1.GENERAL

BFC Tech Inc, has recently completed an extensive experimentation program on an old chemical process known as 'Fast Pyrolysis'. The scope was to transfer basic concepts of the process, widely known on a scientific level, into an industrial technology able to overcome the weak points of the traditional pyrolysis.

The project included not only the construction, but also the full validation of a new process able to overcome most of the critic points connected to the pyrolysis technology; validation included: obtaining a plant having high yields in transforming solid carbonic products into light fuels (diesel and kerosene), and assuring high quality standards both from an environmental point of view, and for health and safety issues. The organic feedstock containing carbon and hydrogen arrives to the physical conditions which allow a fast decomposition of the complex tridimensional organic compounds maintaining the hydrogen bond to the carbon to form the linear molecule of diesel oil (C_nH_{2n}), avoiding its bond to light gases. The changes, compared to a traditional pyrolysis process are:

- **Fast energy transfer to the reacting product**: The energy is directly transferred inside the reacting mass. It is obtained part through a friction pump , and part through an electroshock system. Proprietary technology assures that the energy is exchanged in a very short time while the reacting media is subject to an intense mixing.
- **Catalyst Aided Reaction:** The feedstock is finely dispersed into mineral oil together with a catalyst and a neutralizer. An intensive mixing allows the contact of catalyst with reacting feedstock. It helps hydrogen bond to carbon avoiding its escaping as gas.
- **Working at low temperature:** The temperature inside the reactor remains below 300°C, against the 550°C of a common pyrolysis process.
- **Reduced solid residual:** The solid residual is reduced to mineral salts entrapped with the feedstock, and residues of carbon. Usually one tenth of a traditional pyrolysis.
- **Reduced reaction time:** The combination of fast energy transfer, intensive mixing, catalyst aid, brings to a retention time of the reacting media inside the system of few minutes, against the hours of a pyrolysis.
- **Reduced gas release:** The very low reaction time and the catalyst action strongly reduce the quantity of syngas released. With typical agriculture byproducts used as feedstock, the syngas released is usually neutral, and does not require any washing or neutralizing before being used.

Finally the technology gives an energy transfer from feedstock to a light fuel oil (diesel and/or kerosene) higher than 75%.

An high quality light fuel is obtained at an energetic yield among the highest on the market.

BFC TECH has now validated a first industrial plant having a capacity of 150 lt/hr up to 250 lt/hr of diesel oil output, and is designing a scale up to bigger plants from 1000 to 2500 lt/h of diesel output.

The plant using this Bio Fuel Catalytic Cracking Technology (below named BFC) has been tested and validated for a continuous heavy duty run.

1. PROCESS DESCRIPTION

The Bio Fuel Catalytic Cracking (herein after BFC) is a continuous process where the carbonic feedstock is in continuous dispersed trough a mineral oil. Such oil works as transfer media, transporting the feedstock through the subsequent sections of the plant, until the end of the reaction inside the BFC reactor where the light fuel resulting from the reaction and the gaseous phases evaporate inside a distillation column, while the mineral oil remains as bottom product. In order to compensate the mineral oil mass flow inside the system, part the bottom oil is continuously extracted from the BFC reactor, separated from solid content and re circulated to the feedstock preparation section. Vapors and gases flowing out from the distillation column pass through a condenser where liquid phase (light fuel oil and reaction water) is collected to the water/oil separator, while gases flow through a vacuum pump and then are used as combustible aid for the diesel generator feeding the plant.

In detail, section by section:

a. Feedstock preparation and charge to the processing section

This section provides the feedstock preparation and continuous delivery to the BFC Reactor. The solid feedstock, in form of shredded materials, is dispersed in a mineral oil working as transfer media at a ratio of 1 solid against 2 to 3 of mineral oil.

It contains the following equipment:

- N° 1 Feeding hopper and loading conveyor
- N° 2 Preparation Blenders equipped with internal ribbon impeller for mixture blending and de aeration, and a bottom screw conveyor for the product extraction to the suction of the slurry feeding pump
- N° 1 flash column for water vapours and un condensable matters extraction
- N° 1 condenser
- N° 1 vacuum pump
- N° 1 Slurry Feeding Pump

The two horizontal blenders work alternatively one for the mineral oil/solid feedstock preparation to a suitable slurry finely mixed and de aerated, and the other for the slurry controlled delivery to the Smoldering Reactor.

