UNIVERSITY OF KHARTOUM
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A COMPARATIVE STUDY OF THE GASIFICATION OF
PETROLEUM COKE AND CHARCOAL

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A DISSERTATION SUBMITTED IN PARTIAL FULLFILLMENT FOR
THE DEGREE OF MASTER OF SCIENCE IN CHEMICAL
ENGINEERING

2008
Acknowledgement

I gratefully express my thanks to my supervisor Dr Abd-elshakour Awad Elkarim for his patience, guidance and assistance. My appreciation and thanks are due to many companies: Khartoum Refinery, Central laboratory - Ministry of Science & Technology, Central Petroleum Laboratories, Garri Plant for Thermal Electric Generation. I sincerely, wish to express my deep thanks to many individuals: Engineers: Abdelazim, Amir, Gasan, Safa, Omer, Mr. Hilmi, Miss. Mysa and many others. Also, I extend profound thank to my colleagues at the Energy Research Institute. Finally thanks are due to my family for the continuous support and encouragement.
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Abstract

This preliminary study aims to investigate the possibility of Sudanese petroleum coke (Fula crude) gasification, and its technical challenges. It provides experimental comparative data between charcoal as traditional gasification fuel and the petroleum coke, as fuel and as producer gas.

The study is divided into two main themes:

1- Fuel Tests: moisture content, ash content, density and fuel calorific value.

2- Gas Producer Characteristics Tests: gas mixture components, flame temperature, flame duration, fuel consumption rate and ash residue amount after the gasification.

The type of gasifier which was used in the experiments is updraft gasifier (thermal application).

The results showed that petroleum coke gasification is far better than charcoal gasification because it has high heat density, low ash content and lower fuel consumption.
مستخلص

تمكن من تحقيق الدراسة هذه تهدف إلى تحويل البترول في الغازات (منتج الغاز) وفحص الغازات (وفحص المنتجات) بين التجربة والمقارنة بياناً تقدم تشفيره، ظروف ودراسة في التجربة الغاز منتج، كما أن الاتجاهات للدراسة

1- الأداء

- الأوائل

- تحليل

- تحليل

- بحث

- تحليل

- تحليل

- بحث

- تحليل

- تحليل

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CHAPTER ONE
1-Introduction

1-1General

Energy is essential to all human societies. It is used to create goods from natural resources and to provide many services we have come to take for granted. Its presence represents sustainability to national progress. In Sudan, like many other developing countries, the demand for energy is increased exponentially [1]. This increase refers to many reasons such as: population growth accelerated urbanization, enlargement of the industrial activities …etc. It is of utmost important that more efforts be exerted to access to new energy sources and applying modern efficient technique. Those techniques may provide better utilize of this wealth, in order to face the increased demand for energy and maintain it through successive generation.

Sudan, still, depend mainly on forest as energy source which account for about seventy percent of the energy consumption. Charcoal is the principle fuel which can be used in household as well as in the industrial sector. [1] After Sudan petroleum exploitation, petroleum coke appears as unusable by-product of oil refining. It can be used as a source of energy for power generation or in cement production.

Gasification is thermo-chemical process occur in a reactor (gasifier) to convert solid fuel (charcoal, petcoke, and biomass residue) into a combustible gas mixture (producer gas). The producer gas can be used in: direct heat application (kilns, boilers...etc) or shaft power application (internal combustion engines). Charcoal gasification is not a new technique; although it faces efficiency reliability. The introduction of petroleum coke in gasification appears as a recent trend worldwide [2] The need to convert this residue into more marketable products, while meeting increased refinery need for hydrogen and clean electric power appear to be shifting the interest in favor of petroleum coke gasification.[2]

This study provide a comparable experiments between gas produced from petroleum coke gasification and gas produced from charcoal gasification, in term of the components percentage, gas flame temperature, durability and fuel consumed.
1-2 World energy Supply

The majority of world energy resources are from the sun's rays hitting earth. The term solar constant is the amount of incoming solar electromagnetic radiation per unit area, measured on the outer surface of earth's atmosphere, in a plane perpendicular to the rays. The solar constant includes all types of solar radiation, not just the visible light. It is measured by satellite to be roughly 1366 watts per square meter[3], though it fluctuates by about 6.9% during a year - from 1412 W/m² in early January to 1321 W/m² in early July, due to the earth's varying distance from the sun, and by a few parts per thousand from day to day. For the whole Earth, with a cross section of 127,400,000 km², the power is $1.740 \times 10^{17}$ W plus or minus 3.5%.

The estimates of remaining worldwide energy resources vary, with the remaining fossil fuels totaling an estimated 0.4 YJ (1 YJ = $10^{24}$ J) and the available nuclear fuel such as uranium exceeding 2.5 YJ. Fossil fuels range from 0.6-3 YJ if estimates of reserves of methane catharses are accurate and become technically extractable. The world also has a renewable usable energy flux that exceeds 120 PW.

Table (1): Worldwide energy supply in TW (2004).[3]

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>38</td>
</tr>
<tr>
<td>Gas</td>
<td>23</td>
</tr>
<tr>
<td>Coal</td>
<td>26</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>6</td>
</tr>
<tr>
<td>Nuclear</td>
<td>6</td>
</tr>
<tr>
<td>Geothermal,Solar,Wind and Wood</td>
<td>1</td>
</tr>
</tbody>
</table>
1-3 World energy consumption

The twentieth century saw a rapid increase in the use of fossil fuels. Between 1980 and 2004, the worldwide annual growth rate was 2%, although there is at least 10% uncertainty in the world’s energy consumption. Not all of the world’s economies track their energy consumption with the same rigor, and the exact energy content of a barrel of oil or a ton of coal will vary with quality. Energy consumption broadly tracks with gross national product, although there is a significant difference between the consumption levels of the United States with 11.4 kW per person and Japan and Germany with 6 kW per person. Canada has the highest energy consumption per person, whereas the lowest energy consumption takes place in developing and under-developed economies. [3]


<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Energy/year in EJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>180</td>
</tr>
<tr>
<td>Gas</td>
<td>110</td>
</tr>
<tr>
<td>Coal</td>
<td>120</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>30</td>
</tr>
<tr>
<td>Nuclear</td>
<td>30</td>
</tr>
<tr>
<td>Geothermal, wind, solar and wood</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>471</td>
</tr>
</tbody>
</table>

1-4 Sudan Energy Resources & Consumption

Wood fuels (fuel wood & charcoal) are the principle sources of energy in Sudan. They are used by household for heating and cooking; they are also used by commercial operations like: baking, brick making and tobacco curing. Other biomass like sugar cane bagasse and cotton stalk met a significant part of energy needs. Biomass energy share decrease form 89% in 1990 to 69% in 2005, this refers to the exploration of Sudan’s petroleum and the increased use of its products. In 2005 the total energy
supply was estimated to be 13.35 million tons of equivalent (TOE), but the actual energy consumption was 9 million (TOE), this difference between supply and consumption is due to the low efficiency of energy utility appliances. Household sector is the largest consuming sector with 51% out of which 94% is wood fuels. [1]


<table>
<thead>
<tr>
<th>Type of supply</th>
<th>1990</th>
<th>%</th>
<th>2005</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>9589</td>
<td>86</td>
<td>8922</td>
<td>69</td>
</tr>
<tr>
<td>Petroleum</td>
<td>1450</td>
<td>13</td>
<td>4327</td>
<td>30</td>
</tr>
<tr>
<td>Hydropower</td>
<td>111</td>
<td>1</td>
<td>108</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>11150</td>
<td>100</td>
<td>13350</td>
<td>100</td>
</tr>
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</table>

Table (4): Sudan Energy Consumptions in Year 2005 in TOE.[1]

<table>
<thead>
<tr>
<th>Sector</th>
<th>Consumption</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household</td>
<td>4590</td>
<td>51</td>
</tr>
<tr>
<td>Transport</td>
<td>1980</td>
<td>22</td>
</tr>
<tr>
<td>Services</td>
<td>1260</td>
<td>14</td>
</tr>
<tr>
<td>Industry</td>
<td>1080</td>
<td>12</td>
</tr>
<tr>
<td>Agriculture</td>
<td>90</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Total</td>
<td>9000</td>
<td>100</td>
</tr>
</tbody>
</table>
1-5 Objectives

1-5-1 General Objective

Maximize the efficiency of petroleum resource utilization through gasification technique by upgrading the unusable by-product -petroleum coke into usable gaseous fuel.

1-5-2 Specific Objectives

1/ To determine the characteristic of petroleum coke producer gas in comparison with charcoal producer gas.

2/ To identify petroleum coke gasification operational problems if any and how to over come them.

