CLEAN COAL CONVERSION OPTIONS USING FISCHER-TROPSCH TECHNOLOGY

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Introduction

Any meaningful utilization of the vast coal resources in places like China, India, Australia, South Africa and the USA will involve conversion into some other form of energy. Coal, as a solid, has a high energy density and is therefore reasonably convenient as a heating fuel. The problem is that the associated pollutants negate any advantages compared to other cleaner burning fuels. Coal is rather converted into other cleaner forms of energy such as liquid hydrocarbons, synthetic natural gas (SNG) and electric power. Initially these conversion plants simply concentrated the pollutants in one large scale conversion site while enabling the end user of energy to experience a cleaner fuel. With time, more and more success has been achieved in cleaning up the emissions from large scale coal conversion facilities.

One fact that cannot be avoided is that every ton of carbon in mined coal will sooner or later end up as 3.67 tons of carbon dioxide in the atmosphere. Although some attention has been paid to the possibility of carbon dioxide sequestration this is not currently, and may never be a viable option. Certainly the cost of sequestration seems likely to favour the use of other fossil fuel alternatives such as crude oil and natural gas while these are still readily available.

The increased production of carbon dioxide per unit of useful energy for coal relative to other fuels is inevitable. Assuming this is acceptable, it becomes important to ensure that, when coal is used, it is used as efficiently as possible.

Combined production of hydrocarbon liquid and electrical power

The coal fired power stations in South Africa and elsewhere produce some of the world's lowest cost electrical power but this large scale coal combustion has an environmental penalty. An alternative approach is to gasify the coal in order to produce a low heating value synthesis gas which may be cleaned prior to combustion in a combined cycle power plant using both steam and gas turbines. There are alternative uses for this synthesis gas that may offer opportunities that are both economically more attractive and result in more efficient use of the coal. Where a region's economy is dependant on coal utilization, there is a strong case to be made to switch to more efficient and less polluting coal conversion technologies as these become available.

Synthesis gas can also be made from natural gas and the following comparison has been published previously by Shell[1]:

Syngas Manufacture	Fischer-Tropsch	Thermal* Efficiency	Relative Capital Cost
Coal:			
$2(\text{-CH-}) + O_2 \rightarrow 2CO + H_2$	$\rightarrow (\text{-CH}_2\text{-}) + CO_2$	60%	200
Natural Gas:			
$CH_4 + \frac{1}{2}O_2 \rightarrow CO + 2H_2$	$\rightarrow (\text{-CH2-}) + H_2O$	80%	100

* Theoretical Maximum

This appears to paint a bleak picture for coal utilization but it ignores two factors. Firstly the high energy density of coal allows the feed to be delivered to the conversion plant at a lower cost. Secondly the lower energy efficiency ignores the opportunity to convert the byproduct heat into electrical power.

Another potential use for some of the byproduct heat is to generate steam for the use in the water gas shift reaction to modify the above coal conversion reaction as follows:

$$H_2O + 2CO + H_2 \rightarrow CO + 2H_2 + \underset{\substack{\downarrow \\ \text{Removed}}}{CO_2} \rightarrow (\text{-CH}_2\text{-}) + H_2O$$

This then becomes equivalent to the natural gas route for the synthesis gas conversion step but twice as much oxygen has been used to prepare the synthesis gas and the cost of generating steam and removing carbon dioxide provides a further cost penalty.

The above equations also ignore the reality that coal is gasified with both steam and oxygen together. This leads to a lower oxygen consumption for gasification than is indicated by the above equations. For the coal conversion options considerd, the oxygen consumption per unit of synthesis gas is actually not double that for the partial oxidation of natural gas.

The cost penalty is somewhat negated by the fact that steam generation is required anyway to remove the heat generated by the Fischer-Tropsch reaction and to cool the hot synthesis gas exiting the gasifier. Synthesis gas cleanup to remove acid gases is also required anyway for use is gas turbines.

