Biyani's Think Tank

A concept based exclusive material

Energy Resources and Utilization

B.Sc. (Biotechnology)
Part-I

Rajneesh Kumar Mishra
M.Sc.
Lecturer
Deptt. of Science
Biyani Girls College, Jaipur

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Sector-3, Vidhyadhar Nagar,
Jaipur-302 023 (Rajasthan)
Ph : 0141-2338371, 2338591-95 • Fax : 0141-2338007
E-mail : acad@biyanicolleges.org
Website :www.gurukpo.com; www.biyanicolleges.org

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Preface

I am glad to present this book, especially designed to serve the needs of the students. The book has been written keeping in mind the general weakness in understanding the fundamental concepts of the topics. The book is self-explanatory and adopts the "Teach Yourself" style. It is based on question-answer pattern. The language of book is quite easy and understandable based on scientific approach.

Any further improvement in the contents of the book by making corrections, omission and inclusion is keen to be achieved based on suggestions from the readers for which the author shall be obliged.

I acknowledge special thanks to Mr. Rajeev Biyani, *Chairman* & Dr. Sanjay Biyani, *Director* (*Acad.*) Biyani Group of Colleges, who are the backbones and main concept provider and also have been constant source of motivation throughout this Endeavour. They played an active role in coordinating the various stages of this Endeavour and spearheaded the publishing work.

I look forward to receiving valuable suggestions from professors of various educational institutions, other faculty members and students for improvement of the quality of the book. The reader may feel free to send in their comments and suggestions to the under mentioned address.

Author

Syllabus
B.Sc. (BT) Part-I
301 : ENERGY RESOURCES AND UTILIZATION

Section A

Introduction : Nature : Crude and Bio-Crude; Synthetic Fuels and their Manufacture; Bio-Fuels and their Synthesis; History Properties of Coal; Agriwaste as Bio-Fuels; Briqueting.

Environmental Audit : Carbon Sequestration, Carbon Credits.

Section B

Gas from Coal : Gasification Technologies; Steam / Oxygen and Steam /Air Gasification; Hydro-Gasification and Catalytic Gasification; Underground Gasification.

Bio-Fuels : Biomass Production, Bio-Fuel Resource Production and Improvement of Bio-Fuels, Solid, Liquid Bio-Fuels, Hydrocarbons from Plants, Bio-Diesel, Bio-Ethanol, Non-Edible Oils as Bio-Fuel Resources, Euro I, II, III Standards of the Fuels.

Section C

Conversion Fundamentals : Pyrolysis including Vacuum Pyrolysis; Gasification, Gas Shift and synthesis; Direct Liquefaction; Comparison of Synthetic Fuel and Bio-Fuels.

Conversion : Ethanol Production Technologies; Bio-Chemical Conversion; Thermal Conversion; Catalysts : Environmental Aspects – Environmental Effects and their Measure; Air Pollution Control; Water Management; Solid Waste Disposal.

Section D

Economic and Perspective : Large Scale Production and Conversion Technology for the Bio-Fuel Resources; Bio-Refineries; Economic Considerations; Resource,

Process and Product Consideration; Industrial Furnaces used in Chemical Process Industry. Fuels for the Future; Hybrid Fuels and Economy.

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Content

4.2 Biorefineries

4.3 Industrial Furnaces

4.4 Future Fuels

4.5 Hybrid Fuels

B.Sc./M.Sc.(Pt.I)
8003-BT-301 **Biotech. I**

B.Sc./M.Sc. (Part I) EXAMINATION, 2008
(FACULTY OF SCIENCE)
(Common to Three and Five Year Integrated Course)

BIOTECHNOLOGY
PAPER BT - 301
(Energy Resources and Utilization)

TIME ALLOWED : THREE HOURS
Maximum Marks – 580

Question No.1 is compulsory. Answer Five questions in all, selecting at least one question from each section

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1 Write the following question in short -

(i) Write two names of hydrogen producing (biohydrogen) plants.
(ii) Biodiesel is produced from which plant?
(iii) What substrates are used to produce bioethanol?
(iv) For maximum methane production what is the most suitable C : N ratio of substances?
(v) Name microorganism which is used to produce biobutanol?
(vi) What is fossil fuel?
(vii) Give an example of hybrid fuel.
(viii) Write name of plant which can be used in production of biogas.
(ix) What do you call a fuel when it is derived from the biomass?
(x) Euro norms had been implemented for the first time in which country and for what purpose?
(xi) Which technology is used for briquetting?
(xii) What is coal tar?
(xiii) Define synthetic fuel.
(xiv) What is gasohol?
(xv) Define coal.
(xvi) Write the products of pyrolysis.
(xvii) What is charcoal?
(xviii) Name the raw materials used in pyrolysis.

(xix) Give the full form of B.O.D.

(xx) What are fuel cells?

SECTION - A

2 What is carbon sequestration? Describe novel techniques for long term sequestration of carbon in various ecosystems.

3 Define agriculture waste. Write techniques to convert them into biofuels.

SECTION - B

4 Describe the production of gas from coal using various gasification technologies.

5 Write notes on –

(i) Hydrocarbons from plants

(ii) Bioethanol production

SECTION - C

6 Enumerate the various methods commonly employed for the disposal of solid wastes. Discuss the importance of recycling in solid waste management.