3/ To take advance step toward today's modern global gasification systems and their subsequent techniques: hydrogen energy, fuel cell…etc.
CHAPTER TWO
2-Literature Review

2-1 Petroleum Coke

In petroleum refineries, useful products such as gasoline, jet fuels, diesel fuel and waxes are separated from crude petroleum, leaving a heavy tar-like residue. More products can be made from this heavy residue by processing it at a high temperature and pressure to crack large molecules into smaller molecules. This process, called coking, leaves behind a hard, coal-like substance called petroleum coke. It consists mostly of carbon with small amount of hydrocarbon (oil), sulfur and trace amount of metals. Petroleum coke can be categorized generally as either green or calcined coke. The initial product of coking process, green coke, is used as a solid fuel, further processing of green coke at higher temperature and pressure result in calcined coke, which is used in the manufacture of graphite electrodes or for minor application such as carbonization of steel.

Table (5): Typical Properties of Delayed Petroleum Coke.[4]  
(Ultimate Analysis as Received Weight%)

<table>
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<tr>
<th>Constituent</th>
<th>Average</th>
<th>Range</th>
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<tbody>
<tr>
<td>Carbon</td>
<td>79.74</td>
<td>75.0-86.0</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>3.31</td>
<td>3.0-3.6</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.61</td>
<td>1.3-1.9</td>
</tr>
<tr>
<td>Sulfur</td>
<td>4.47</td>
<td>3.4-5.3</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.00</td>
<td>0.0-0.1</td>
</tr>
<tr>
<td>Ash properaties,ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vanadium</td>
<td>&lt;2,000</td>
<td>500-2,000</td>
</tr>
<tr>
<td>Nickel</td>
<td>336</td>
<td>250-450</td>
</tr>
<tr>
<td>Iron</td>
<td>84</td>
<td>50-250</td>
</tr>
</tbody>
</table>
2-1-1 World petroleum coke production: At the start of 2006, global production capacity for marketable petroleum coke was 82.5Mtpy. Close to half of that capacity was located at refineries in the USA. As much as 35MTpY of new capacity may come on-stream between 2006 and 2010 and by 2012 a total of 45.2MTpY could have been added. Around 45% of that new capacity will be in Canada and Venezuela, to meet the needs of rapid growing.

An important development in the first half of this decade has been the rise in coke exports from Canada and Venezuela, which has resulted from rapidly growing production by the up graders. Canada's exports have increased from around 90,000tpy to more than 600,000tpy, while those from Venezuela were 3.5Mt in 2005, compared with 0.9Mt the previous year.

Globally, around three quarters of petroleum coke consumption is in energy applications, mainly as a refinery fuel (catalyst coke), for electricity generation and for heating cement kilns (marketable coke). Demand for coke in these applications is strong and likely to increase further.

The energy sector in the USA has enabled US power utility companies to increase their use of petroleum coke as a more cost-effective alternative to coal. Consequently, North America has become the largest user of petroleum coke in power generation, with estimated consumption of 8.1Mt in 2005.

In the industrial sector, the largest use for petroleum coke is as a fuel for cement production. The estimate Organization of Economic Co-Operation and Development (OECD) countries consumption in cement production at 8.7Mt, a figure that has probably changed little in recent years, as cement production has been fairly stable. At a global level, the greater part of cement output is from non-OECD countries, so total consumption of petroleum coke by this industry is undoubtedly much higher. The largest individual consumer is almost certainly China, which accounted for close to half of world cement output in 2005 and has been responsible for 70% of the growth in production since 2000.

Global consumption of calcined petroleum coke in aluminum production is estimated at 11-12Mtpy. Aluminum production has been on a steady upward trend for some years and the demand for petroleum coke is expected to continue rising. One area of risk to future demand for petroleum coke in this market is the research being undertaken by the aluminum industry into inert anode technology, which involves no petroleum coke. The successful introduction of such technology could ultimately remove one of the major end uses for high-grade petroleum coke. [3]
2-1-2 Sudan petroleum coke production

Khartoum Oil Refining Co., Ltd. Sudan is a joint venture refinery constructed and managed by CNPC and Energy Resource and Mineral Products Ministry of Sudan. The delayed coking units with an annual capacity of 2Mt belong to the new-built units. A set of delayed coking unit with an annual capacity of 1Mt was constructed in Phase I, which is composed of the following eight sections: electrostatic desalting; coking tower; heating furnace; fractionation column; steaming out and venting; rich gas compression; rich gas desulphurization; coke storage basin-settling basin cutting coking water circulation and cold coking water circulation. The second set of delayed coking unit consists of six sections such as coking tower, heating furnace, fractionation column, rich gas compression, absorption and stabilization, LPG desulfuration and dethioalcoholization will be constructed in phase II, will match with the annual capacity of 2Mt. The annual pet coke production in 2007 was 402,000 ton. [5]

There are proposed project under construction to use Sudanese petroleum coke as fuel:

**Garri (4) Power Plant:**

It will start operating in October 2008. It consists of two units using Circulating Fluidized Bed Boiler (CFB). Each unit will consume 17 ton per hour of petroleum coke, and produce 55MW.hr. [6]

**Atbara Cement Company:**

The new branch in Oum Eltiuor, West Nile will start operating in January 2009 with a productivity rate of 2 million ton per year of cement using 500-600 ton of petroleum coke as kiln fuel. [6]
2-1-3 Coking process

Green coke, the initial product of coking process, can be produced by one of three processes:

-Delayed coking.
-Fluid coking.
-Flexi coking.

Delayed coking:–

It is the most widely used technology in the refining industry. It consists in the thermal decomposition of hydrocarbons in an empty drum where the coke produced in the reaction is deposited. At the same time, the light hydrocarbons exit the drum and are routed to a treatment plant.

History of delayed coking process:–

Petroleum was first made in 1860’s in the early oil refineries in Pennsylvania which boiled oil in small iron distillation still to recover kerosene, a much needed lamp oil. The stills were heated by wood or coal fires build underneath them, which over-heated and coked the oil near the bottom. After the distillation was completed, the still was allowed to cool and workmen could then dig out the coke and tar. In 1913, William Merriam Burton, working as a chemist for the Standard Oil of Indiana, was granted a patent for Burton thermal cracking process that he had developed. He was later to become the president the Standard Oil of Indiana before he retired. In 1929, based on the Burton thermal cracking process, Standard Oil of Indiana built the first delayed Coker. It required hard manual decoking. In the late 1930's, Shell Oil developed hydraulic decoking using high-pressure water at their refinery in Wood River Illinois. That made it possible by having two coke drums, for delayed decoking to become a semi-continuous process. From 1955 onwards the growth in the use of delayed coking increased. As by 2002, there were 130 petroleum refineries worldwide producing 172,000 tons per day of petroleum coke. Included in those worldwide data, about 59 coking units were operating in the United States and producing 114,000 tons per day of coke. [7]
**Feed Types:** Delayed coking units generally process heavy residues such as:

- Vacuum residue.
- Catalytic cracking decant oil or slurry.
- Visbreaker residue or thermal cracking tar.
- Asphalt or lube oil extracts

**Coking Process Description**

The 40 ºC mixed crude oil sent from tank farm passes through feedstock- overhead circuiting oil heat exchanger, feedstock –diesel oil (III) heat exchanger and feedstock coker gas oil (II) heat exchanger to be heated up to 143 ºC. The heated crude is combined with heat exchanged crude in Phase I to enter into four-stage electrostatic desalting treatment (see figure 1).

The desalted crude out of desalting tank is divided into two routes, one route goes to the heat exchanging equipment of Phase II to exchange heat, the other route is heat exchanged to 186 ºC through feedstock - diesel oil (I) heat exchanger and then enters feedstock oil buffer tank. The crude oil in the buffer tank is pumped out by feedstock oil pump to exchange heat via feedstock-diesel oil (I) heat exchanger, feedstock-Coker gas oil reflux exchanger, feedstock - Coker gas oil (I) heat exchanger to reach 278 ºC. Then the crude oil enters into the convection section of the heating furnace to be heated to 320 ºC and then divided into two routes to enter the top and bottom of the six-layers duckbilled type column tray at the lower section of fractionation column, where it contacts with the oil gas from coking tower counter currently to exchange heat and mass transfer.

The fractions heavier than Coker gas oil (CGO) in the feedstock oil flow to the column bottom together with the condensate fraction (called circulation oil) of overhead oil gas from the coking tower. At a temperature of 366 ºC, the mixture is pumped to the radiation section of the furnace by heating furnace radiation section feeding pump to be promptly heated up to 500 ºC. Then it enters coking tower via four way valve, where cracking and condensation reactions are occurred to produce oil gas and coke. The mixture of high temperature oil gas escaped from coking tower top to the duckbilled type tray in the lower section at the bottom of the fractionation column. Circulation oil fraction is condensate, the rest large amount of oil gas passes through washing plate to enter vaporization stage
where it rises to distillation stage above the CGO collection pot to separate the cuts such as coking rich gas, gasoline, diesel oil and CGO.