The concept of producing Fischer-Tropsch liquid hydrocarbons and electrical power from coal derived synthesis gas has been around for quite a long time. A 1978 patent from Chevron pointed out the advantages of using this concept to cope effectively with power demand variations[2]. The US Department of Energy (DOE) supported by contracted studies by MITRE Corporation[3,4] and companies such as Texaco[5], Air Products[6,7] and Rentech[8,9] showed that LTFT reactor technology can be used together with coal or petroleum coke gasifiers for the co-production of hydrocarbon liquids and electrical power. Fluor Daniel[10] have proposed the use of HTFT for this purpose.

It is possible that the combined production of hydrocarbon liquids and electricity can compete with natural gas conversion to only the hydrocarbon liquids. This option has been studied for two

Fischer-Tropsch conversion options i.e. Low Temperature Fischer-Tropsch (LTFT) and High Temperature Fischer-Tropsch (HTFT) both using Iron based catalysts.

Cases Studied

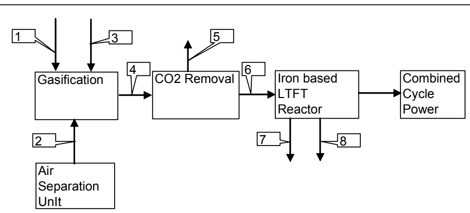
For both cases the use of a Texaco Gasifier was assumed to make a synthesis gas with the following composition (mol%):

H_2	37.36
CO	29.26
CO_2	13.30
CH_4	0.16
H_2O	19.43
Inert	0.49

For the LTFT case this gas is fed to a two stage reactor system to form liquid hydrocarbon products. The tailgas is sent to a gas turbine to produce power. Other sources of power are the steam generated in the process of cooling the synthesis gas from the gasifier and in removing the heat generated in the Fischer-Tropsch reactors.

For the HTFT case, a similar quantity of hydrocarbon product can be produced with a single stage reactor. For this case the synthesis gas is subjected to a sour gas shift prior to acid gas removal in order to increase the hydrogen to carbon monoxide ratio in the synthesis gas. This was also found to significantly increase the utility requirements for the acid gas removal step.

The mass and energy balances for the two cases are shown below. These are not necessarily fully optimized but are considered realistic to provide a fair basis for comparison.



Solid Stream Summary

Stream Number	Stream Name	Flowrate kg/h	LHV kJ/kg	LHV MW
1	Coal	928063	30506	7864
2	Oxygen	951597	0	0
3	Water	654404	0	0

Gas Stream Summary

Stream Number	Stream Name	Flowrate k nm3/h	LHV kj/nm3	LHV MW
4	Raw Gas	2243	9843	6133
5	CO2	364	0	0
6	Syngas	1879	11781	6148
7	Tailgas	695	7831	1513

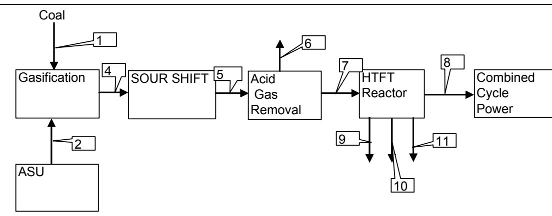
Liquid Stream Summary

Stream Number	Stream Name	Flowrate bbl/day	LHV MJ/bbl	LHV MW	ton/day	MJ/kg
8	Condensate	18248	4635	979	2090	40.5
9	Wax	35844	5809	2410	4740	43.9
	Total	**54092**		**3389**		

Thermal Efficiency

Stream	LHV MW	%
Coal	7864	100.0
Condensate	979	12.4
Wax	2410	30.6
Power	566	7.2
Overall	**3955**	**50.3**

Figure 1. LTFT Based.