7 Discuss air pollution control measures. Give an account of the remedial steps taken by the Indian Government.

SECTION - D

8 Explain the following in detail –

(i) Hybrid fuels

(ii) Biorefineries

9 Describe conversion technology for production of biofuel on large scale. Discuss its economic perspective in comparison to traditional.

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SECTION-A

Introduction & Environmental Audit

Q.1 Give the Historical Properties of Coal.

Ans.: Coal is a fossil fuel extracted from the ground by underground mining or open-pit mining. It is a readily combustible black or brownish-black sedimentary rock.

Early History : The word "coal" came from the Anglo-Saxon ccl, which meant charcoal, but archaeological evidence demonstrates a history of use for much longer. Out crop coal was used in Britain since the Bronze Age where it was detected as forming part of the composition of funeral pyres.

Carbon is formed more than 50% by weight and more than 70% by volume of coal.

Origin of Coal : Dicrhodium fern fossils is drillcore Surat Basin, Queensland from silt parting in coal beds forrelised plant material implies this coal formed around plants.

Types of Coal :

i) **Lignite :** It is also referred to as brown coal, is the lowest rank of coal.

ii) **Sub-bituminous Coal :** Whose properties range from those of lignite to those of bituminous coal & are used primarily as fuel for steam electric power generation.

iii) **Bituminous coal :** It is a dense coal, usually black sometimes dark brown, often with well defined bonds of bright and drill material used for electric generation.

iv) **Anthracite :** The highest rank, used primarily for residential and commercial space heating.

Q.2 What is Nature Crude & Biocrude?

Ans.: **Biocrude : Biocrude** oil is produced by the thermal decomposition of solid biomass under heat and pressure in the absence of oxygen. It is also called "Pyrolysis oil". It is under investigation as substitute for petroleum. It is produced out of dried biomass in a reactor at temperature of about 500^0C and cooled immediately within 1-2 seconds. The produced heat is transferred to dry the biomass.

The biomass is split into solid liquid and gaseous components under the influence of heat only (anhydrous pyrolysis). The produced charcoal may be used for heating the process or as activated carbon in absorption processes. The gas consisting of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2) and methane (CH_4), may be burned but the condensable gases have to be kept gaseous until the combustion. The heating value is 15-202 MJ/m3, which is much lower than natural gas.

Natural Crude : Oil produced by the thermal decomposition of solid fossilized organisms under heat and pressure and in the absence of oxygen is called natural crude. It is nonrenewable. Example – petroleum, diesel.

Q.3 What is Synthetic Fuel?

Ans.: Synthetic fuel or Synfuel is a liquid fuel. Obtained from natural gas or biomass. It can sometimes refer to fuels derived from other solids such as oil shale, tar sand, waste plastics or from the fermentation of biomatter.

Process of producing synthetic fuels are three types -

i) CTL (Coal to Liquids)

ii) GTL (Gas to Liquids)

iii) BTL (Biomass to Liquids)

Depending on the initial feed stocks the best known process of synthesis is the –

(a) Fisher Tropasch Synthesis

Others are -

(b) Bergius Process

(c) The Karrick Process

Fisher Tropasch Process (FTP) : In FTP synthetic fuels are made from ethanol, methanol etc.

Original Process : $(2n + 1)\ H_2 + 2C_n \rightarrow C_nH_{2n+2} + H_2$

H2 & CO can be derived from : $CH_4 + \frac{1}{2}O_2 \rightarrow 2H_2 + CO$

**** It is most commonly used process.***

Bergius Process : In this process lignin is added with heavy oil & catalysed by nickel or tungsten which further gives mixed oil, light oil or gasoline.

Karrick Process : In this process materials are brushed in the absence of air at 270^0C – 680^0C temperature and we get gasoline as a main product.

Material

↓

Burnt in the absence of air at 680^0C

↓

Gasoline is produced

We also use destructive distillation process by which we get coal and from it we produce synthetic fuel.

Q.4 What is Biofuel?

Ans.: Biofuel is a fuel that is derived from biomass. It is a renewable energy source, unlike other natural resources such as petroleum, coal & nuclear fuels.

Biofuel is any fuel with 80% minimum content by volume of materials derived from living organisms harvested within the ten years preceding its manufacture.

Examples : Liquid biofuels – bio-ethanol, bio-diesel

Gaseous bio-fuels – biogas

Solid bio-fuels – processed wood etc.

Q.5 What is Briquetting?

Ans.: **Briquetting in General :** Briquetting is a process where some type of material is compressed under high pressure.

Example : if the raw material is wood the lignin content of the wood is liberated under high pressure thus binding the material into a briquette.

Q.6 What is Carbon Credits & Carbon Sink?

Ans.: **Carbon Credit :** Carbon credits are measured in units of certified emission reductions (CERs). Each CER is equivalent to one tonne of carbon dioxide reduction. India has emerged as a world leader in reduction of greenhouse gases by adopting clean development mechanisms (CDMs) in the past two years.

Carbon Dioxide Sink or Carbon Sequestration : Carbon sequestration is the term describing processes that remove carbon from the atmosphere.

