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Sulphur removal from coal or from products: is prevention better than cure? - a techno-economic review

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4 PREVENTION ALTERNATIVES

The previous chapter gave the background to the origin of the sulphur species in the coal, the gasification process that converts the coal (and the sulphur) to gas, the raw gas purification and sulphur recovery steps. This chapter addresses the various alternatives to prevent the sulphur species from ending up in the raw gas.

All forms of sulphur, organic, inorganic, sulphate, elemental, react in one way or another when exposed to the high temperatures and pressures of process equipment like boilers and gasifiers. Consequently, sulphur compounds will be present in the reaction products of the processes: sulphur dioxide (SO_2) and sulphur trioxide (SO_3) resulting from the combustion processes, hydrogen sulphide (H_2S) and carbonyl sulphide (COS) from the reducing environments in gasifiers.

The off-gas stream resulting from the purification processes for the raw gas stream from the gasifiers and the sulphur recovery units contains hydrogen sulphide. Although the sulphur concentrations in the final off-gas stream released into the atmosphere are within the permit requirements and well below any danger levels, an un-acceptable smell can still occur if the wind conditions are such that proper dispersion is hindered. Also, in line with Sasol's environmental policies, every effort is to be done to prevent or mitigate potentially harmful emissions.

The logical conclusion is to prevent these sulphur products from forming in the first place, or, if this cannot be done, to prevent them from progressing from the gasifiers to units further downstream in the process chain. The question is whether this can be done on the required scale with an acceptable economical impact to the business and still satisfies the technical requirements of the processes.

Three approaches are available:

- Removal of the sulphur compounds **before** the coal utilisation process,
- Handling the sulphur compounds **during** the process,
- Treatment of the products **after** the process.

(The last option is no longer a prevention method; the product has been formed, has left the producing process and now needs to be dealt with. Hence, technologies applied for this option are "Cure" technologies, and will be discussed in chapter 5).

4.1 Sulphur Removal Before The Coal Utilization Process

The most logical approach to prevent sulphur from entering a process system is to select the correct feedstock, and to ensure that this feed material stays sulphur free or does not get contaminated with other material, thus increasing the sulphur content. The selection of the feedstock and the influence of the mining process are briefly discussed.

Several other methods are available to reduce the amount of sulphur in the coal and prevent it from entering the process. Some of these sulphur removal methods are well established and commercially available for several years. Others have progressed from demonstration scale to semi-commercial application. A range of innovative methods has been developed over the years ranging from microbiological removal of organic and pyritic sulphur to chemical leaching of sulphur compounds from the coal. Few of these methods have progressed further than laboratory scale, due to either excessive costs of the process or low production potential.

Various options are available, and they can basically be classified into three categories:

- Biological treatment methods: the use of bacteria.
- Chemical treatment methods: temperature, pressure, catalysts, reactions.
- Physical treatment methods: the well-known beneficiation processes.

What has to be kept in mind when evaluating a process is that the coal, once processed, must still be useable in the technologies employed for the conversion of that coal into value-added products. In the Sasol Synfuel complex in Secunda, Sasol-Lurgi Fixed Bed Dry Bottom gasifiers are used to convert the coal into raw synthesis gas. These gasifiers require coal of a particular size range, viz. approximately 5 to 100 mm or preferably an even narrower range from 5 to 50 mm for reasons of effective coal conversion, product slate and gas production rate requirements. Therefore, any process that relies for its efficiency on the reduction of size to enhance liberation and removal of unwanted mineral matter must be evaluated and considered carefully for suitability.

4.1.1 Coal selection and the mining process

The easiest way of preventing sulphur from entering a process is of course selecting the proper feedstock to begin with. The required characteristics of a feedstock for a particular process are known when the process is selected. Potential feedstocks are screened for the long-term suitability for the processes. Geological surveys are done to determine the location of the various qualities of coal in the reserves. A mining program is developed to ensure that the quality of the coal produced will be as close as is practically possible to

the process requirements for the duration of the economic activity of the processes. Usually, a compromise between maximum reserve utilization and minimal impact on the downstream coal utilization processes has to be made.