After cooled to 40 °C via fractionation column overhead air cooler, the oil gas out of fractionation overhead enters fractionation column overhead oil gas separator. The separated rich gas is compressed by rich gas centrifugal compressor together with the rich gas separated in the Phase I and then cooled and separated. The condensate oil is sent to oil gas separator at the compressor outlet by condensate oil pump, while the compressed rich gas to absorption column. Overhead circulation oil is pumped out from the third tray of fractionation column via overhead circulation oil pump to enter feedstock - overhead circulation oil heat exchanger to exchange heat with feedstock. After cooled to 78 °C via overhead air cooler, the oil returns to the top of the fractionation column. Diesel oil pumped out from the 14th tray by diesel oil pump passes through feedstock - diesel oil ( ) heat exchanger and feedstock - diesel oil ( ) heat exchanger to reach 170 °C. And then it is divided into two parts, one part as reflux returns back to the 12th tray of the fractionation column, the other part exchanges heat with feedstock - diesel oil ( ) heat exchanger , rich absorbing oil- diesel oil heat exchanger and diesel air cooler to be cooled to 50 °C and then is divided into two routes (when needs Phase I coking unit supply all required absorbent of the reabsorbing tower).

One route is sent out of the unit, the other route is pressurized by Phase I diesel oil absorbent pump and cooled to 40 °C by Phase I diesel oil absorbent cooler and then enters reabsorbing column . The rich absorbing oil at the bottom of the column, exchanges heat with rich absorbing oil- diesel oil heat exchanger and then returns back to the fractionation column.

After sequent entering bottom reboiler of stabilization column and mid-way circulation steam generator, the mid-way circulation oil pumped out from the 18th tray of the fractionation column by mid-way reflux oil pump is divided into two parts, one part is injected into the reaction oil gas outlet of the coking tower as quench oil, the other part returns back to the 16th tray of the upper coking fractionation column as reflux oil.

CGO from CGO collection pot flows automatically into CGO stripping column. The overhead oil gas returns back to the 32nd tray of the coking fractionation column. The oil pumped out from the column bottom by CGO pump exchanges heat with feedstock – CGO ( I ) heat exchanger and feedstock – CGO ( II ) heat exchanger to reach 231 °C and then is divided into two parts (when needs
Phase I coking unit supply all required sealing oil for high temperature oil pumps). One part is sent to the oil sealing tank after cooled to 80 °C via oil sealing cooler, the other part exchanges heat with deoxygenated water-CGO heat exchanger and fuel gas-CGO heat exchanger to 140°C.

Then by passing through CGO air cooler, blower stops when conveying bot CGO) and CGO post cooler, then send it to FCCU in hot feeding way. If sending to tank farm, start and (E- to cool the part to 80 °C and then discharge it out of the unit.

In addition, the unit adopts CGO reflux to remove heat so as to adjust circulating ratio. CGO is pumped out of the CGO collection pot by CGO reflux oil pump and then exchanges heat with feedstock-CGO reflux heat exchanger to reach 233 °C. The heat exchanged CGO is divided into two routes to return back to the fractionation column, one route returns to the 31st tray of the fractionation column, the other route to the 34th tray of the fractionation column. In order to prevent the coking of the fractionation column bottom, circulation oil pump is furnished at the fractionation column bottom. After pressured by the pump, the bottom oil is divided into two routes to return back to the lower part of the 1st duckbilled type tray and the lower of the 6th tray respectively. A large amount of steam and a small amount of oil gas generated by coking tower steam blowing and coke cooling enter the contact cooling tower for washing. The washed heavy oil is pumped to contact cooling tower bottom oil and rejected oil cooling water tank by contact cooling tower bottom dirty oil pump to cool to 80 °C. One part returns to the top of the contact tower as cold reflux, the other part is refined or sent out of the unit. After cooled and condensed by passing through the contact cooling tower overhead air cooler and contact cooling tower overhead post cooler, the cooled overhead steam and light oil gas enter contact cooling tower overhead oil water separator.

The separated dirty oil is sent to a dirty oil tank by contact cooling tower overhead dirty oil pump, the sewage is either discharged to the coking water storage basin or the cold coking water tank as make-up water or discharged the oil containing sewage to the under ground sewage pipe network.

The coke accumulated in the coking tower is removed by the high pressure water supplied by the high pressure water pump. The removed coke together with water flows to coking storage basin. After separation, the decoked water flows to settling basin for reuse.

The cooling coke water from the coking tower flows automatically into the cooling coke water buffer tank or the cooling coke water settling tank. After oil is cut off, the water enters cooling coke
water lift pump to be lifted to the oil water cyclone separator to separate oil from water. The separated water phase enters air cooler to be cooled and then goes to cooling coke water storage tank for storage where it is pumped to the coking tower for cooling coke by cooling coke water pump. The dirty oil is sent to dirty oil tank where it is pumped to the top of coking tower by dirty oil pump for refining.

After the coke and coke cutoff water discharged from the coking tower enters the coke storage basin ,at first the coke cutoff water enters powder coke basin for sedimentation where large particle powder coke is settled down. Coke storage basin water lift pump lifts coke cutoff water to the settling basin to settle powder coke.

The coke cutoff water sequentially enters No.1, No.2 and No. 3 settling basins, each of which has latticework to hold up coke powder. The settled coke cutoff water is stored in water storage basin from which water is pumped out by the coke cutoff water lift pump and conveyed to the high level water tank to store for high pressure water pump coke cutting. [5]

**Products :** 1-Gases: fuel gas, fraction made up of C3-C4 (7.29% per weight).

2- Naphtha (16.81%W).

3- coke(13.08%W).

4- Diesel (43.40%W).

5-Wax oil (18.92%).

Several type of coke can be produced

**Anode Coke (Sponge coke):**

This coke is called sponge coke of its characteristic spongy appearance. The feed must be low in sulfur and metals. However, the feedstock for this type is often paraffinic and tends to produce low-density coke. Anode grade coke must be calcined before being used.

**Needle Coke:**

It is of a higher quality, produced by coking special aromatic tar such as thermal cracking tar. Its crystalline structure is in the form of small needle. It is used to manufacture graphite electrodes for
electric arc steel mill. It must undergo calcinations and other treatment before it attains its final characteristics

**Fuel Coke (Shot coke):**

Heating coke is the most commonly produced grade of coke worldwide. It is only a by-product of delayed coking operation, used as a tool for converting heavy residues into distillates, it require high concentration of asphaltine in the feedstock, dynamics (velocity and/or turbulence) in the coke drum, and high drum temperatures. Coker feedstock high in oxygen content can also produce shot coke. This grade of coke generally has a high sulfur and metal content. Physically, it look like something between sponge coke and ball-bearing like sphere. It is most generally used as fuel in cement kilns and thermal power plant.

**Fluid coking & flexi coking**

**Process Overview**

Fluid coking and its subsequent technology, Flexi coking provide additional hydrocarbon conversion capability to the refinery for transforming the heavier fractions of the crude oil (650 F-plus boiling range) into the lower boiling range, higher value liquid (30F to950F). Both technologies are based on fluid solid reactor concept. Fluid coking is a non-catalytic process, converting heavy hydrocarbon feed into lighter liquid products with investment levels compare with delayed coking. Feedstock capabilities range from atmospheric residuum, vacuum residuum, and deasphalter bottoms to oil sand bitumen.

Flexi coking is an extension of the fluid coking process that adds a third fluid vessel to the flow scheme, it is a continuous process developed and licensed by Exxon Petroleum Company. It includes thermal cracking in a bed of fluidized coke and gasification of the coke produced. The process allows virtually total conversion (99%) of the feed into gaseous and liquid products. The remain (1%) is a solid bottom discharge, which contains over (99%) of the metal present in the feed. The naphtha and distillate produced are processed in the refinery catalytic cracking and hydro treating unit, as well as in the desulphurization units which can recover (95%) of the sulfur present in the feed. The gas is termed low BTU gas and is burned in furnaces or thermal power plant in the refinery or in the neighboring facilities. The solid bottom discharge from the can reserve as feed stock for metal recovery unit. [8]
History of Fluid & Flexi-coking

The first fluid coking was constructed and started up in 1954 at Carter Oil Billing. Over the next five years, seven additional units were started up bringing the cumulative design capacity for fluid coking to nearly 120 kB/D. Of these eight units, three remain in operation today (the first fluid Coker at the Billing refinery Exxon Mobil and two other license units). Due to market conditions (demand for mogas and fuel oil), no additional units were constructed until the late 1960's when three additional fluid Coker were installed and added 40kB/D of design capacity.

During the same time frame, the late 1960's, process development was initiated on Flexi coking. Environmental concerns in some regions indicated that the utilization of high sulfur coke from fluid coking as boiler fuel was going to be restricted. By gasifying the coke internal to the process would reduce this and other environmental concerns from the fluid coking. The coke would therefore be converted into clean burning fuel. During 1974-1975, the Flexi coking process was demonstrated in a 750 B/D prototype unit at Esso Baytown refinery.