There are two **methods for removal of carbon dioxide -**

(i) **Natural Sinks :**

(a) Forests

(b) Oceans

(c) Soils

(ii) **Artificial Sequestration :**

(a) Carbon capture

(b) Oceans

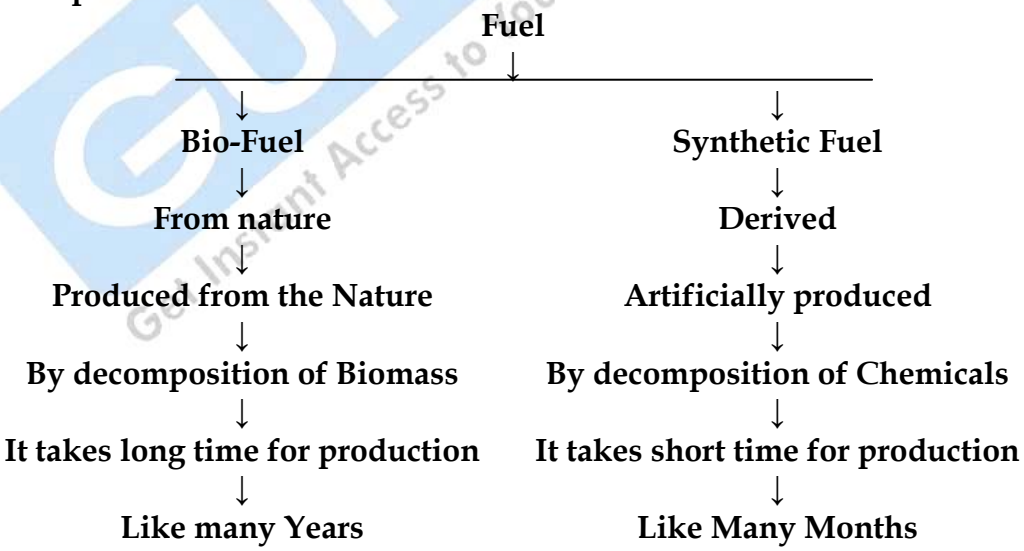
(c) Geological sequestration

(d) Mineral Sequestration

Q.7 What is the difference Between Biofuel & Synthetic Fuel?

Ans.: Biofuel is a biological component which are used as fuel where as synthetic fuel has no biological synthetic cells made up providing energy as fuel.

Comparison :



Comparison between Bio-fuel & Synthetic Fuel:

S.No.	Biofuel	Synthetic Fuel
(i)	Obtained from biological sources like crops e.g., wheat, maize, corn etc.	Obtained from the non-biological sources like fossil fuels e.g., coal & coke etc.
(ii)	The product of the biofuel is the $CO_2 + H_2O$.	The product of the synthetic fuel is the synthetic gas which is $CO+H_2$.
(iii)	Occurs in the solid, liquid and gas forms.	Occurs only in the liquid form
(iv)	It is environment friendly gas.	It is not an eco-friendly process. The reaction is $C+H_2O \rightarrow CO + H_2$
(v)	Biological processes are involved.	Chemical processes are involved.
(vi)	Does not involve very high temp.	Involves very high temperature.
(vii)	Involves micro organisms like Yeast, Amoeba etc.	Does not require the use of the micro organisms.
(viii)	Less toxic for the environment.	More toxic for environment.

□ □ □

SECTION-B

Gas from Coal & Bio-Fuels

Q.1 What is Gasification?

Ans.: Gasification is a thermo-chemical conversion process in which fossil fuel & biomass are converted into gaseous fuels.

Gasification is a process in which high density substrate is converted into low density product & low energy containing substrate is converted in high energy containing product.

Q.2 What is Biomass?

Ans.: Biomass are recently living organisms or their metabolic byproducts such as manure from cows/cattles.

Biomass is a renewable energy source, unlike other natural resources such as petroleum, coal & nuclear fuels.

Biomass is used as fuel often consists of underutilized type like chaff & animal waste.

Q.3 What is Renewable Energy Resources?

Ans.: Natural resources are part of our atmosphere hydrosphere & lithosphere. Natural resources are inexhaustible, available for man for million of years e.g., water, forest, life forms

Renewable Resources are conventional type or traditional e.g., water, forest, food crops, plant species, wild life, aquatic life. These can be called replaceable resources also because they can be replaced from time to time due to their life cycle

– Forest resources, food resources, aquatic wild life & live stock resources are prominent renewable source of energy to sustain life on the earth.

- Some resources do not have life but can be recycled (water resources) & are renewable -

  1) water 2) live stocks 3) forest

Q.4 What are the Principles of Gasification?

Ans.: Gasification reaction comprises three principle stages. These stages are as follows -

(i) Cleavage

(ii) Oxidation

(iii) Reduction

Cleavage : In this step substrate (fossil fuel on biomass) is cleaved into smaller molecules. Cleaved can be described by following Reaction -

$(C_6H_{10}O_5)_n + Heat \rightarrow C_xH_y + CO$ …… (1)

Starch/Cellulose (Lower Hydrocarbons)

$(C_6H_{10}O_5)_n + Heat \rightarrow C_nH_mO_y$ …… (2)

(Lower carbohydrates)

Oxidation : This is exothermic reaction substrate & product of reaction (1) & (2) are oxidised by gasification agent into lower molecules weight product & heat.

$C_xH_y + O_2 \rightarrow CO_2 + H_2O + Heat$ …… (3)

$C_nH_mO_y + O_2 \rightarrow CH_4 + H_2O + CO + CO_2$ …… (4)

$C + O_2 \rightarrow CO_2 + Heat$ …… (5)

$H_2 + O_2 \rightarrow H_2O + Heat$ …… (6)

Reduction: Ash (Charcoal) produced during combustion reaction with other gases to form fuel gas. This reaction is endothermic in nature coltar is mainly gasified during this step.