The mining activities are spread over the reserve to ensure that the combined output of the mining sections will closely match the requirements of the processes. Alternatively, but preferably in addition to this, aboveground blending at stockpiles reduces the variation in coal quality parameters. Both methods will ensure that the coal quality to the user, including the sulphur content, is at least constant over time. Processing of the coal will still be required if the sulphur content required by the process is too high, or as a step to reduce the sulphur burden to the environment.

The coal mining process is supposed to remove only the coal from the seam and not dilute this with adventitious mineral matter. In practice, the contamination of coal mined with adventitious mineral matter is difficult to prevent. Roof, floor, sills and dykes are mined too, and the extent to which this happens will have an influence on the mineral content of the coal send to the user, hence on the concentration of sulphur in that coal.

During test work by Sasol Technology [14], an evaluation was done to determine the effect of the origins of the mineral matter (roof, floor, lenses, etc.) on the total sulphur content of the coal. Geologists used a visual analysis of various heaps of coal produced in different mining sections to classify in-seam material from non-seam material. “Roof” and “Floor” are obvious non-seam material and produced during the mining process by cutting too high and too low with the continuous mining equipment.

After the visual separation of the various material types by the geologists into the six groups used, the material was analysed using standard analytical methods including X-ray Diffraction (XRD) and X-ray fluorescence (XRF) to identify the mineral content and mineral types present and the sulphur content.

Table 4.1 presents selected analysis results for the groups. It can be seen that the sulphur in the material classified by the geologists as “Roof” and “Floor” material are only minor contributors to the total sulphur concentration in the coal, and that therefore the mining method in itself will not have a major effect on the sulphur content in the coal produced (where the mining takes place in the coal seam is a different aspect, but more on that later).

Table 4.1 Properties of inorganic groups (courtesy Sasol Technology R&D)

	Groupings, from visual classification by geologists					
	"Carbonates"	**"Shale"**	**"Pyrite"**	**"Roof"**	**"Floor"**	**"Siltstone"**
% of mineral matter	6	19	12	18	23	22
% total S (AD)	17	1.5	15.4	1.7	1.1	1.6
Dominant oxide types	SiO_2, Fe_2O_3, CaO	SiO_2, Al_2O_3	SiO_2, Fe_2O_3, CaO	SiO_2	SiO_2, Al_2O_3	SiO_2, Al_2O_3
Contribution to total S	1.02	0.29	1.85	0.31	0.25	0.35
% of total contribution	**25**	7	**45**	8	6	9

The mining of floor and roof material should be limited as much as is possible (although it is sometimes necessary from a safety or strata stability point of view) as it dilutes the coal and increases operating costs of the mining process as well as of the processes of Sasol Synfuel. The table shows however, that the from a sulphur perspective, the focus should be on the coal itself, since the contributions of sulphur in the groups "Carbonates" (being coal with visible amounts of calcites) and "Pyrites" (being coal material with visible amounts of visible pyrite inclusions) are the most significant sulphur contributors. These materials cannot be separated from the coal in the seam during the high volume mining processes employed by Sasol.

4.1.2 Biological treatment

Bacteria can be used to convert the sulphur species present in the coal to hydrogen sulphide.

Lab scale lab demonstration [Stevens [(21)]] of a system employing *Thiobacillus ferrooxidans*, *T. thiooxidans* and *Leptospirillum ferrooxidans* as the biological step, followed by a flotation cell operation rendered an 89% reduction in the pyritic sulphur content of the Illinois no.6 coal treated, as well as a 30% reduction in mineral matter. The coal however, had to be ground to 80% minus 150 micron and the residence time in the biological step was five days (!). The processing steps are wet, and it will be necessary to dewater the product to client-acceptable levels. This is costly.

Work by Acharya [(22)] using *Aspergillus*-type fungi reports similar results: the coal needs to be very finely ground, to less than 74 micron, resulting in a reduction of the total sulphur content by 70-80% after 10 days. Mainly the organic sulphur components were reduced, although this could be due to the nature of the coal – the sulphur in the Assam (India) coal used in their research is predominantly organic sulphur.

Alkaline pre-conditioning of the coal may activate the surface of the pyrites, and enhance the bacterial desulphurisation of the coal [Tripathy [(23)]].