The unit operated for 16 months, processing a wide range of residuum feed stocks. Start-up of the first commercial Flexi coking unit was in 1976. Between 1978 and 1986, four additional Flexi coking were constructed and started up. [7]

Feed Types

It is a highly flexible process that can be applied to a wide variety of feeds. It can process almost all liquid fractions, including atmospheric and vacuum residues of any origin, even those rich in contaminants (metals, sulfur, nitrogen, etc).

Products

Flexi coking yield the same type of gaseous and liquid hydrocarbon products as delayed coking with one exception instead of coke, the unit produces a low BTU gas (heating value of around 4200-500 KJ/std m³).
2-2Charcoal

It is the solid residue remaining when wood is "carbonized or pyrolysed" to obtain a fuel of reduced size, reduced weight, smokeless fire and a higher calorific value per weight. The process occurs in a closed space under controlled conditions.

2-2-1 Carbonization Process

First, the wood is dried and heated up to 280°C, in atmosphere not containing oxygen; it is thermally spilt into a mixture gaseous components and charcoal. This stage is endothermic; the energy needed has to be supplied. Then, the process becomes exothermic and charcoal is formed. Two basic types of carbonization process exist.

Charcoal Kiln

In the traditional charcoal kiln or pit, some of the wood loaded into the kiln is burned to dry and raise the temperature of the whole of the wood charge, so that pyrolyses starts, once it started, it continue by itself and gives off considerable heat. However, this pyrolyses or thermal decomposition of cellulose and lignin of which the wood is composed does not start until the wood's temperature is raised to about 280°C. The conversion efficiency of wood to charcoal is 25-5% by weight of the dry matter depending on wood characteristic, kiln type and labor profession.

Retort Process

Wood is converted to charcoal in a closed space heated from outside. The hot flue gas is conducted through the retort drying and heating the stored wood. This led to high yields of quality charcoal using the heat of pyrolyses, normally wasted, to raise the temperature of the incoming wood, so that pyrolyses is accomplished without burning additional wood. No combustion takes place in the retort due to the absence of oxygen. The efficiency of this process is about 20-35% by weight.

All carbonizing systems give higher efficiency when feed with dry wood, since removal of water from wood needs large input of heat. In Sudan, 546,000 hectares (1 hectare = 154.17 m$^3$) or 28, 4% of the total land is forested. The wood removal in 2005 for energy purpose is 19, 514,000 cubic meters. [9]
2-3 Gasification

Gasification is a partial oxidation process (occur in a limited amount of air/oxygen and in the presence of heat) whereby a carboneous solid or liquid, is broken down into carbon monoxide (CO) and hydrogen (H₂), plus carbon dioxide (CO₂) and possibly hydrocarbon molecules such as methane (CH₄). This mix of gases is known as 'producer gas' or product gas, wood gas, coal gas depending on the feedstock. The precise characteristics of the gas will depend on the gasification parameters, such as temperature, and also the oxidizer used. The oxidizer may be air, in which case the producer gas will also contain nitrogen (N₂), or steam or oxygen.

2-3-1 Types of Gasification

Low Temperature Gasification

If the gasification takes place at a relatively low temperature, such as 700 °C to 1000 °C, the product gas will have a relatively high level of hydrocarbons compared to high temperature gasification. As a result it may be used directly, to be burned for heat or electricity generation via a steam turbine or, with suitable gas clean up, to run an internal combustion engine for electricity generation.

The combustion chamber for a simple boiler may be close coupled with the gasifier, or the producer gas may be cleaned of longer chain hydrocarbons (tars), transported, stored and burned remotely a gasification system may be closely integrated with a combined cycle gas turbine.

High Temperature Gasification

Higher temperature gasification (1200 °C to 1600 °C) leads to few hydrocarbons in the product gas, and a higher proportion of CO and H₂.

This is known as synthesis gas (syngas or biosyngas) as it can be used to synthesize longer chain hydrocarbons using techniques such as Fischer-Tropsch (FT) synthesis.

If the ratio of H₂ to CO is correct (2:1) FT synthesis can be used to convert syngas into high quality synthetic diesel biofuel which is completely compatible with conventional fossil diesel and diesel engines[10].
2-3-2Historical Background.[10]

Although gasification was invented in the early-1800s, the technology has undergone a complete transformation in the last 50 years (with the most rapid changes in the last two decades). Gasification has gone through five stages:

1850 to 1940: Gasification was first used to produce “town gas” for light and heat. And—until development of natural gas supplies and transmission lines in the 1940s and 1950s—virtually all gas for fuel and light was manufactured from the gasification of coal.

1940 to 1975: The second stage of gasification began during World War II when German engineers used gasification to produce synthetic fuel.

This technology was exported to South Africa in the 1950s, where it was further developed to produce liquid fuels and chemicals.

1975 to 1990: The next stage in the evolution of gasification began after the Arab Oil Embargo of 1973. In reaction to that event and the ensuing “energy crisis,” the U.S. government provided financial support for several proof-of-concept gasification projects, including the world’s first Integrated Gasification Combined Cycle (IGCC) electric power plant. Another seminal event during this period was conversion of Eastman Chemical’s flagship manufacturing plant from petroleum to syngas from coal.

1990 to 2000: The fourth stage of gasification’s development began in the early 1990s when government agencies in the United States and Europe provided financial support to four medium-sized (≈ 250 MW) projects to further “demonstrate” the feasibility of the IGCC process.

2000 to present: The current stage in the evolution of gasification began when commercial developers started building IGCC power plants without government subsidies. These new IGCC facilities (all outside the United States) are adjacent to refineries where petroleum coke and other residual hydrocarbons are readily available.
2-3-3 Gasification in Use at Present

In 2004, The Gasification Technologies Council in United states of America conducted a survey of global gasifier use and projected development. The GTC survey identified 385 gasifiers in use at some 177 projects in 27 nations. Major projects are operating successfully on four continents.

Africa:

The world’s largest concentration of gasifiers is in South Africa where synthetic fuels and chemicals have been produced from coal since 1955. The gasification projects use about 100 gasifiers to produce more than 40 percent of South Africa’s liquid fuels and a variety of chemical products.[10]

Gasification in Sudan:

In 1985, Gasification technique is introduced in Sudan by the former National Energy Administration (NEA) in co-operation with the French Agency of Energy, where a French downdraft gasifier with generator is used between 1986-1987 for irrigation purpose. It had a capacity of 25 K w using wood ship as fuel at Shambat Institute. In 1987-1989, the same gasifier was used for lighting at a rate of 6-8 hour/day at Wad Elbur and Elrof villages at Gezira using cotton stalk and groundnuts shells briquettes as fuel. The project was stopped due to some technical and administration problems. In 1980, downdraft gasifier was designed and constructed locally at Energy Research Institute (ERI). It was coupled with a diesel engine which provided 80% of the energy needed from charcoal for output of 3 k w. In 1995, updraft gasifier was designed and constructed at ERI using charcoal as fuel for heating purposes at a rate of 6 hour/day. In 1998, downdraft gasifier was also designed and constructed at Energy Research Institute (ERI) for Military Manufacture Company. It was coupled with internal combustion engine and had capacity of 5 kw using charcoal as fuel. [11]

Asia

The Indian projects produce ammonia fertilizer at sites, the Chinese projects produce fertilizer or chemicals, and the Japanese project produces electricity from pet coke at Yokoham refinery.

Europe

There are five large IGCC projects operating in Western Europe, with the greatest concentration in Italy. The three Italian projects produce more than 1,500 MW of electricity from refinery residuals at
Priolo (Sicily), Sarroch (Sardinia), and Sannazzaro (Northern Italy). The other IGCC projects – located at Puertollano (Spain) and Buggenum (Netherlands) – generate electricity from coal and petroleum coke.

**North America**

Gasification is used to produce chemicals, fertilizers, and electricity at several sites across the United States. Major projects include a coal-to-chemicals facility in Kingsport, Tennessee; a coal-to-methane (natural gas) project in Buelah, North Dakota; an ammonia fertilizer plant in Coffeeville, Kansas; and IGCC power plants in Tampa, Florida, and Terra Haute, Indiana.[10]

### 2-3-4 The Future of Gasification.[10]

Gasification is a technology on the threshold of extraordinary growth. Dozens of projects are under design and construction in the United States and around the globe. Here is one likely scenario based on the 2004 Gasification Technologies Council survey and general industry consensus:

**2005 to 2010:** During this period the IGCC process will be used to produce electricity at refineries in the United States from pet coke and similar materials. New coal-based projects will greatly expand the production of chemicals in China. And, an entirely new application will be seen in Canada, where syngas from gasification will be used to increase petroleum production in the Alberta oil sand fields.

**2010 to 2015:** The first generation of large-scale (500 MWe or greater) coal-based IGCC power plants will come online in the United States. These projects will further demonstrate to regulators and lenders that such projects are technically and financially sound. Gasification use for fertilizer and chemical production will grow dramatically (particularly in China).