$CO_2 + C + Heat \rightarrow 2CO$ …… (7)

$H_2O + C + Heat \rightarrow CO + H_2$ …… (8)

Q.5 Explain the Gasification Technology?

Ans.: There are five **techniques for gasification** -

(i) Processing of Biomass/Coal
- Size reduction
- Drying

(ii) Preparation of substrate

(iii) Gasification

(iv) Gas purification sulfur removal

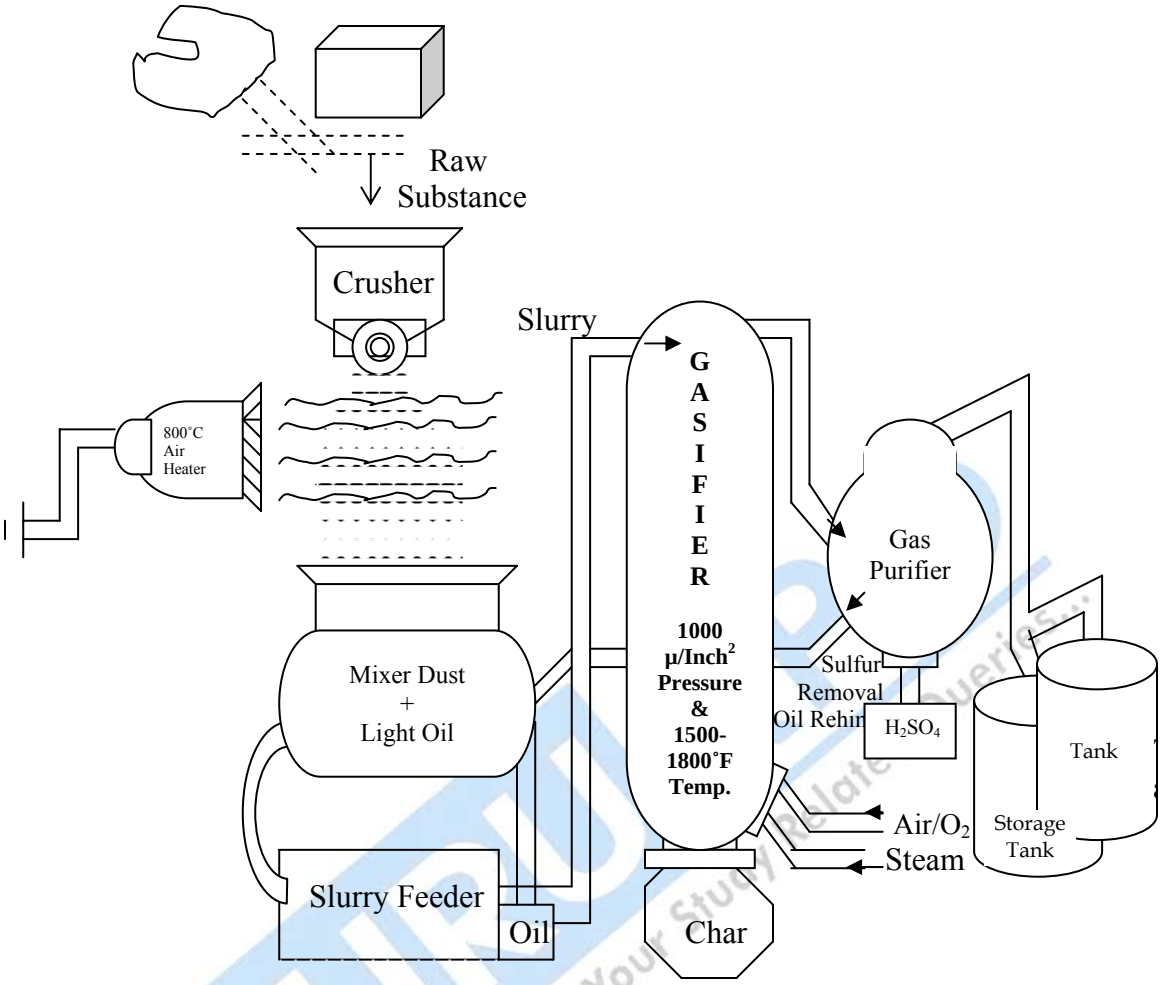
(v) Storage & Usage

(i) **Processing of Biomass / Coal :** Biomass used for gasification is generally rich in starch & carbohydrate. Such biomass & coal should be processed before reaction. Firstly size of substrate is reduced to dust from or 1 cm or less cubes. Then they are dried to remove the moisture by using a hot air drier. Normally temperature of substrate rise up to 700^0 to 800^0 F. Due to this high temperature pyrolysis & cleavage occurs.

(ii) **Preparation of Substrate :** Substrate for gasification can be present either in solid or in slurry phase. Slurry is formed by mixing dust/cubed into light & consisting of slurry is maintained according to type of gasifier.

(iii) **Gasification :** Gasification occurs in a closed chamber of gasifier. Cleaved substrate is oxidized by oxidants or gasification agent. Sequence of reaction occurs these & gaseous fuel is formed.

It is necessary to control the oxidant supply, so nitrogenous compound should not oxidize in NOx. This is done to check the particulate emission of pollutants by fuel.