Organisms like *Brevibacterium* and *Pseudomonas aeruginosa* are able to weaken the bond between carbon and sulphur in the organic structure of coal [van Afferden [24]], thus enabling faster break down by other organisms. This will reduce the residence time required in a bioreactor, but is still measured in days rather than seconds.

Test work done by the Centre for Bioprocessing Technology [Andrews [25]] divides the pyrite inclusions in 3 groups:

- Coal particle is smaller than the size of the pyrite inclusion. Here, the pyrite particle is free and can be removed.
- Coal particle is between 1 and 10 times the size of the pyrite inclusion. The pyrite particle is now semi-locked in the coal structure, and treatment processes do not have access to the entire pyrite surface. Difficult upgrading.
- Coal particle is much larger than 10 times the pyrite inclusion. The pyrite is locked in completely, and treatment processes will be difficult if not impossible.

This work shows that microbial degradation of pyrites is only possible if the coal is ground very fine to liberate the pyrite inclusions. 90% plus reduction of pyrite is only possible if several million of minus 10 µm inclusions can be removed. The cost of pulverization and after-treatment dewatering will be prohibitive for commercial scale operation. That is, if a client can be found for this ultra fine material. Further development work by the same team [19] shows that a reduction of 89% could be achieved for a minus 100-mesh Illinois no.6 coal sample after 5 days of reactor residence time.

A similar experience by Moran [26], who combined biotreatment of micron sized material with cyclones to remove pyrites and ash, led to a reduction of the sulphur content by 41.7% and the ash content by up to 58.9%. Here too the questions of dewatering and client size requirements are very relevant. In another study by Moran [27] it was found that pyrite reduction by approximately 25% was obtained after bio-treating 0.5 by 1 mm coal for 51 days. Although it proves the point that somewhat larger particles can also be treated with bacteria to remove pyritic sulphur, it is still hardly applicable in large-scale, high volume industrial applications like the Sasol process under review.

That reaction time does play a role was also indicated by Juszczak et al [28] who found that material smaller than 60 micron needs more than 7 days reactor time to achieve more than 40% pyritic sulphur reduction.
Bio-desulphurisation of high sulphur containing coals a packed-column leaching or leaching on a large heap was evaluated by Cara [29, 30] and here also time played a significant role : the packed-column method required 125 days to achieve a 24% total

sulphur reduction, the heap leaching method 23% in 70 days. One has to consider this when practical, large scale commercial operations are evaluated.

The studies indicate that the form of sulphur most affected by microbial treatment is pyritic sulphur, and predominantly the forms with high surface area open for attack (framboidal pyrite) [Acharya [31]] and that organic sulphur is hardly affected.

Scientists have been applying other bacteria in their biotreatment cocktails in attempts to remove other forms of sulphur too. Haggin [32] reported that researchers at the Institute of Gas Technology had developed a mixed bacterial culture code named IGT-57, which could also reduce some of the organic sulphur (15% reduction was reported). This culture was a mixture of *T. ferrooxidans* and *T. thiooxidans*, with *Sulfolobus acidcaldarius* added.

Fecko [33], after achieving 71% removal of pyritic sulphur after one month of biotreatment, also concluded that hardly any of the organic sulphur had been affected by the *T.* bacteria and that a mixture with *S. acidcaldarius* may render better results.

A good summary of reported results on bio-desulphurisation is shown by Vernon [34]. None of the microbiological treatment processes developed has progressed further than large-scale bench tests. Throughput and residence time are still the limiting factors for commercialisation of these technologies, and that is besides the capital and labour intensiveness of the processes and the operating and capital costs of the dewatering processes. Also, the need to precisely control the process conditions in the bioreactors to sustain the micro-organisms, especially the pH and the temperature, may pose control problems in large-scale applications. Moreover, the basic particle size range requirement for successful biotreatment will not satisfy the requirements of the Lurgi gasifier.

Treatment of coal for the removal of sulphur compounds with the aid of bacteria is therefore interesting from a research and theory point of view, but for the foreseeable future not practical on large commercial scale.

4.1.3 Chemical treatment

Several processes have been developed on bench and pilot scale for the removal of the sulphur compounds through the reaction of the sulphur with an added chemical compound, with or without the aid of heat and pressure or catalysts / promoters. The TRW Gravimelt process uses molten sodium hydroxide or potassium hydroxide to displace the sulphur.