**2015 to 2025:** The second generation of large-scale IGCC plants will be built. They will take advantage of “lessons learned” in prior IGCC installations and may be sited at locations where the carbon dioxide created in the plants can be captured and stored in underground geological formations. Such projects may also be designed with the flexibility to produce power, chemicals, fuels, and other products depending upon prevailing.[10]
2-3-5 Types of Gasifiers

There are four main gasifiers types:

- Updraft gasifier.
- Downdraft gasifier.
- Cross draft gasifier.
- Fluidized bed gasifier. (see figure.2)

Updraft Gasifier

In updraft gasifier as known as counter current gasifier the feed stocks enter from top of the reactor vessel. The air is blown at the bottom, ash passes downward, whereas the produced gas passes upward and is driven through an outlet at the top of the reactor. Within the gasifier four zones are distinguished, from top to bottom:

- Drying zone.
- Pyrolysis zone.
- Reduction zone.
- Oxidation zone.

The advantage of the system is

- High thermal efficiency.
- Simple design.
- Accept a variety of fuels and fuels sizes.
- Suitable for direct heat application.
- Small pressure drop.
- Little tendency towards slag formation.
The disadvantages are:

- The produced gas is not clean and contains many condensates such as tar. Therefore, it requires costly and complex cleaning, which restrict its uses for shaft power application.

- Relatively long time required for start up of Internal Combustion engine.

- Poor reaction capability with heavy gas load.

- The dust and condensate filtered from the gas are unacceptable loads for most countries.

**Downdraft Gasifier**

The gasifier was named because of its characteristics that feedstock’s and gas move downward whereas the air is introduced in the reactor vessel almost at its bottom. The four zones situated differently from top to bottom

- Drying zone.

- Pyrolysis zone.

- Oxidation zone.

- Reduction zone.

The produced gas has to pass through the hot hearth area before entering the reduction zone. The gasifier is therefore able to produce a practically tar-free gas suitable to power internal combustion engines. The geometrical design of the hearth zone is most important for the gas output and the gas quality of this gasifier.

The advantages of the system are:

- Good thermal efficiency.

- Tar-free gas.

- Reactor of simple design.

- Suitable for internal combustion engines.

- Flexible aaptation of gas production to load.

The disadvantages are:
- Accept only dry fuel of block size (match box to cigarette box size), granular or even briquetteed biomass is unsuitable.

- Hearth zone and air intake nozzles have to be from heat resistant steel.  - Design tend to be tall.

**Cross draft Gasifier**

The air enters on one side and the produced gas leaves on the opposite side at the same level in the combustion zone. The air is blown with high speed. As the residence time is short, there is only a reduced transformation from CO₂ to CO. In the oxidation zone temperature are up to 2000 °C, thus air and water-cooled nozzles for air intake is mandatory.

The advantages are:

- High thermal efficiency.

- Suitable for vehicles because they are light and of quick response to load change.

- Short design height.

- Flexible gas production

The disadvantages are:

- Complex and expensive design

- High slag formation.

- High pressure drop
FIG. (2)

(a) UP DRAFT

(b) DOWN DRAFT

(c) CROSS DRAFT

(d) FLUIDIZED BED
Fluidized–bed Gasifier

In fluidized bed gasifier the air is blown upwards through the biomass bed. The under such conditions behave like boiling fluid, the intensive and homogenous mixture of feedstock and gas lead to an extensive heat and gas exchange, excellent temperature uniformity and provide efficient contact between gaseous and solid phase. The fuel has to be of granular size in determined dimension to allow easy fluidization of the bed.

Some systems use sand or similar products to support the heat exchange between the feedstock particles. To obtain a gas of continually equal quality constant mass stream are necessary. This calls for a high investment in control and equipment. The produced gas is almost tar-free but has to be purged from dust and ash in adequate high and low temperature filters. The conditioned gas is of high purity is suitable to power internal combustion engines.

The advantages of the system are:

- High volumetric capacity.

- Relatively low thermal efficiency.

- Flexibility to feed rate, accept dry biomass of granular size, with high ash content as fuel i.e.: saw dust, peat… etc, sulfur in the stack gas can be minimized by adding lime to the feedstock. The disadvantages are:

- The fuel has to be reduced in size.

- The complexity of design makes it only feasible for capacities of more than 250kw
2-3-6 Gasification Process

There are four distinct processes take place in the gasifier to convert the solid fuel into combustible gas

a) Drying of fuel.

b) Pyrolysis—a process take place in which tar and other volatiles are driven off.

c) Combustion.

d) Reduction.

Though there is a considerable overlap of the processes, each can be assumed to occupy a separate zone where fundamentally different chemical and thermal reactions take place (see figure 3)

These zones can be summarized as follows:

**Combustion Zone**

It is lies near the base of the gasifier, where the air is fed (see fig.4). The combustible substance of a solid fuel is usually composed of elements carbon, hydrogen and oxygen.

In complete combustion, carbon dioxide is obtained from carbon in fuel and water is obtained from the hydrogen, usually as stream. The combustion reaction produce incombustible gases, it is exothermic and yields a theoretical oxidation temperature of 1456°C. The main reactions, therefore, are:

\[ C + O_2 = CO_2 \ (+393 \text{MJ/kg}) \]  

**Reduction Zone**

In general it is adjacent to the combustion zone, but no air is admitted. The products of partial combustion (water, carbon dioxide and uncompensated partially cracked pyrolysis products) now pass through a red hot charcoal bed where the combustible gases (CO, CH₄, H₂) are produced through the following reduction reactions:
C + CO₂ = 2CO (-164.9 MJ/kg)------------------------(2-2)
C + H₂O = CO + H₂ (-122.6 MJ/kg)------------------(2-3)
CO + H₂O = CO + H₂ (+42 MJ/kg)-------------------(2-4)
C + 2H₂ = CH₄ (+75 MJ/kg)--------------------------(2-5)
CO₂ + H₂ = CO + H₂O (-42.3 MJ/kg)-----------------(2-6)

Reactions (2-2) and (2-3) are main reduction reactions and being endothermic have the capability of reducing gas temperature.

Consequently the temperatures in the reduction zone are normally 800-1000 ºC. Lower the reduction zone temperature (~700-800 ºC), lower is the calorific value of gas. The combustible gases (CO, CH₄, and H₂) are produced.

**Pyrolysis Zone**

It always lies above the reduction zone. The products depend upon temperature, pressure, residence time and heat losses. However, following general remarks can be made about them. Up to temperature of 200 ºC only water is driven off. Between 200 ºC to 280 ºC, carbon dioxide, acetic acid and water are given off. The real pyrolysis, which takes place between 280 ºC to 500 ºC, produces large quantities of tar and gases containing carbon dioxide. Besides light tars, some methyl alcohol is also formed. Between 500 ºC to 700 ºC, the gas production is small and contains hydrogen. The solid material remaining after pyrolysis is carbon, in the form of charcoal which passes down through the gasifier and is consumed in the combustion and reduction zones.

**Drying Zone**

It is located at the top of the gasifier. No chemical reaction occurs here due to the low temperature, the main process is the drying of the feedstock. The fuel moisture and some organic acids are driven off.
FIG (2)

UPDRAFT GASIFIER REACTIONS ZONES

\[ \text{biomass feed} \]

- Drying zone
- Pyrolysis zone
- Reduction zone
- Combustion zone

- Gas

- Tar & other volatile driven off

- \[ \text{C} + 2\text{H} \rightarrow \text{CH}_4 \]
- \[ \text{C} + \text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2 \]
- \[ \text{C} + \text{CO}_2 \rightarrow 2\text{CO} \]
- \[ \text{C} + \text{O}_2 \rightarrow \text{CO}_2 \]
2-3-7 Application of Gasification Process

The main applications of gasification process are:

a) Direct heat application.

b) Shaft power systems.

c) Chemical productions.

Direct Heat Application

The producer gas is burnt directly in furnace or boiler. It may be used in agricultural applications like drying of farms produce or grains, green house heating and running of absorption refrigeration and cooling systems. The gas quality is less critical than in shaft power systems and consequently they are less demanding on cooling and cleaning equipments.

Most of the direct heat gasifier currently available are of updraft or fluidized bed types. Their output varies from 0.25-25 Gj/hr. Since the production of gas fluctuates with time it is sometimes necessary to have storage of gas. This can provide very uniform quality of gas. Because of low content of producer gas (~5Mj/ m³) which is about 10- 15% that of natural gas, special burners are needed. Since the adiabatic flame temperature of producer gas is about 1400 ºC. The highest temperature applications using the gas for 1600 ºC. Direct heat systems can be coupled to other renewable energy systems like solar for thermal applications.

Shaft Power Systems

The producer gas can be used in driving IC engines, both spark ignition and compression ignition. However in actual practice for long period of time, some technical problems appear. Producer gas being low energy gas has certain combustion characteristics that differ markedly from gasoline or diesel oil. Thus in future it is worthwhile to do considerable work to make an engine specific for the gas.

