OIL REFINING AND ZERO FUEL OIL PRODUCTION WITH INTEGRATED GASIFICATION COMBINED CYCLE

G. L. Farina and L. Bressan - Foster Wheeler Italiana, SpA
D. Todd - General Electric

The world crude oil production is progressively deteriorating in quality. The average gravity and sulphur content of the crude oils processed by the U.S. Refineries in the past ten years is shown in Figure 1. Similarly Table 1 gives the average sulphur content of crude oils processed in different European regions.

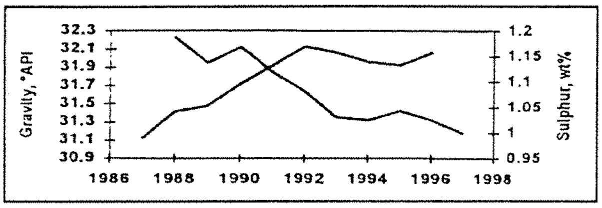

Figure 1

For the same run of crude oil, this trend results in a greater production of high sulphur heavy fuel oil, which not only reduces the revenue, but also finds increasing use restrictions due to the upcoming more stringent environmental regulations.

In this scenario the challenge of the Refiners is to process heavier crudes with less production of heavy residues.

Conversion technologies are available to match this target, either based on carbon rejection or hydrogen addition. However they are all capital intensive and leave the Refiner with a residual bottom product reduced in volume but containing more sulphur and heavy metals.

Today, Refiners, in various parts of the world, are looking with increasing interest to residue gasification because is the only technology which makes possible the zero residual bottom.product target, producing a range of added values products: hydrogen, steam and syngas based chemicals, methanol formaldehyde, ammonia, MTBE, TAME etc. Further, gasification, integrated with a combined cycle (IGCC) is today the highest efficiency technology available to convert refinery residues to electric energy.

Table 1

Year	N.W. Europe Region	Atlantic Region	Mediterranean Region
1990	1.12	0.96	1.30
2000	1.14	1.02	1.44
2010	1.20	1.13	1.48

IGCC technology was originally conceived as a clean conversion of coal to electricity, but more recently has been proposed as a solution to the problem of heavy oil surplus. Table 2 lists ongoing coal and oil IGCC projects.

Table 2

Project	Process	Start-up	Power Output	Feed
Cool Water (California)	Texaco	1984	100 MW	coal
Dow Plaquemine (Louisiana)	Destec	1986	220 MW	coal
Demkolec (Netherlands)	Shell	1993	250 MW	coal
Tampa Electric(1) (Florida)	Texaco	1996	250 MW	coal
Texaco-Eldorado (Kansas)	Texaco	1996	40 MW	petcoke
PSI-Wabash(1) (Indiana)	Destec	1996	262 MW	coal
Schwarze/Pumpe (Germany)	Noell	1996	40 MW	coal/oil
Shell Pernis (Netherlands)	Shell	1997	127 MW+H_2	heavy oil
Sierra Pacific(1) (Nevada)	KRW	1998	80 MW	coal
Elcogas (Spain)	Prenflow	1998	300 MW	coal/coke
ISAB (Italy)	Texaco	1998	540 MW	asphalt
SARAS (Italy)	Texaco	1999	550 MW	vb. tar
STAR (Delaware)	Texaco	1999	240 MW	petcoke
API (Italy)	Texaco	1999	250 MW	vb. tar
Fife Power (Scotland)	BGL	1999	120 MW	coal/sludge
IBIL/Sanghi (India)	Tampella	2000	60 MW	lignite
GSK (Japan)	Texaco	2000	540 MW	vb. tar
Fife Power (Scotland)	BGL	2000	400 MW	coal/RdF

Note (1): Clean Coal Programs

A schematic description of the oil based IGCC is given by the Block Flow Diagram of Figure 2.