Another process developed by TRW-Meyers uses a regenerable aqueous ferric sulphate solution to oxidize the pyritic sulphur to elemental sulphur, at “low temperatures and pressure“ (approximately 100 to 130 °C and up to 7 bar). General Electric and Batelle developed similar processes.

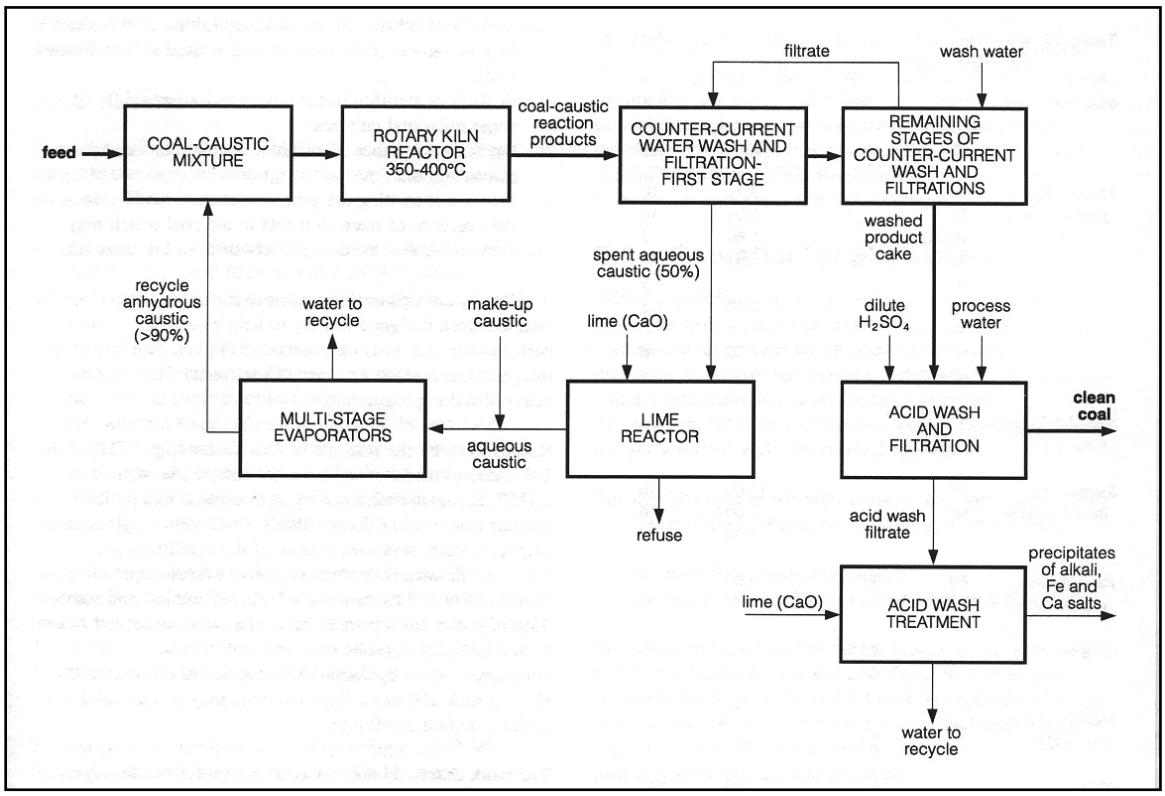


Figure 4.1 TRW Gravimelt process for sulphur removal from coal

PETC, Ames, TRW and ARCO all developed processes for the selective oxidation of sulphur compounds in a pressurised hot environment with the aid of promoters.

All these processes have good (80% +) removal of the pyrite species of the sulphur compounds. However, all of them work with particle sizes smaller than 6 mm and require residence times of 10 minutes to several hours to complete. [Edgar [35], Vernon [36]]

The conditions under which these processes are operated require significant energy to be achieved: energy for milling, for pressure and for heat. An overall energy balance will show that the energy input into the combined processes (preparation, conversion, product upgrading) may very well be close to, if not more than, the energy content of the final product to the consumer.