Spark Ignition Engines

When spark ignition engine is converted to operation on producer gas it is derated to about 40-50%. The deration is primarily because of low energy density of producer gas. This accounts for about
30% loss of power. The rest is accounted for by the pressure drop in intake valves and piping. spark ignition engine on whole requires very little modification to run on producer gas. Generally depending upon the make of the engine(compression ratio and rpm), the ignition timing has to be advanced by about 30-40 degrees due to the low flame speed. Thus an engine with engine with 1500-2500 rpm is ideal for producer gas application. It should be noted that in general the overall efficiency of the IC engine itself does not change though the power derating takes place. Thus a conservative figure of 15-20% can be used as efficiency of spark ignition engines.

**Compression Ignition Engines**

It cannot be operated on producer gas completely without injection of small amount of diesel. This is because the producer gas cannot ignite by itself under prevailing pressure. Thus for compression ignition engines to run on producer gas they have to be either.

a) duel fuel engine or, b) converted into spark ignition engines.

Since diesel engines have compression ratio between 16-20 and are run at lower rpm than gasoline engines they are ideally suited to run on producer gases with spark ignition.

However, conversion of the engine to spark ignition is costly and elaborate affair and the advantages are nullified by the cost. Thus most of the diesel engines running on producer gas have to be of a dual fuel type. Because of high compression ratio and low speed, the derating of diesel engines running on producer gas is only between 15-30%.

This is far superior to the gasoline engine’s derating. Even if gasoline engine are used in dual fuel mode their derating is still between 40-50%.On average the diesel engine can run on 15-20%( of the original consumption) diesel and rest on producer gas. Generally the engine is started on diesel and as the gas generation builds up the diesel consumption is then kept up at idling level. The engine efficiency in this case is about 25%.In both the diesel and gasoline engines the introduction of producer gas to gas to the engine is by a T valve where, from one section of the T air is sucked in. Thus the complicated carburetor is greatly simplified by the above arrangements. Many arrangements have been developed for introduction of air/gas mixture in the engine.
Chemical Production

Methanol

Commercial methanol synthesis involves reacting carbon dioxide (CO), hydrogen (H₂) and steam over a copper-zinc oxide catalyst in the presence of small amount of carbon monoxide (CO₂) at a temperature of about 260 °C (500°F) and the presence of about 70 bar (1015 psi).

The methanol synthesis reaction is equilibrium controlled, and excess reactants (CO and H₂) must be recycled to obtain economic yields. The formation of methanol from synthesis gas proceeds via the water-gas shift reaction and the hydrogenation of carbon dioxide.

\[ \text{CO} + \text{H}_2\text{O} = \text{H}_2 + \text{CO}_2 \] (water gas shift) \[ \text{CO}_2 + 3 \text{H}_2 = \text{CH}_3\text{OH} + \text{H}_2\text{O} \] (Hydrogenation of carbon dioxide)

\[ 2 \text{H}_2 + \text{CO} = \text{CH}_3\text{OH} \]

Methanol production also occurs via direct hydrogenation of CO, but at much slower rate. To best use the raw product syngas in methanol synthesis and limit the extent of further syngas treatment and steam reforming, it is essential to maintain:

- A ratio (H₂/CO) of at least 2.
- A ratio (CO₂/CO) of about 0.6 to prevent catalyst deactivation and keep the catalyst in an active reduced state.
- Low concentration of N₂, CH₄, C₂+, to prevent the build up of inert within the methanol synthesis loop.
- Low concentration of CH₄ and C₂+ to limit the need for further steam reforming.
**Synthetic Fisher-Tropsch (FT) Fuel**

The Fisher-Tropsch (F-T) process converts syngas into a mixture of various chain length paraffinic and olefinic hydrocarbons. The F-T synthesis takes place over a cobalt or iron based catalyst where carbon monoxide and hydrogen react to form hydrocarbons and water.

The hydrocarbon product includes material of varying properties such as light gases (C2-C4) through waxy liquids such as (C50+) molecules. The process normally operate at a relatively moderate temperature (204-288 °C) [400-550°F] and moderate pressure (9-38 bar) [130-550 psi].

The syngas is first treated for trace sulfur removal to 0.5 ppm, and then fed to F-T reactors with H2: CO molar ratio typically between 1.5-2.1. The F-T synthesis reaction can be written in the general form:

\[(n/2 + m) \text{H}_2 + m \text{CO} = C_m \text{H}_n + m \text{H}_2\text{O}\]

Where \(m\) is the average chain length of the hydrocarbon formed, and \(n\) equals \(2m+2\) when only paraffin are formed, and \(2m\) when only olefins are formed. [12]
2-3-8 Gasification Hazards

Toxic, fire and explosion hazards are the main categories

Toxic Hazards

An important constituent of producer gas is carbon monoxide (40-70%), an extremely toxic and dangerous gas because of its tendency to combine with the hemoglobin of the blood and in this way prevent oxygen absorption and distribution. A summary of the effects caused by different concentrations of carbon monoxide in the air is given in Table (6).

Fortunately normal producer gas installations work under suction, so that even if a minor leak in the installation occurs, no dangerous gases will escape from the equipment during actual operation. The situation is different however during starting-up and closing down of the installation.

During starting-up the gas is generally vented, and it is necessary to ensure that the gases produced cannot be trapped in an enclosed room. As a rule a suitable chimney will provide sufficient safety.

During closing-down of the installation a pressure buildup in the gasifier will occur, caused by the still hot and pyrolysing fuel. As a result gases containing carbon monoxide will be released from the installation during a relatively short period. It is because of the danger from those gases that it is generally recommended that a gasified installation be located in the open air, if necessary covered by a roof.
Table (6): Toxic effects of different concentrations of carbon monoxide in the air.[12]

<table>
<thead>
<tr>
<th>Percentage of CO in air</th>
<th>ppm</th>
<th>effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>50</td>
<td>no significant effects</td>
</tr>
<tr>
<td>0.02</td>
<td>200</td>
<td>possibly headache, mild frontal in 2 to 3 hours</td>
</tr>
<tr>
<td>0.04</td>
<td>400</td>
<td>headache frontal and nausea after 1 to 2 hours, in the back of the head after 2.5 to 3.5 hours</td>
</tr>
<tr>
<td>0.08</td>
<td>800</td>
<td>headache, dizziness and nausea in 45 min. collapse and possibly unconsciousness in 2 hours</td>
</tr>
<tr>
<td>0.16</td>
<td>1600</td>
<td>headache, dizziness and nausea in 20 minutes, collapse, unconsciousness and possibly death in 2 hours</td>
</tr>
<tr>
<td>0.32</td>
<td>3200</td>
<td>headache and dizziness in 5 to 10 minutes, unconsciousness and danger of death in 30 minutes</td>
</tr>
<tr>
<td>0.64</td>
<td>6400</td>
<td>headache and dizziness in 1 to 2 minutes, unconsciousness and danger of death in 10 to 15 minutes</td>
</tr>
<tr>
<td>1.28</td>
<td>12800</td>
<td>immediate effect; unconsciousness and danger of death in 1 to 3 minutes</td>
</tr>
</tbody>
</table>

There has been some dispute, deriving from Swedish experience, whether chronic poisoning can occur as a result of prolonged inhalation of relatively small amounts of carbon monoxide which give no acute effects. It seems that the issue now has been resolved: no chronic symptoms can occur through carbon monoxide poisoning.
However this does not mean that the symptoms mentioned in Swedish literature (tiredness, irritability and touchiness, difficulty in sleeping) did not result from prolonged exposure to producer gas. There is a possibility that some other compound(s) in the gas are responsible for the symptoms. The above stresses again the importance of placing stationary installations in an open environment as well as of taking care to avoid close contact with the gases during the starting-up and closing-down phases.

**Fire Hazards**

Fire hazards can result from the following causes:

- High surface temperature of equipment
- The risk of spark during refueling.
- Flames through gasifier air inlet on refueling lid.
- Risks can be considerably decreased by taking the following precautions:
  - Insulation of hot parts of the system.
  - Installation of double sluice filling device
  - Installation of back-firing valve in gasifier inlet.

**Explosion Hazards**

Explosions can occur if the gas is mixed with sufficient air to form an explosive mixture.

This could occur for several reasons:

- Air leakage into the gas system.
- Air penetration during refueling
- Air leakage into a cold gasifier still containing gas which subsequently ignites.
- Backfiring from the fan exhaust burner when the system is filled with a combustible mixture of air and gas during starting-up.
Air leakage into the gas system does not generally give rise to explosions. If a leakage occurs in the lower part of the gasifier (as is generally the case) this will result in partial combustion of the gas leading to higher gas outlet temperatures and a lower gas quality.

When the pyrolytic gases in the bunker section are mixed with air (as is bound to happen during refueling) an explosive mixture can be formed. It is not unusual for this to result in small and relatively harmless explosions, especially when the fuel level in the bunker is relatively low.