The blender working as preparation, once filled with the due quantity of solid feedstock receives the mineral oil coming from the recirculation oil tank. Temperature of the oil is around 260°C, and the mixture with the cold feedstock will drop down temperature below 200°C. Catalyst and neutralizer are also loaded. A slow blending assures de aeration and fine mixing of the products, while the flash column will catch the water vapors and the air trapped in the feedstock, and send them out to the condenser and to the vacuum system. The mixture will finally arrive to the optimum conditions required from the process, and the blender will be ready to the switch with the other blender which has in the same time completed the transfer of its charge of slurry to the BFC section.

The physical conditions inside the blender remain below the limits at which any chemical reaction could start. An external coil on the shell assures a thermal oil circulation for temperature control of the slurry inside the blenders; the thermal oil is both connected to hot and to the cold loop.

The slurry ready for delivery is extracted by the bottom screw conveyor and delivered to the suction of the Slurry Feeding Pump. The flow to the BFC Section is automatically controlled.

b. **BFC Reactor**

The BFC reactor assures the right conditions for the reaction to take place. The slurry entering the reactor immediately passes from the neutral conditions of the preparation blender to the reacting conditions by receiving a shock energy supply immediately when entering into the reactor. Then it flashes into the reacting ballast. A friction pump assures a continue recirculation of the ballast, and in doing it the slurry is subject to a strong mixing and fast energy supply, both conditions required to obtain the fast pyrolysis reaction. Vapors of light fuel oil and reaction water, plus non condensable gases, flow through the distillation column up to the condenser, while the controlled extraction of the excess mineral oil entering the reactor and solid residuals balances the mass flow.

The section contains the following equipment:

- BFC reactor
- Shock Energy Supply Device to give energy and mixing to the fresh slurry entering the system
- Friction Pump for fast energy supply and reaction sustaining
- Distillation column
- Excess Oil Extraction Pump

Temperature inside the reactor is controlled through the friction pump speed control and through a liquid reflux from the condenser.

Suitable devices assure the system temperature lowering in case of unexpected rise up.

c. **Condenser**

Vapours flowing out from the distillation column are condensed, while gases are continuously sucked out from the vacuum system

d. **Water/Oil Separator**

Condensed liquid, formed by light fuel and water, are collected in a single stream to the water/oil separator.

e. **Vacuum system**

A vacuum pump assures the pressure control inside the condenser by continuously sucking the non condensable gases flowing out from the Smoldering Reactor. Gases are then delivered to the diesel generator and used as fuel in mix with diesel oil.

f. Excess Oil extraction and Ashes Treatment

The level control inside the smoldering reactor actuates a pump for the continuous extraction of the excess oil. The mineral oil flowing is flowing in closed loop inside the plant. Once it is extracted from the reactor it is passed through a continuous filtration unit for the separation solid ashes carried out from the reaction area, then re injected into the preparation section, and from here back to the Smoldering Reactor. Fuel vapors are delivered to the main condenser and recovered to the oil/water separator.

The section contains:

- Oil Extraction Pump
- In line filtration unit
- Filtered Oil Pump delivery to the recirculation oil tank
- Recirculation Oil Tank
- Sludge heating and pressing
- Flash column

g. Reaction Water Cleaning

Water coming out from water/oil separator is recovered in a water tank and processed at batch for final light oil separation with a vacuum distillation system. The energy for the distillation is recovered from the excess heat inside the system.

h. Diesel Generator

A diesel generator provide the electricity for the plant operation.

Te fuel used is diesel oil, plus gases coming from the vacuum system which have energetic value as carbon monoxide and traces of other combustible gases.