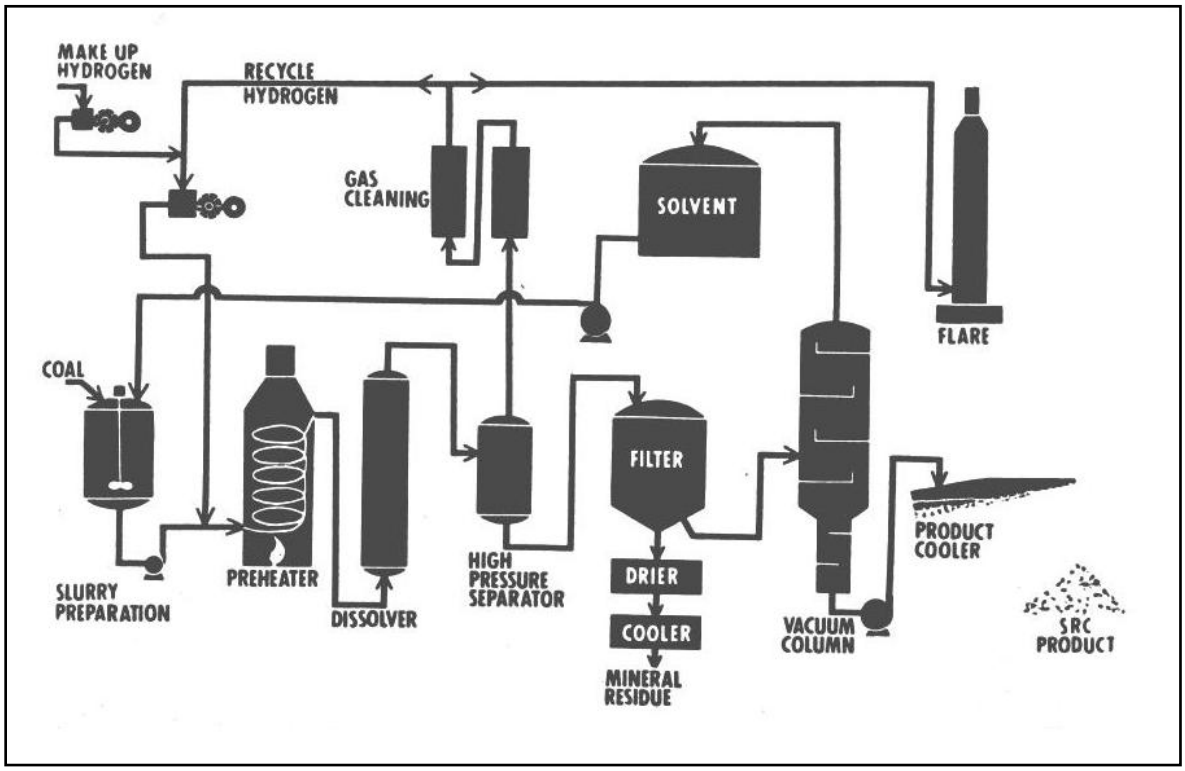


Figure 4.2 Solvent Refined Coal, Catalytic Inc. [McKetta [37]]

Processes have been developed to remove the coal through dissolving the coal under pressure and at elevated temperature with a regenerable solvent. The solution is then filtered to remove a high percentage of the mineral matter including pyritic sulphur. Mineral matter can be reduced to as low as 0.1%, and sulphur to as low as 0.3% [McKetta [37]]. The process as described in figure 4.3 has operated in Wilsonville Alabama, USA, to provide coal for power stations in areas with sulphur (SO_x) emission limitations.

These severe processes may be able to remove a large percentage of the sulphur in the coal, but this is achieved at significant cost. At that time, the Wilsonville operation was reported to add up to US$22 per ton processed, and the Gravimelt process added approximately US$75 to the product price (on an original coal cost of US$25 per ton ….) [Vernon [38]].

Steel et al [39] applied brute chemical force in an attempt to reduce the mineral matter content (and hence the sulphur content) with concentrated HF and HNO_3 mixtures. After several hours, mineral matter was reduced from 7.9% to 0.6%, and sulphur from 2.6% to 1.4%. They found that HF does not attack the pyrite and HNO_3 only above certain concentrations. All coal was reduced to minus 500 micron size to facilitate the reactions.