Risk to the operator can be obviated if the gases in the bunker section are burnt off through the introduction of a piece of burning paper or the like, immediately after opening the fuel lid. Another possibility is to install a double sluice type filling system.

Air leakage into a cold gasifier and immediate ignition will lead to an explosion. Cold systems should always be carefully ventilated before igniting the fuel.

During the start-up of an installation, the gases are as a rule not passed through the entire filter section, in order to avoid blocking the filters with the tars produced during start-up. The filter may thus still contain air, and after an inflammable gas is produced and led through the sometimes quite voluminous – filter section an explosive mixture can result. If the gas is now ignited at the fan outlet a backfire can occur, leading to a violent explosion in the filter section. It is for this reason that it is advisable to fit the fan outlet with a water lock.

**Environmental Hazards**

During the gasification of wood and/or agricultural residues, ashes (from the gasifier and from the cleaning section) and condensate (mainly water) are produced. The latter can be polluted by phenolics and tar. The ashes do not constitute an environmental hazard and can be disposed of in the normal way. For the tar-containing condensate the situation is different, and disposal of those from a large number of gasifiers can have undesirable environmental effects. No hard data are available on the bio-degradation of the phenolic and tarry constituents of the condensates, and the problem of disposal needs careful study.

The properties of exhaust emissions from engines run on producer gas are generally considered to be acceptable, comparable to those of diesel engines. [13]

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3- Experimental Work

This part of the research describes the comparative tests which have been performed to determine the gasification characteristics of petroleum coke and charcoal, these tests are: fuel tests and producer gas characteristics tests.

3-1 fuel Tests

3-1-1 Moisture Content

It is the weight percentage of water molecules contained in the fuel.

Materials
- Petroleum coke obtained from Khartoum Refinery Company (KRC)
- Charcoal obtained from the local market. (see fig. 7)

Apparatus & Equipments
1/ Oven – Gallenkamp.
2/ Analytical Balance.
3/ Porcelain crucibles.
4/ Desiccator (containing silica gel as dryer agent)

Method
- The oven was heated to 105°C
- The porcelain crucible was placed in the oven for 10min
- The crucible was cooled in desiccators for one hour, and then the crucible was weighed.
- About one gram of sample was weighed on the dry crucible (A), which was then placed on the oven at 105°C, for 24 hours.
- The dried sample was put in the desiccators for one hour, and then weighed (B).

Method of Calculations
Moisture Content = (A-B)/A%
3-1-2 Ash Content

It is the mineral content of the fuel that remains after complete combustion measured as weight percentage.

Material
- As described in the moisture test.

Apparatus & Equipments
1/ Muffle furnace – Scott Science.
2/ Analytical Balance.
3/ Porcelain crucibles.
4/ Desiccators (containing silica gel as dryer agent)

Method
- The crucible containing the dried sample (B) from the previous experiment was put in the muffle furnace at 750°C for six hours.
- The crucible was cooled in desiccators for one hour, before being weighed (C).

Method of Calculations:

Ash Content = B/C
3-1-3 Gross Calorific Value $Q_g$ (MJ/kg)

It’s the quantity of energy released when a unit mass of fuel is burned in a constant volume enclosure.

**Materials**
- As described in the moisture test.

**Apparatus & Equipments**
- Oxygen Bomb, Calorimeter, Jacket with stirrer, Thermometers, Timing Device, Sample holder, Firing wire (100mm of No 34B&S gage iron wire or Chromel C resistance wire), Firing circuit (6-16 V).

**Method**
There are two methods to calculate Gross Calorific Value:
- Isothermal jacket method.
- Adiabatic jacket method.

The Isothermal jacket method was used in this experiment as follow:
- About (0.9-1.1)g of the sample is weighed.
- The bomb is charged with oxygen to 3.0MPa (30 atm) gage pressure at room temperature.
- The calorimeter water temperature is adjusted (6 to 2°C below jacket temperature).
- The calorimeter is put in the jacket, and then the stirrer started.
- Five mintues is allowed for attainment of equilibrium, and then the calorimeter temperature is recorded at 1-min intervals for 5 mintues.
- The charge is fired at the start of the sixth minute and the time and temperature is measured.
Method of Calculation

Gross heat of combustion is computed by substituting in the following equation:

\[ Q_g = \frac{(tW-e)}{1000g}. \]

Where:

- \( Q_g \) = gross heat of combustion, at constant volume expressed as MJ/kg,
- \( t \) = temperature rise °C,
- \( e \) = instrument correction.
- \( W \) = energy equivalent of calorimeter, MJ/°C,
- \( g \) = weight of sample.
3-1-4 **Bulk Density (g/ cm³)**

It is the weight per unit volume of material, the higher the bulk density, the similar the gasifier volume since for one charge one can get power for longer time.

**Materials**
- Petroleum coke obtained from (KRC).
- Charcoal obtained from the local market.

**Apparatus & Equipments**
- Balance.
- Measuring cylinder.
- Funnel.

**Method**
- The sample and the funnel are weighed.
- The funnel is suspended above a measuring cylinder.
- The funnel is filled with the sample and allowed to freely flow into the measuring cylinder.
- The scraped off water after putting the weighted sample (W), is collected and then its volume (V) is measured.

**Method of Calculation**
Bulk Density = \( \frac{W}{V} \) (g/ cm³)

3-1-5 **Particle size and size distribution**
- The petroleum coke and charcoal are controlled to have the size of (3cm*3cm*3cm).(see fig. 7)
3-2 Producer Gas characteristics Tests

3-2-1 Introduction

Most of the producer gas characteristics can be determined by the measure of:

1/ Gas Analysis.
2/ Producer Gas Flame Temperature.
3/ Flame Duration.
4/ Fuel Consumption.
5/ Ash Residue.

Materials

-Petroleum coke, same as used in the previous experiments.
-Charcoal, same as used in the previous experiments.

Apparatus& Equipments

1-Updraft Gasifier:
The Gasifier used in the study is 125cm height and 50 cm diameter. It is made of commercial steel plates, and fabricated at Energy Research Institute (ERI). (see fig.4,5)

2-Gas Chromatograph:
Instrument Model: Vinci.
Injection Temperature: 115°C
Column oven: 95-30°C /min, 180-hold  30 min

3- Digital Thermometer.
4-Balance.
5-Time Device

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Method
- About 24 kg of petroleum coke is put in the gasifiers, which fill it till level 3 (45 cm over the hearth cone base) (see fig 4, 5).
- The coke then ignited using paper from the bottom of the gasifier.
- The blower is operated to maintain constant air draft through the coke bed, with regulating valve open fully for 10 minutes, and then the air valve is reduced to 1/4 of the full opening degree.
- The gas coming out from the gasifier is ignited till it is put off, its temperature is measured by digital thermometer at interval time of 5 minutes, and the flame duration is also recorded using stop watch.
- The air valve is then opened fully for 10 minutes, and then reduced to 1/4 of the full opening degree.
- The gas coming from the gasifier is reignited, its temperature and the flame duration is measured.
- The above steps are repeated for two hours.
- The gasifier is left for 24 hours to cool, then the ashes are collected and weighed, the coke left is also weighed.
- The same procedure was repeated with exception that the air flow through the gasifier is maintained with the controlling valve opened fully for 5 minutes, and then it reduced to 1/4 of the full opening degree.
- The experiment is repeated for the fully opening of the air valve for 10 minutes, then reduced to 1/8 of the full opening degree.
- The same procedure is done for charcoal using 22 kg, which fill the gasifier till level 3 (45 cm over the hearth cone base).
CHAPTER FOUR
### 4-Results and Discussion

#### 4-1 Fuel Tests Results

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Test Method</th>
<th>Unit</th>
<th>Petroleum Coke</th>
<th>Charcoal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Contents</td>
<td>ASTM D3173</td>
<td>Percentage</td>
<td>3.29</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.56</td>
<td>5</td>
</tr>
<tr>
<td>Ash Contents</td>
<td>ASTM D4422</td>
<td>percentage</td>
<td>3.92</td>
<td>2.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.35</td>
<td>3-4</td>
</tr>
<tr>
<td>Calorific Value</td>
<td>ASTM D240</td>
<td>MJ/kg</td>
<td>35.69</td>
<td>36.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>28.20</td>
<td>28</td>
</tr>
<tr>
<td>Density</td>
<td>ASTM D1895B</td>
<td>g/cm³</td>
<td>1.04</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.64</td>
<td>0.4-0.6</td>
</tr>
<tr>
<td>Size</td>
<td>-</td>
<td>3cm*3cm</td>
<td>3cm*3cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>3cm*3cm</td>
<td>3cm*3cm</td>
<td></td>
</tr>
</tbody>
</table>
Discussion

The fuel type which is suitable for gasification must have:

- Moisture content less than 20%.
- Ash content less than 6%. [12]

Moisture Content

It is noticed that the two fuels are on the appropriate range for moisture content. The tests results values are approximately as the values reported in literature. Water in fuel may cause many technical problems like:

- The condensate water drop will result in poor gas quality with less heat value.
- The possibility of acids composition which cause corrosion.
- Much more heat will be needed to evaporate water and reduce the energy budget of the process.