Solid Stream Summary

Stream Number	Stream Name	Flowrate kg/h	LHV kJ/kg	LHV MW
1	Coal	928063	30506	7864
2	Oxygen	951597	0	0
3	Water	654404	0	0

Gas Stream Summary

Stream Number	Stream Name	Flowrate k nm3/h	LHV kj/nm3	LHV MW
4	Raw Gas	2243	9843	6133
5	Shift Gas	2680	7923	5898
6	CO2	799	0	0
7	Syngas	1881	11341	5925
8	Tailgas	360	14553	1453

Liquid Stream Summary

Stream Number	Stream Name	bbl/day	LHV MJ/bbl	LHV MW	ton/day	MJ/kg
9	Decant Oil	1799	6099	127	249	44.1
10	Stabilised Light Oil	34070	4859	1916	3899	42.5
11	Condensate	25002	4112	1190	2334	44.1
		60871		**3233**		

Thermal Efficiency

Stream	LHV MW	%
Coal to Gasifier	7864	100.0
Liquid Products	3233	41.1
Power Export	393	5.0
Overall	**3626**	**46.1**

Figure 2. HTFT Based

Discussion of the results

Natural gas conversion processes can be expexted to have thermal efficiencies in the range of 60 to 66%. For the current state of the technology, cost effective facilities will have thermal efficiencies closer to 60%. Coal conversion is clearly less efficient. It seems 50% efficieny is achievable. The cost of feedstock per unit of energy must therefore be less in order to compensate for this efficiency deficit. However, this is not unrealistic. Existing coal conversion plants operating with thermal efficiencies closer to 40% are cash positive.

Compared to natural gas conversion, the capital cost based on similar quantities of energy product are higher for a number of reasons. Firstly there is the need for acid gas removal from the synthesis gas. This step is not required for a sweet natural gas feed. The capital cost of synthesis gas generation is also significantly higher mainly due to the higher oxygen requirement (by a factor of nearly 1.7). The Fischer-Tropsch conversion step is marginally more expensive for the HTFT technology and nearly double the cost for the LTFT route when compared to natural gas conversion. This is the result of the coal derived synthesis gas being unsuitable for use with modern supported cobalt Fischer-Tropsch catalysts. Another factor that negatively impacts the coal conversion plant is that it is more utility intensive than a natural gas conversion plant. This is an inevitable consequence of the lower thermal efficiency.

Considering the comparison between the HTFT and LTFT options, it is clear that the LTFT route is more efficient. The main reason for the lower efficiency of the HTFT option is that the acid gas removal step becomes more utility intensive. As mentioned previously though, the capital cost for the Fischer-Tropsch section is higher. Only a detailed study beyond the scope of this paper will be able to determine whether the higher efficiency of the LTFT route can compensate for the higher capital cost. The preferred solution may be different for different potential application sites and may be influenced by whether gasoline or diesel is the desired primary product.

The economic success of the coal conversion plant will inevitably depend on the price received for the products. It seems unlikely that the price for liquid hydrocarbons will be sufficient to provide a suitable return on the capital invested while the energy resources of crude oil and natural gas are still readily available. However, if some assistance is provided for the initial capital costs, coal conversion to liquid hydrocarbons together with electrical power is an efficient option relative to other coal conversion options. It may be important to reduce dependence on imported energy for countries with abundant coal resources. The coal conversion efficiencies are higher when liquid hydrocarbons are produced than for facilities producing only electricity.

Production of liquid hydrocarbons from coal as described above has two further advantages. Firstly the market is huge and the facilities can take advantage of economics of scale for very large facilities producing hydrocarbon fuels steam together with electricity. However, the huge capital investment involved is another reason why state assistance will probably be necessary to fund such a coal conversion facility. The other benefit is that the final liquid hydrocarbon fuels will be ultra clean and will not contain sulfur or nitrogen. This will lead to local environmental benefits where these fuels are used.

Conclusions

Certainly coal conversion to hydrocarbon liquids and electricity is economically attractive from an income/ cash cost viewpoint. However large capital investments are require to reap the benefits from economics of scale and the return on capital invested is not particularly attractive. It is therefore expected that these coal conversion plants will only become a reality if there is some form of state assistance with the initial capital investment, such as low interest loans. This would be motivated by the independence from imported energy and the more efficient and cleaner utilization of the local energy resource. The Chinese government has accepted this approach and China is likely to be the pioneer for this technology option. Places that have abundant coal are likely to use this resource. It is the duty of technology providers to ensure that technology is made available to allow the coal to be used as efficiently as possible.

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