Schematic Diagram for Gasification

(iv) **Gas Purification :** Obtained gas is purified for various aspects -

Solid particles are separated. Sulfur containing product are reduced to form H_2SO_4, to improve the nature of fuel. It also check pollution emission. Produced H_2SO_4 can be used further.

$$SO_2 + H_2O \xrightarrow{LiAlH_4} H_2SO_4 + O_2$$

$$SO_3 + H_2O \longrightarrow H_2SO_4 + O_2$$

(v) **Storage & Usage :** Purified gas is stored in containers with adequate temperature and pressure gaseous fuel can be used either in boilers heaters & as engine fuel.

Q.6 Explain the Types of Gasification?

Ans.: **Gasification reactions** can be classified on the basis of different types of oxidation agents -

(i) **Hydro-gasification :** Gasification reaction involving water or steam as gasification agent is called hydro-gasification.

(ii) **Steam/Air Gasification :** Here gasification agent is mix of steam & air.

(iii) **Steam/Oxygen Gasification :** Gasification reaction involving steam & oxygen as gasification agent is called steam/oxygen gasification.

(iv) **Air Gasification :** Gasification involving air as oxidant is called air gasification.

(v) **Oxygen Gasification :** Reaction with oxygen as gasification agent.

Q.7 How plants are used as Biomass Resources for Biodiesel?

Ans.: **Plants as Biomass Resources for Biodiesel :**

Edible Oils : These oils account for a significant fraction of world-wide edible oil production. There are also used as fuel oils.

(i) Coconut oil, cooking oil, high in saturated fat particularly used in baking and cosmetics.

(ii) Corn oil, a common cooking oil with little odor or taste.

(iii) Cotton seed oil used in manufacturing potato chips and other snack foods very low in trans-fats.

(iv) Canola oil one of the most widely used cooking oils from a cultivar of rapeseed.

(v) Olive oil, used in cooking, cosmetics, soaps and as a fuel for traditional oil lampes.

(vi) Palm oil, the most widely produced tropical oil also used to make biofuel.

(vii) Peanut oil (Ground nut oil) a clear oil used for dressing salads and, due to its high smoke point, especially used for frying.

(viii) Soyabean oil, produced as a by product of processing soyameal.

(ix) Sunflower oil a common cooking oil also used to make bio-diesel.

(x) Mustard oil used in India as a cooking oil and also used as a massage oil.

Non Edible Oils : These oils are extracted from plants that are cultivated solely for producing oil based biofuel. These, plus the major oils described above have received much more attention as fuel oils than other plant oils.

(i) Algae oil, recently developed by MIT Scientist "Isaac Berzin", by product of smoke stack emission reduction system.

(ii) Copaiba, an oleoresin tapped from species of genus "Copaifera", used in Brazil as a major sources of Bio-diesel.

(iii) Honge oil, pioneered as a biofuel by "Udipi Shrinivasa"in Bangalore, India.

(iv) Jatropha oil widely used in India as a fuel oil.

(v) Jojoba oil, from the simmondsia chinensis, a desert shrub.

(vi) Euphorbia oil.

(vii) Karanjia oil.

(viii) Castor oil, with many industrial and medicinal uses.

Q.8 Explain the term Biodiesel with its Production Process?

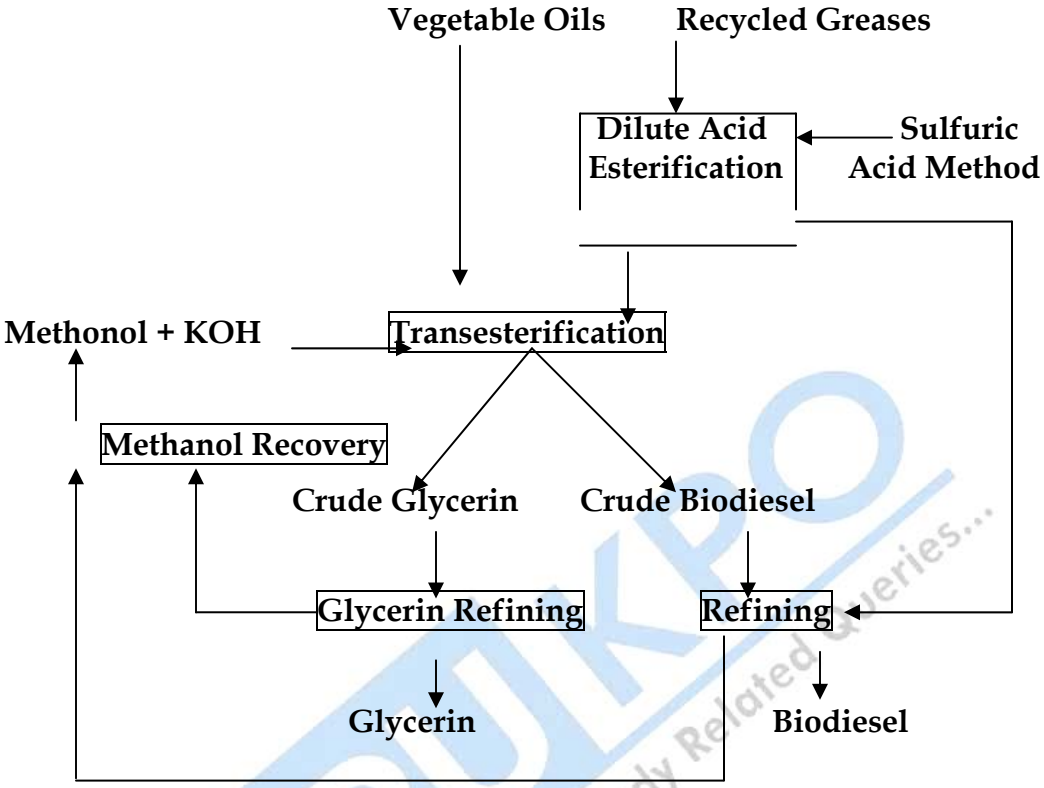
Ans.: Biodiesel is safe, biodegradable, and reduces serious air pollutants such as particulates, carbon monoxide hydrocarbons, airtoxics.