Thus, it recommended letting the upper fuel gate open for 5 minute after combustion to evaporate water and that was done in this test.

Ash content

The ash content of fuel has two major impact on trouble free operation of gasification:

- It can fuses together to form slag and this clinker stops or inhibits the downward flow of feed in continuous process.
- It can shelter the point in fuel where ignition is initiated and thus lowers the fuel reaction response.

In fact some fuels with high ash content can easily be gasified if evaporate ash removal system is installed in the gasifier.

It is found that ash result for petroleum coke is on the accepted range, but charcoal is exceed the range which may refer to the charcoal quality.

Charcoal gasification process efficiency may reduce due to its higher ash content.

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Fuel Calorific Value

It is an indicator for the energy budget of the gasification process. It is used to compute the average energy of solid into gaseous.

\[ \mu_{\text{Gas}} = \frac{\text{calorific value of gas (MJ/Kg)} \times \text{volume of gas (m}^3\text{)} \times \text{calorific value of fuel (KJ/kg)} \times \text{fuel}}{\text{calorific value of fuel (KJ/kg)}} \]\n
The test results for the two fuels are typically similar to the values reported in literature.

Bulk density of the fuel

Fuels with high bulk density are advantageous because they represent a high energy-for-volume value. Consequently, these fuels need less bunker space for a given refueling time. Low bulk density fuels sometimes give rise to insufficient flow under gravity, resulting in low gas heating values and ultimately in burning of the char in the reduction zone. The bulk density varies significantly with moisture content and particle size of the fuel. The test results for the two fuels are in the acceptable range.

Particle size and size distribution

Up and down draft gasifiers are limited in the range of fuel size acceptable in the feedstock. Fine grained feedstock may cause flow problems in the bunker section of the gasifier as well as an inadmissible pressure drop over the reduction zone and a high proportion of dust in the gas. Excessively large sizes of particles or pieces give rise to reduce reactivity of the fuel, resulting in startup problems and poor gas quality, and to transport problems through the equipment. Too large particle sizes can cause gas channeling problems, in up draft gasifiers.

acceptable fuel sizes for gasification systems depend to a certain extent on the design of the units. In general, acceptable fuel sizes for charcoal gasifiers are ranging between 1 x 1 x 1 cm. and 3 x 3 x 3 cm.
4-2 Gas Producer Characteristics Tests
4-2-1 Producer Gas Components

Table (8): Producer Gas Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Test Method</th>
<th>Petroleum Coke Producer Gas</th>
<th>Charcoal Producer Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Test Results</td>
<td>Literature Results [15]</td>
</tr>
<tr>
<td>CO</td>
<td>ASTM D 2163</td>
<td>35</td>
<td>48.6</td>
</tr>
<tr>
<td>CH4</td>
<td></td>
<td>7.77</td>
<td>0.5</td>
</tr>
<tr>
<td>N2</td>
<td></td>
<td>45</td>
<td>1.9</td>
</tr>
<tr>
<td>CO2</td>
<td></td>
<td>13.5</td>
<td>15.4</td>
</tr>
</tbody>
</table>
4-2-2 Gas producer  Flame Temperature, Flame Duration, Fuel Consumption  
Petroleum Coke

Table (9): Gas producer  Flame Temperature, Flame Duration, Fuel Consumption and Ash Residue:

<table>
<thead>
<tr>
<th></th>
<th>Test(1)</th>
<th>Test(2)</th>
<th>Test(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Temperature, °C</td>
<td>40</td>
<td>36</td>
<td>43</td>
</tr>
<tr>
<td>Gas Temperature, °C</td>
<td>62</td>
<td>56</td>
<td>53</td>
</tr>
<tr>
<td>Time for Air Valve opening (full), min</td>
<td>10</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Time for Air Valve opening (1/4 full) / Flame Duration, min</td>
<td>20-25</td>
<td>10-15</td>
<td>-</td>
</tr>
<tr>
<td>Time for Air Valve opening (1/8 full) / Flame Duration, min</td>
<td>-</td>
<td>-</td>
<td>30-35</td>
</tr>
<tr>
<td>Maximum Temperature, °C</td>
<td>650</td>
<td>750</td>
<td>520</td>
</tr>
<tr>
<td>Fuel Consumption, kg/hr</td>
<td>1.53</td>
<td>2.55</td>
<td>2.04</td>
</tr>
<tr>
<td>Ash Residue, kg</td>
<td>0.0106</td>
<td>0.213</td>
<td>0.0289</td>
</tr>
</tbody>
</table>
### Charcoal

**Table (10): Gas producer Flame Temperature, Flame Duration, Fuel Consumption and Ash Residue:**

<table>
<thead>
<tr>
<th></th>
<th>Test(1)</th>
<th>Test(2)</th>
<th>Test(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Temperature, °C</td>
<td>36</td>
<td>40</td>
<td>46</td>
</tr>
<tr>
<td>Gas Temperature, °C</td>
<td>58</td>
<td>56</td>
<td>60</td>
</tr>
<tr>
<td>Time for Air Valve opening (full), min</td>
<td>10</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Time for Air Valve opening (1/4full) / Flame Duration, min</td>
<td>20</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Time for Air Valve opening (1/8full) / Flame Duration, min</td>
<td>-</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Maximum Temperature, °C</td>
<td>560</td>
<td>510</td>
<td>400</td>
</tr>
<tr>
<td>Fuel Consumption, kg/hr</td>
<td>0.9375</td>
<td>4.375</td>
<td>3.125</td>
</tr>
<tr>
<td>Ash Residue, kg</td>
<td>0.2103</td>
<td>0.2558</td>
<td>0.2328</td>
</tr>
</tbody>
</table>
Discussion

1/ The gas chromatograph used in the test read only the components reported in the table (8), thus Hydrogen is not detected. The nitrogen percentage in the gas analysis test is high than the reported in the literature because the air was used in the test as oxidizer agent but in the literature reported test they used oxygen. It is known that the gas producer contain Hydrogen as main component with percentage (33.2% for petroleum coke & 20% for charcoal) according to the same sources.

2/ It is noticed that the air valve opening degree (full) for a period of 10 minutes is better than 5 minutes in the beginning of the test and after the flame is put off. It is an indicator that the combustion occurrence and thus increases the combustion reaction gasses (CO₂, H₂O) and sequent the reduction reaction occur, this appear as increase of flame duration time.

3/ After ignition the flame duration increase as the air valve opening degree decrease (reduction period), it noticed that also the temperature decrease.

3/ Maximum temperature of flame in charcoal gasification measured during the tests was 560 °C, it exceed the maximum temperature reported in literature(400 °C), which is indication that partial combustion is taking place, that generally happens when the air flow rate through the gasifier is higher than the design value which need more balance in experimental work. The maximum temperature of flame in petroleum coke gasification is 750°C, no data for updraft gasifier flame temperature.
4/ Fuel consumption and ash residues are lesser in the first hours of the tests and increase with time, which may due to incomplete fuel combustion. It also noticed that air valve opening degree (full) for period 5min increase the fuel consumption and ash residues more than 10 min full opening time, which means that the combustion time is not enough to led to reduction and sequent the flame is getting off faster then air is open again and ignite more fuel. Fuel consumption and ash residues are lesser in petroleum coke gasification than in charcoal gasification, which mean that petroleum coke gasification is more efficient than charcoal gasification.
CHAPTR FIVE
5- Conclusion and Recommendation

Experimental results showed that petroleum coke gasification has many advantages over charcoal gasification:

- Its producer gas with higher flame temperature.
- Under the same conditions, petroleum coke producer gas and charcoal producer gas, have the same flame duration but petroleum coke gasification consume lower rate of fuel which increase the gasifier efficiency.

The main disadvantage is that petroleum coke has high metal content (sulfur, vanadium and other heavy metals), which need chemical and physical treatments.

Petroleum coke gasification has some difficulties in the initial ignition and combustion duration.

Air flow and producer gas flow need more appropriate optimization to increase flame duration.

The possibilities of gasifying mixture of petroleum coke and charcoal need further study to have the benefits of the higher calorific value of petroleum coke producer gas with lower fuel consumption and the ease ignition and combustion durability of charcoal
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10-Fred H. Hutchison" About Gasification" edited on: July 05, 2006 retrieved on 20 April 2008 from:
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   Retrieved on 25 April 2008 from:
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ANNEX
FIG (4)
UPDRAFT GASIFIER IN ERI

SECTION A-A
(1) UPDRAFT GASIFIER

(2) BALANCE & THEROMETER
(3) CHARCOAL & PETROLEUM COKE
(4) GAS CHROMATOGRAPH

(5) BOMB CALORIMETER