The heat of the exhaust gases is recovered through an heat exchanger and recovered through a thermal oil system.

i. Heat Recovery System

A thermal oil system provide the distribution of the recovered heat and the regulation of temperature in specific sections of the plant. The system has two loops: one for heat transfer, and the other for cooling purposes.

j. Cooling Water system

A closed loop circulates the cooling water for condensation. Cooling is obtained through external air coolers.

k. Control System

A centralized control system assures the monitoring and controlling of the process parameters:

- Levels
- Mass flow
- Temperature
- Pressure
- Pumps rotation
- Energy supply

The process is fully controlled by the system. Operator may manually interact through the control panel. Remote control is also allowed.

The system also controls the side sections: ashes treatment, cooling, heating.

A database takes record of process working parameters and trends.

l. Process Safety

Working parameters are all monitored and controlled during the normal operation, according to the working program selected.

Critical parameters are also subject to automatic actions by the control system once they passes the second level of alarm:

- Temperature inside the Smoldering Reactor and Distillation Column: In case temperature goes out from the range allowed by the normal operation and the control system is not able to solve the problem, an alert is given for the operators. In case the operator cannot solve the problem and a second level alarm arrives, corrective actions are automatically started from the system out of any decision of the operator. The first level is a nitrogen purging, if problem continues, a second level start with controlled water injection for steam saturation.

The system is also provided with:

- Containing barrier for eventual oil leaks
- Alarms for pressure and normal equipment operation
- Automatic shut down procedures with emergency procedures remaining active

A complete risk analysis will be available with before the plant commissioning.

2. PROCESS DATA

a. The chemistry

The technology consists in an improvement of the well known ‘Fast Pyrolysis Process, described since last century in many scientific publications. The effort pursued by BFC TECH was to apply the concepts already described in many University Reports to an industrial facility able to work in continuous and in heavy duty conditions. The preindustrial program was assisted by the Rome University Applied Chemistry Department with laboratory trials and continuous feedback from an industrial facility. The Research Team tried to transfer the scientific concepts to an industrial facility; the work focused on three basic points: transfer in the fastest way possible the energy to the reacting mass, avoid the hydrogen release from the basic molecule, work in continuous.

The chemical reaction differs from the pure pyrolysis, where the simple heat transfer to the biomass, in absence of oxygen and a temperature around 520°C, causes the separation between heavy hydrocarbon vapors and light gases from the carbon and others non combustible matters.

In the BFC process the presence of a catalyst, associated to a patented system able to give energy to the reacting biomass in a very fast way and under intense mixing conditions, creates the conditions for the catalyst to bind to the hydrocarbons resulting from the partial smoldering of the biomass molecule (olefins, alkanes, plastics, etc.), and the hydrogen atoms in excess, resulting also from the biomass molecule smoldering, substitutes the catalyst bond to the hydrocarbons. The result is an hydrogenation at a temperature below 320°C and at atmospheric pressure.

It gives a great advantage compared to the current hydrogenation processes used for producing fuels oils, which require high pressures and temperature above 700°C.

Taking as example the biomass in form of cellulose, we can assume the following theoretical intermediate passage:

$$C_6H_{10}O_5 = CO_2\ (2{,}5) + (CH_2)n\ (3{,}5) + H\ (4)$$

The four hydrogen atoms hydrogenates the reacting biomass replacing the catalyst (cation-aluminium-sylicate).

Finally the reaction (cellulose biomass) may be theoretically summarized as follow:

$$10\ C_6H_{10}O_5\ (1{,}63\ kg) = 19\ CO_2\ (0{,}836\ kg) + C_{20}H_{42}\ (0{,}282kg) + C_{21}H_{44}\ (0.296\ kg) + 12\ H_20\ (0.216\ kg)$$

And per Kg of pure cellulose:

1 kg Cellulose + 0,01 Kg of catalyst = 0,513 Kg CO_2 + 0,355 kg of middle distillate + 0,132 kg water

b. **Preliminary Mass and Energy balance**

Due to the fact that the biomass never contains 100% cellulose, and assuming a 90% reaction efficiency , we experiments the following average yields:

Per 1 Kg of dry biomass:

- 24 to 30% diesel fuel oil
- 45 to 50% CO_2 + traces of light gases (CO, CH_n)
- 15 % water
- 10% salts, catalyst and carbon residues

Higher yields in diesel oil can be achieved when using as feedstock plastic materials or richer hydrocarbons.