Blends of 20% bio-diesel with 80% petroleum diesel (B20) can generally be used in unmodified diesel engines, Bio-diesel can also be used in its pure form (B100), but it may require certain engine modifications to avoid maintenance & performance problems & may not be suitable for winter time use.

The best emission reductions are seen with B100. In the U.S. Bio-diesels are mainly derived from soyabean oil & in Europe from the sunflower oil. However, as India is deficient in edible oils non edible oils may be material of choice for producing bio-diesel like Jatropha.

The use of Bio-diesel decreases the solid carbon fraction of particulate matter [since the oxygen in bio-diesel enables more complete combustion to CO_2] & reduces the sulfate fraction (Bio-diesel contains less than 15 ppm sulfur). While the soluble or hydrocarbon, fraction stays the same or increases. Therefore, bio-diesel work well with emission control technologies such as diesel oxidation catalysts. Bio-diesel fuel can be made from new or used vegetable oils & animal fats, which are nontoxic, biodegradable, renewable resources. Bio-diesel can be produced by a variety of esterification technologies. The oils & fats are filtered & preprocessed to remove water & contaminants.

Production Process :



(i) Acid Esterification → Mechanical Extraction using a series of presses

(i) Acid Esterification → Mechanical Extraction / Solvent Extraction

(ii) Refining

(iii) Degumming

(iv) Bleaching

(v) Neutralization

Transesterification : The main reaction for converting oil to bio-diesel is called transesterification.

Triglycerides + Free Fatty Acids (<4%) + Alcohol → Alkylesters + Glycerin.

(i) **Acid Esterification :** Oil feed stocks containing more than 4% free fatty acids go through an acid esterification process to increase the yield of bio-diesel these feed stocks are filtered preprocessed to

remove water & contaminants & then fed to the acid esterification process. The catalyst sulfuric acid is dissolved in methanol & then mixed with pretreated oil. The mixture is heated.

There are two main process for the extraction of vegetable oil :

(a) **Mechanical Extraction :** This is a process of mechanical separation of the oil from the oil from the oil seed this process produces a crude oil & a cake meal, which contain approximately 10% of the oil content. This seeds are firstly cleaned to remove stones & pieces of metal, which may be present.

(b) **Solvent Extraction :** This is a process where by a solvent is used to remove the oil. Prior to solvent extraction. Most processes use a mechanical extraction process to remove around 20% of the oil content. The remaining cake is then fed into a solvent extractor on a moving bed. The solvent is sprayed over the cake in a counter – current clockwise stream & the oil is removed, as it is soluble in the solvent.

(ii) **Refining** : Once the crude oil has been extracted., it must go through a refining process. The impurities present in the oil need to be removed as they can affect the trans esterification process.

(iii) **Degumming :** This process is used to remove the phospholipids minerals, chlorophylls & colloidal proteins using phosphoric acid.

(iv) **Bleaching :** Bleaching is a process used to remove the colour pigments in the oil. These pigments are absorbed into the bleaching earth. The bleaching earth also removes trace metals soaps & oxidation products.

(v) **Neutralization :** The addition of an alkali (Caustic Soda) in a centrifuge removes the free fatty acids. This process also removes heavy metals, which would start the oxidation of the oil.

Q.9 What are Euro I, II and III standards?

Ans.: Emission standards are requirements that set specific limits to the amount of pollutants that can be released into the environment. Standards

generally regulate the emission of NO_x, particulate matter (PM) or root, carbon mono-oxide (CO) or volatile hydrocarbons. The main components of automobile exhaust, carbon dioxide (CO_2) and water vapor (H_2O), have so far not been regulated by emission standards mandatory CO_2 standards and USA has reflected it in the greenhouse gas score.

European emission standards are sets of requirements defining the acceptable limits for exhaust emissions of new vehicles sold in EU member states. The standards are defined in a series of European union directives staging the progressive introduction of increasingly stringent standards.

EURO I : EURO I was the emission standard for cars introduced in the EU (European Union) in 1992 that limits cars emissions to 8 g/kwh of Nitrogen oxides and 0.36 g/kwh of PM (Particerle Matter). It was replaced by EURO II in 1995.

EURO II : EURO II was the emission standard for cars introduced in the EU in 1995 that limits car emissions to 7g/km of NO_x and 0.15 g/km of PM (Particle Matter) when tested using the NEDC driving cycle.

It was replaced by EURO III in 1999.

EURO III : EURO III is the emission standard for vehicles introduced in the EU in 1999. It limits diesel car emission to 0.5 g/km of NO_x and 0.05 g/km of particulate matter (PM), Petrol cars to 0.15 g/km NO_x and heavy goods vehicles (HGVs) to 5 g/kwh of NO_x and 0.1 g/kwh of PM.