Superacid HF/BF_3 mixtures were applied by Shimizu et al [40] at temperatures as high as 420 °C and pressures up to 85 bar. Their experiments yielded up to 69% reduction in sulphur in the coal, which was ground to minus 250 micron first. The aggressiveness of the acid mixture would be a challenge to contain in industrial applications.

Efforts with hydroiodic acid were more successful. Andres [41] used a combination of microwaves (for heating) and concentrated HI to remove more than 80% of pyrite and sulphate in coal samples. Again, this was done at temperature, 230 °C, but could be achieved in relatively short periods (minutes) for a 5 gram sample.

Microwaves were also used by Jorjani [42] in combination with peroxyacetic acid. The microwaves are thought to cause localised heating of the pyrite, causing it to decompose to FeS or $FeSO_4$. Microwave irradiation enhanced the sulphur removal from the coal structure from 49.9% to 86.6% for the pyritic sulphur, and 23.8% to 35% for the organic sulphur. The work was performed at temperatures between 25 and 85 °C, and the coal needed to be ground to finer than 300 micron to obtain access to the pyrites by the chemicals.

A mixture of hydrogen peroxide and sulphuric acid was used by Vasilakos and Clinton [43] to almost completely remove the pyritic and sulphate sulphur in coal at ambient temperature conditions. Due to the acidic conditions of the process, the ash content was also reduced. The organic sulphur in the coal matrix was however not much affected. Here too, the coal needed to be ground very finely to be effective.

Sulphates can be removed from coal after grinding to fine sizes, by washing with strong hydrochloric acid (>3M). Louie et al [44] used formic acid on coal ground to minus 75 micron. Although successful to an extent, this method is also more suitable for laboratory work.
Balaz et al [45] used NaOH instead of an acid, in a simultaneous grinding and leaching process to achieve reduction in the organic and inorganic sulphur content of the coal. They claim to be more effective than the Molten Caustic Leach processes.

The removal of organic sulphur compounds in the coal was attempted by Prasassarakich and Thaweesri [46], who used sodium benzoxide. Again, milling of the coal was required, to minus 1 mm in size, and approximately 68% of the pyritic sulphur and approximately 33% of the organic sulphur could be removed.

Supercritical methanol at 400-450 °C and 34 to 137 (!) bar was used by Meffe et al [47] to remove organic sulphur from coal ground to minus 20 micron. The sulphur removal ranged from 34 to 53% for a 15 minute operation, depending on the pressure employed.
Ratanakandilok [48] also used methanol but at more modest temperatures (up to 180 °C) and with the addition of water or potassium hydroxide to the methanol. Depending on the reaction conditions, 36% to 74% of the pyritic sulphur and 20% to 42% of the organic sulphur was removed from the coal after 60 to 90 minutes reaction time.

Sugawara [49] combined potassium hydroxide treatment of coal at 280 °C to convert organic sulphur, with flash pyrolysis at 960 °C in a rapid heating, free fall pyrolyser. The best result achieved was a reduction from 0.44% to 0.04% in organic sulphur in a coal from Mushwell Brooke, USA.

The transformation of sulphur in Chinese coal during pyrolysis and hydropyrolysis was studied by Chen [50] and others, who found that the mineral matter in the coal could actually act as catalysts in the desulphurization reactions, and may capture some of the hydrogen sulphide produced during the pyrolysis to form lower sulphur content char.
In a further report by Chen [51] it was indicated that the hydrocarbons in the coal with hydrogen donor ability may promote the reduction of pyrite during pyrolysis with indigenous hydrogen in the coal. To be effective, all coal was ground to below 75 micron.

Treatment of lignites with hydrochloric acid (HCl) enhances the liberation of sulphur species from the minerals, and improves the desulphurisation of the lignite when exposed to pyrolysis conditions of up to 950 °C [Uzun [52]]. Lignite is probably more amenable to this sort of treatment than coal, since the original organic material in lignite is less metamorphosed than that of coal. An issue to resolve is how to recover the heat that was used to bring the lignite to process temperatures, dry the material and make it suitable for use by the end-user.
Sydorovych [53] and Lolja [54] evaluated the desulphurization of coal using an air/steam mixture at elevated temperatures. Desulphurization did take place as a result of the oxidation of pyritic sulphur to form SO_2, but this also increased the ash content of the remaining material somewhat through a loss of carbon from carbon dioxide formation at the reaction temperatures.