The energy requested to operate the process is produced with a diesel generator integrated in the plant supply, for producing electricity and heat. The consumption remains below 15% of the diesel oil produced, usually below 10%.

No oxidation takes place, it is a natural chemical reaction which transforms the complex tridimensional cellulose molecule to simpler linear light fuel oil molecules .

The gaseous products coming out from the reaction are collected through a vacuum pump to the suction of a diesel generator which uses 10% of the fuel produced by the system to produce electricity and heat needed for the plant operation.

c. Noise

The plant has a noise level below 60 dB

d. Emissions and byproducts

- Emissions to atmosphere: As it can be observed going through the process description above, no oxygen is added to the reacting product, no oxidation takes place, it is simply a chemical transformation from one complex tridimensional molecule to simpler linear molecules. The carbon dioxide sent to atmosphere through the exhaust gas system from the diesel engine producing the energy for the plant operation comes out from natural transformation giving a short term zero balance on the CO2 content into atmosphere.
- Liquid emissions: Out of the light fuel representing the useful product of the technology, we have production of water coming out from the two condensers downstream the distillation column. The raw water separated through the oil water decanter contains traces of light fuel oil; it is stored into a water receiving tank, and at batches is processed through a double step process of mechanical oil separation first, which separates: a) quality light fuel oil sent to the oil receiving tank, b) aqueous phase containing traces of oily emulsion. it is passed through a vacuum distillation process where the water is returned to different cleanness levels, (from the lower for use in agriculture, to the higher which gives high quality water suitable to be sent to the surface natural rivers), while the small part of oily ballast is reprocessed through the preparation blenders.
- Solid residuals: The 10% max of solid residuals is formed by inorganic salts with catalyst and carbon. The product could be either used for energy production (carbon briquettes), or in agriculture for soil enrichment. The above solution are possible when using agricultural byproducts as feedstock. Different feedstocks could require the landfilling of the solid residual.

e. Hazards and environment controls

The constant long exposition of the reacting products to temperatures around 320°C assures that eventual traces of poisonous intermediates eventually formed arrive to complete destruction during the process.
The whole process, from the feedstock preparation and feeding, to the output of solid, liquid and gaseous phases, is completely closed. No air or any other substance is allowed to enter into the system. Finally we have:

- Non condensable matters gases separated from liquid phases in the condensers are sucked by a vacuum system (below 1000 pascal) which forces them through the suction filter of the diesel engine used to produce electricity and heat for the plant operation. Such gases are mainly neutral carbon dioxide, plus traces of light gases (hydrogen, carbon monoxide, mercaptanes, and similar). The complete oxidation which takes place inside the internal combustion engine assures that all combustible gases are returned as spent neutral gas, and odors are destroyed. Light combustible gases eventually formed (hydrogen and carbon monoxide) and odors are so completely oxidized, with its energy recovered for process use.

- Gases and vapors eventually released during the transient phases (shut down) still passes through the diesel engine which continues its operation until the system cooling. Additionally gases are automatically diverted through a carbon filter in case of diesel engine failure, for a complete neutralization.
- Solid residuals extracted from the system passes first a mechanical separation which recover the oil and then heated up for the complete evaporation of the oil . The oil is recirculated to the Smoldering reactor.
- The process operates at low temperatures (below 320°C), in absence of oxygen. No combustion takes place. The addition of lime assures also the neutralizing of acid gases eventually formed, before they are stripped with the vapors.
- The absence of oxygen and the permanence for prolonged time at temperature around 300°C avoid formation of dioxine precursors.
- The system works at atmospheric pressure, reducing the risk of leaks of gases to the external.
- Containing barriers avoid any oil leak to expand in the building, the liquids from the contained area are collected by gravity to an external recovery tank .
- The electric and instrument system inside the process area meets explosion proof requirements

f. **Feedstock Specifications**

The process requires the feedstock to be load as selected fraction. For this in most agricultural byproducts a preprocessing is required. Usually it consists in a fine shredding and drying down to 10% humidity. Higher humidity affects the energy consumption of the process.