It has been replaced by EURO IV in 2005.

Q.10 What is Bio-ethanol & how it can be obtained?

Ans.: Bio-ethanol :

Ethanol produced by microorganisms eg. Saccharomyces cerevisiae from biomass is called Bio-ethanol.

→ Bio ethanol is the most widely used bio fuel for transport purposes especially in Brazil & U.S.A.

→ At present bio ethanol is not cost competitive as compared to petrol, but is being used for transport due to government subsidies.

Bio-ethanol Production Process : At present there are three important **routes for the production of bio ethanol -**

(i) **From Starch or Sugar Crops :** Including roots, tubers or grains that are rich in starch. Sugar crops including molasses or juice derived from sugarcane palm or sugarbeet from cellulose (wood or waste product rich in cellulose) follow enzymatic hydrolysis.

(ii) **From Cellulose follows Chemical Hydrolysis :** Commercial production of ethanol involves three steps -

(a) Preparation of Substrates

(b) Fermentation

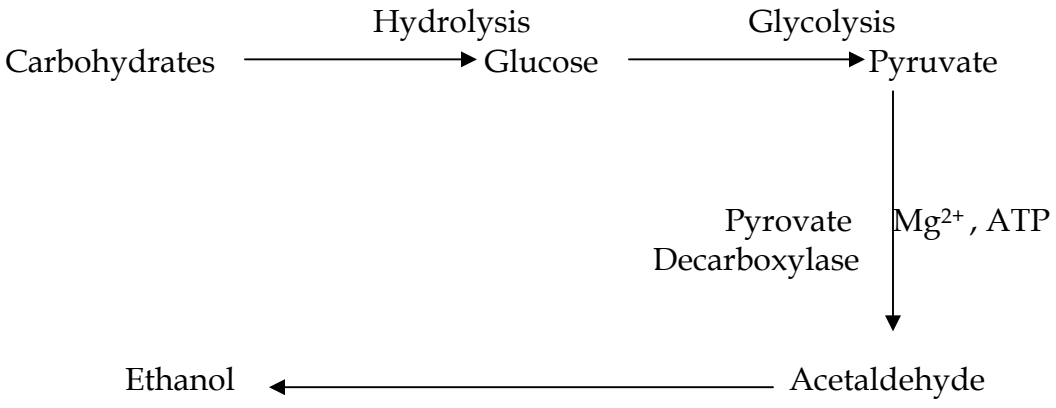
(c) Recovery of Ethanol by Distillation

(a) **Preparation of Substrates :** starts with those of parts of plants which are rich in starch such as seed. First of all seeds are ground filtered and dried. The starch is liquefied by boiling under pressure cooled and then hydrolyzed enzymatically.

(b) **Fermentation :** In India ethanol is produced mainly by fermentation of molasses which are produced as by product in sugar factories and are quite rich in fermentable sugars.

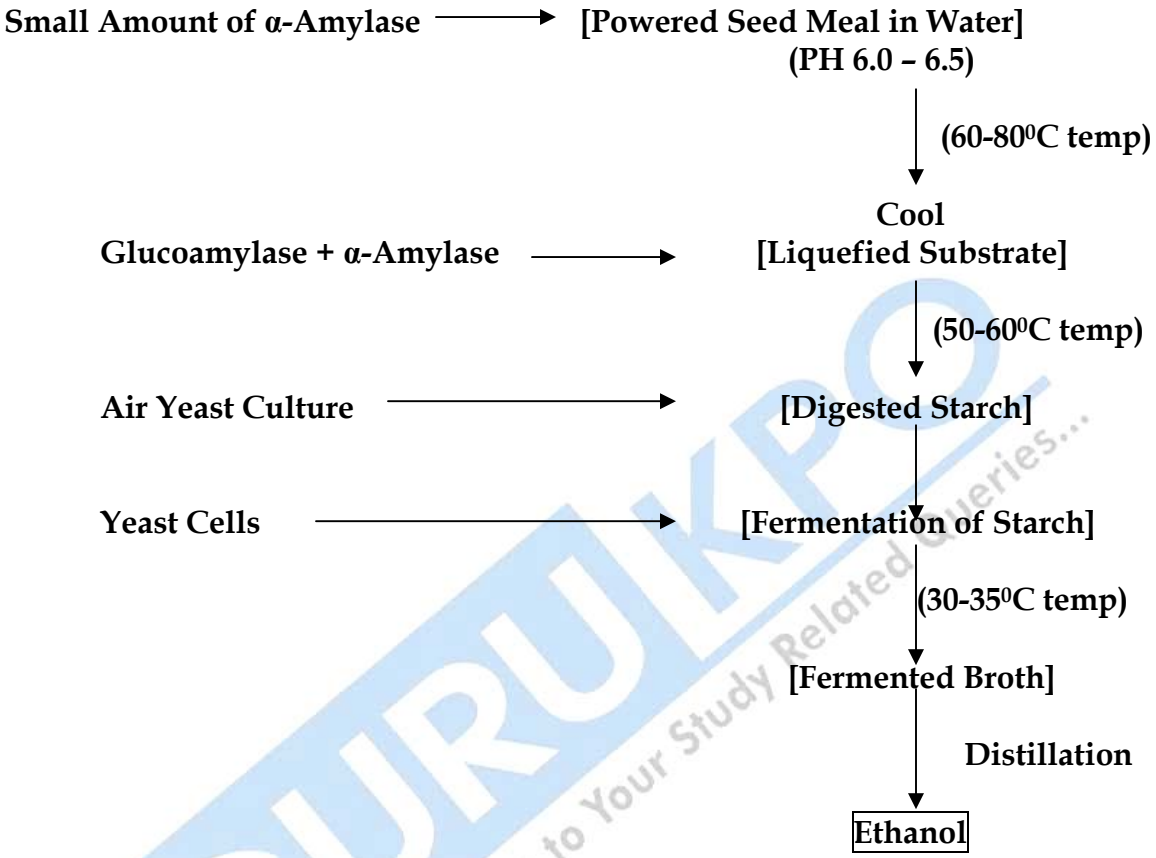
In a typical fermenter using molasses as a substrate di-ammonium phosphate (as a source of nitrogen for the yeast) is mixed up with the substrate. The PH is maintained at 5.0 and fermentation is carried out at 30 -35^{0}C temperature. After fermentation, yeast cells are separated by centrifugation or sedimentation and used again.