What should be considered when evaluating these chemical coal desulphurization alternatives is the whole purpose of the removal of the sulphur compounds: for process and environmental reasons. As soon as energy-intensive chemical processes with additional chemicals are used resulting in additional by-product or waste streams, the net benefit to the environment may very well be negative, i.e. the environmental impact of the

whole process from a life cycle assessment point of view may be more negative than using the coal as-is.

Again, as with the biological treatment of coal, the theory is interesting but the application in large scale commercial operations is very costly with complex process schemes requiring energy and chemicals. Most of the processes are technologically challenging with respect to temperature, pressure and chemical environment. The application of these options appears to be very far away, if ever, and require a high value application for the final product, e.g. as chain reaction moderator material in nuclear energy systems, to make any economic sense.

4.1.4 Physical treatment: Coal beneficiation

The sulphur in the coal is usually present in three forms: pyritic nodules, sulphate compounds and as organically bound sulphur within the coal organostructure. Elemental sulphur does not really occur in the coal seams relevant to the Sasol Synfuel complex in Secunda.

Coal beneficiation can be employed to physically upgrade the coal through the removal of unwanted mineral material. These physical means include density separation, flotation, oil agglomeration, etc. Separation between the organic part of coal and the mineral matter takes place due to distinct differences between the two, e.g. an affinity to water or oil, or a relative density difference. These physical differences have been the basis upon which the world coal beneficiation industry has been based for years, and are the only ones relevant for large-scale commercial operations.

From this thesis' perspective, these processes predominantly focus on the removal of pyritic sulphur. Organic and sulphate sulphur compounds are distributed relatively evenly over the density fractions with only a slight increase in the heavier fractions for the sulphates. Pyrite concentrations, however, increase in the higher density fractions and hence will accumulate in the sinks fraction of a density based coal beneficiation technique.

Surface activity based processes work on the basis of difference between affinity between water or oil or flotation promoters and the materials to be separated: coal (organic material) can be coated and therefore floated or agglomerated, and pyrite will not be coated (that is, with the standard agents used for coal recovery). The organic or

sulphate sulphur species in the coal have very little effect on separation in this type of processes.

There are various types of coal beneficiation processes, and as mentioned before, they are predominantly based on either density differences or surface activity differences between coal (organic matter) and mineral matter.

There are separation processes based on other characteristics of coal and mineral matter. The difference between coal and pyrite with respect to their magnetic properties can be used in high gradient magnetic separation equipment. Optical sorting, by hand or by smart and quick reacting machines, can be used based on the difference in colour or reflectivity between coal and mineral matter. Where the magnetics method uses relatively large amounts of energy to effect a separation, the optical methods can only separate based on what the processor sees. Both will benefit from size reduction to liberate mineral matter, neither is particularly effective nor suitable for high throughput applications.

Surface activity based processes like froth flotation and oil agglomeration require small particle size material in order to have a high active surface available for coating and to achieve a sharper separation. This requires reduction of the coal particles to sizes smaller than 1 mm, or alternatively, these processes are applied on the finer material that has formed in the processes to handle the coarser material.

As discussed in the previous chapters, the reduction of coal particles to sizes smaller than 5 mm is not an option for the Gas Production section of the Sasol Synfuel process. There is enough fine coal as it is from the mining operations, more than what is required by the steam generation units, and additional size reduction of coarse coal would just add to that imbalance. The Sasol-Lurgi gasifier is not able to operate with coal that has been reduced in size to suit the surface activity based beneficiation processes.

For the purpose of this thesis, these processes will not be further discussed. The focus will be on the density based beneficiation technologies. Since this is the basis for comparison between “Prevention” and “Cure”, the more detailed discussion of density-based coal beneficiation technologies is left for chapter 6.

4.2 Sulphur Removal <u>During</u> The Coal Utilization Process

The sulphur in the coal as presented to the reactions in the coal utilization processes is released from that coal structure and reacts with the reagents in the process. