240 + 60921000
= Rs 34.66 crores

Income Tax = 40% Gross Profit
= Rs. 13.86 crores

Net Profit = Gross Profit - Income Tax
= Rs 20.79 crores

Payout period = FCI / (Net profit +depreciation)
= 0.539 years
= **6.4 months**

Rate of Return on Investment = Net profit/FCI
= **1.729**

Since the Rate of Return is 1.729, the process is economically viable.

8. APPLICATIONS

Activated carbon is used in a wide range of industrial applications like gas and air cleaning involving traditional reusable substance recovery applications. The selection of the most suitable type of activated carbon for a specific application depends on the physical and chemical properties of the substances to be adsorbed. Growing environmental awareness and the enforcement of strict emissions guidelines has led to the development of new applications in the area of air pollutant removal. It has a wide range of applications and is also used in the treatment of water, including drinking water, groundwater, service water and wastewater. Its principle role in this context is to adsorb dissolved organic impurities and to eliminate substances affecting odour, taste and colour in halogenated hydrocarbons and other organic pollutants. Another broad field of application for activated carbon is the treatment, purification and decolourization of liquids in the pharmaceuticals, food, beverage and other industries.

9. CONCLUSION

Since the process yields were adapted from available literature, they should be quite accurate. However, because the heat and mass transport parameters of the reactors do not remain constant as the reactor scales up, there ma y be some unpredictability. Since a constant flow rate of water and other process streams is assumed, the flow rates of the pump, conveyer belt, and compressor may be incorrect. As a result, the genuine flow rates experienced by some of the equipment are significantly higher than the stream tables' time-averaged flow rates. The revenue earned by distributing the activated carbon created is fairly accurate since it is computed using the market price of commercially manufactured activated carbon. However, because the activated carbon was priced using the finest quality carbon sold, there may be some variation in actual revenue. The nonlinear correlation between process parameters during scale-up from laboratory-scale equipment to commercial-scale equipment is a possible source of inaccuracy in process design and computations. As previously stated, the process parameters are derived from lab-scale research, which may or may not be applicable once scaled up. However, because data on commercial-scale systems is scarce, a simple geometric scale-up is employed.

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