Fermentation is carried out generally under anaerobic condition -



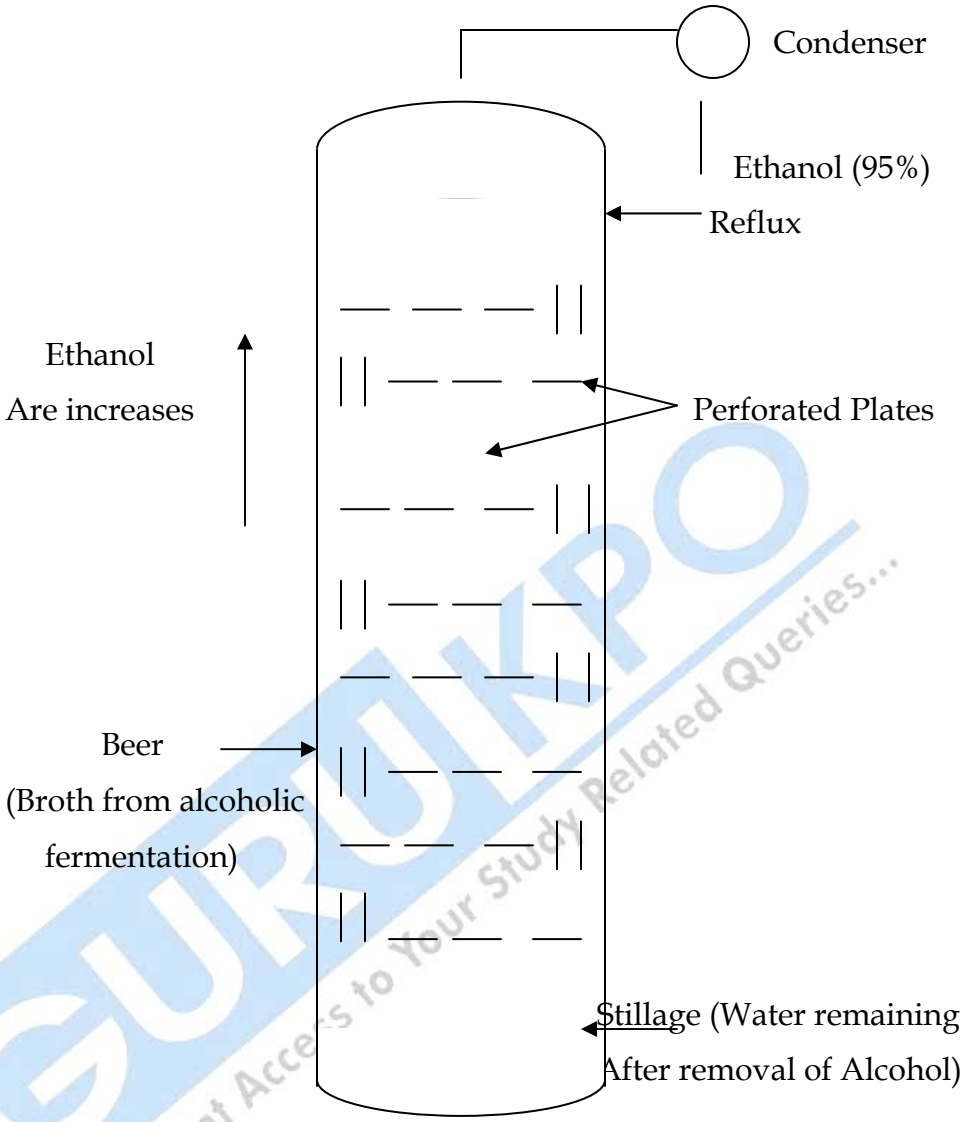
Alcoholdehydrogenase

Flow Chart for Ethanol Production :



(c) **Ethanol Recovery by Distillation :** Ethanol from the fermented mixture is recovered by distillation process. The principle of Sequential distillation column which is divided into chambers perforated plates.

The fermentation broth (Ethanol water mixture, is boiled using steam & the vapor rises in the column. Each chamber of the column functions as a distillation unit so that the proportion of alcohols goes on sequentially. A properly designed column would yield 95% ethanol from its topmost chamber.



Sequential Distillation of Ethanol

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