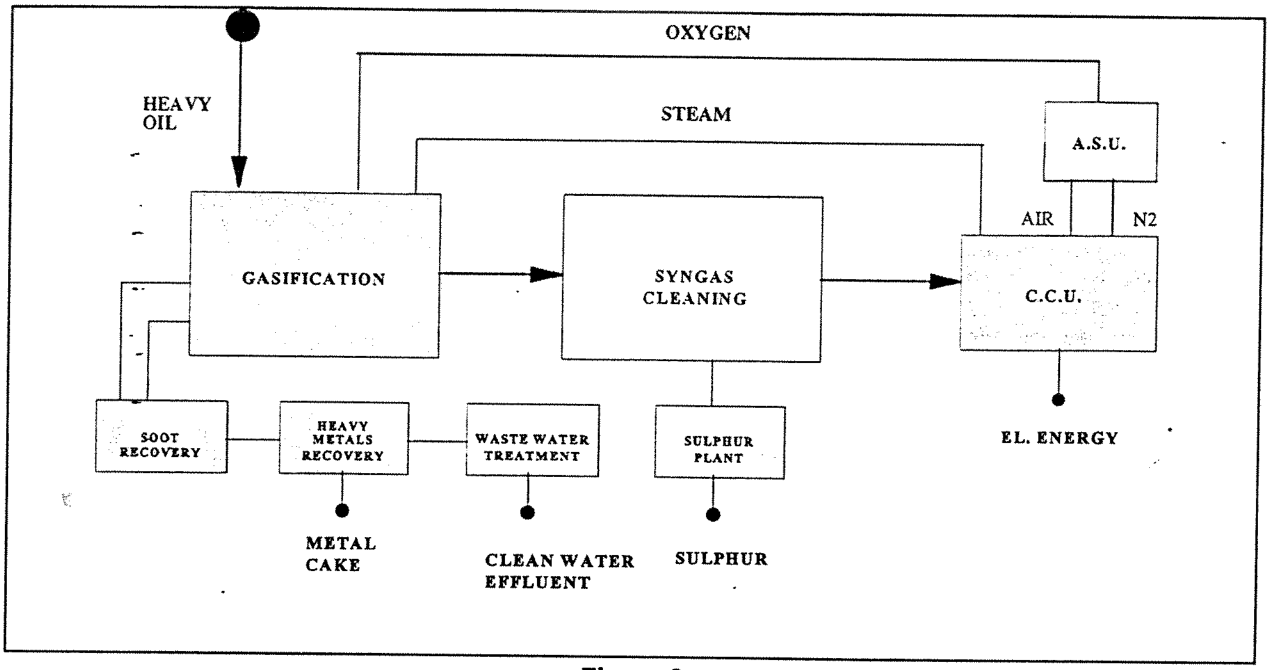

Figure 2

Gasification, by partial oxidation, is a flexible process which can handle any kind of refinery residue, vacuum residue, visbroken tar, asphalt, petcoke, as well as refinery sludges.

Two fundamental types of gasifier exist: quench and waste heat boiler. The first is lower cost, less efficient but more suitable for feeds with high metal contents; the second is more efficient but higher capital cost.
Oil gasification technology is primarily available from two Licensors: TEXACO and SHELL.

Heavy oil is gasified with oxygen (partial oxidation) in presence of steam, as temperature moderator. By-products of the process are: liquid sulphur, a disposable clean water effluent and a solid metal concentrate, usable in the metallurgical industry for vanadium recovery.

Raw syngas cleaning includes various steps: heat recovery, COS hydrolysis, selective H_2S removal, Claus conversion, expansion and, if required saturation.

The clean syngas, from heavy oil, has the following typical composition:

CO	45.5	%vol.
H_2	43.0	%vol.
CO_2	8.2	%vol.
CH_4	1.0	%vol.
Ar	1.0	%vol.
N_2	0.5	%vol.
H_2O	1.5	%vol.
	100.0	**%vol.**

The pressure of the clean syngas may vary from 20 to 70 bar, depending on the designer choice and final use of the syngas. Clean syngas can be employed to produce pure H_2, by selective membrane or shift reaction, followed by PSA purification. A number of chemicals can be synthesized from syngas, methanol, formaldehyde, ammonia etc. Syngas is also an excellent fuel for gas turbines, thus providing a link between inexpensive residual fuels and combined cycle, the most efficient electric power generation technology, with efficiency well above 50%.

In the recent years considerable progress has been made to increase the efficiency and lower the cost of IGCC, utilizing improved gasification processes, advanced F generation gas turbines and optimizing the integrations amongst the main IGCC components, i.e., Air Separation (ASU), Combined Cycle (CC) and Gasification. This process is not yet over, since even more advanced and powerful gas turbines are being developed.

Today "state of the art" IGCC technology is competitive with other traditional and advanced energy technologies, but far superior in environmental performance.

To present the ability of IGCC to fit in a oil refining complex, four modules of different capacities have been designed and estimated. Other modules can be developed to meet the specific needs of each Refinery by selecting the following key design items:

- gas turbine frame model and number
- level of syngas postfiring in the heat recovery steam generator (HRSG)
- size and number of gasifiers

The four IGCC modules studied are defined in the following Table 3.

Table 3

	MODULE 1	MODULE 2	MODULE 3	MODULE 4
Feedstock: type	visb. tar	visb. tar	visb. tar	visb. tar
S % wt	5	5	5	5
flowrate t/h	172	128	86	64
Gasifier: type	WHB	WHB	WHB	WHB
number	2	2	2	2
Gas Turbine: frame	GE9001FA	GE9001EC	GE9001FA	GE9001EC
number	2	2	1	1
NOx control: ppm (15% O_2)	25	25	25	25
type	N_2 dilution	N_2 dilution	N_2 dilution	N_2 dilution
Integration: ASU air from TG	40%	0%	40%	0%
Air temperature °C	15	15	15	15
Cooling water temperature °C	15	15	15	15
Power delivery voltage	380 kV	380 kV	380 kV	380 kV

These modules do not co-produce hydrogen and steam in order to present more clearly the oil to power conversion performance. However co-production of hydrogen and steam can be easily added by either increasing the oil throughput and leaving the power output unchanged or by decreasing the power output and leaving unchanged the oil throughput.

Table 4 gives the most important performance data and the estimated investment cost per unit of power (kW). The investment cost is based on European costs of first quarter 1998 and include all plants of the Complex, process, utilities and offsites. The cost of land is not included. For instance module 1, the largest, can be accommodated in an area of approximately 130000 m^2.

Table 4

	MODULE 1	MODULE 2	MODULE 3	MODULE 4
Feedstock Flowrate t/h	172	128	86	64
Feedstock LHVkJ/kg	38520	38520	38520	38520
Oxygen Flowrate (as 100% O_2) t/h	187	139	93.5	69.5
Thermal Energy of Feedstock MWt	**1841**	**1366**	**920**	**683**
Syngas from Gasifiers MWt	1519	1127	759	563.5
Gasification Efficiency %	**82.5**	**82.5**	**82.5**	**83.5**
Dry Syngas to Gas Turbines MWt	1481	1099	741	549.5
Dry Syngas to Postfiring MWt	0	0	0	0
Syngas Treatment Efficiency %	**97.5**	**97.5**	**97.5**	**97.5**
Gas Turbines Gross Power Output MWe	572	430	286	215
Steam Turbines Gross Power Output MWe	339	241.5	169.5	120.8
Expander Gross Power Output MWe	10	7.5	5	3.7
Gross Electric Power Output MWe	**921**	**679**	**460.5**	**339.5**
Process Units Consumptions MWe	6.5	5	3.2	2.5
Oxygen Plant Consumptions MWe	88	84	44	42
Utility Units Consumptions MWe	13	11	6.5	5.5
Power Island Consumptions MWe	7.5	7	3.8	3.5
Overall Electric Power Consumptions MWe	**115**	**107**	**57.5**	**53.5**
Net Electric Power Output MWe	**802**	**569**	**401**	**285**
Net Electrical Efficiency %	**43.5**	**41.6**	**43.5**	**41.6**
Investment cost $/kW	**1050**	**1140**	**1120**	**1220**

NOTE (1): Step-up Transformers Efficiency 99.5% is included
(2): Steam Turbines Condensing Pressure: 0,032 bar (abs)

The atmospheric emissions of the four modules do not exceed the following limits:

NO_x	50	mg/Nm³ (dry - 15% O_2)
SO_2	10	"
CO	<10	"
Particulate	<1	"

In spite of the poor quality of the feedstock, the emissions are extremely low; much lower than any other available technology can achieve. The sulphur capture efficiency, as a ratio between recovered liquid sulphur and sulphur in the feedstock, is 99.7%.

The cost of electricity delivered by Module 1 has been calculated on the following basis:

- IRR on total investment (100% equity) — 12% and 15%
- Economical life — 20 years
- Equivalent availability — 88%
- Feedstock cost — 30 $/ton
- Operating personnel — 8 million $/y
- Maintenance cost (% of total investment) — 3% per year
- Insurance (% of total investment) — 0.6% per year
- Chemicals — 12 million $/y
- Interest during construction — 8%
- Construction period — 3 years
- Depreciation — 10 years
- Income tax — 35%
- Rate of inflation (excluding feedstocks) — 3% per year

The cost of electricity, US cent/kWh, broken down in its major components, is:

	12% IRR	15% IRR
• Investment	1.713	2.153
• Taxes	0.540	0.730
• Feedstock	0.647	0.647
• Maintenance	0.407	0.407
• Chemicals	0.194	0.194
• Personnel	0.129	0.129
Total	**3.630**	**4.260**

One of the largest refinery bottom IGCC, the 540 MW ISAB Complex (Italy), is now in a an advanced stage of construction. A view of the construction site, from the top of the 130 m stack, is given in Figure 3 and Figure 4.

Figure 3
General View

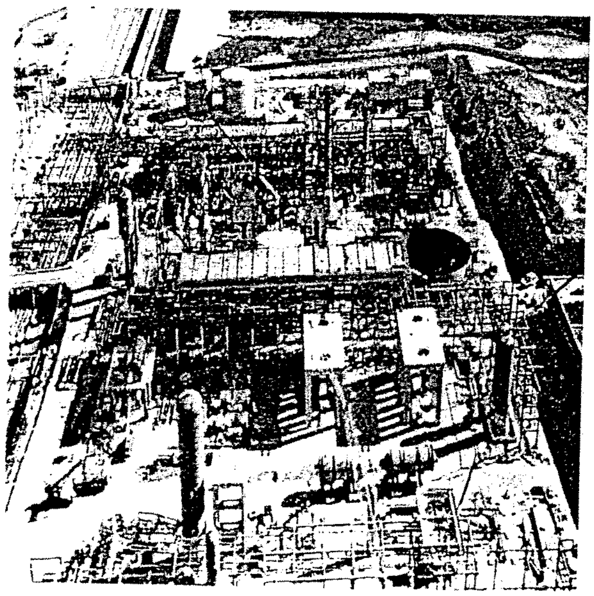

Figure 4
Gasification Area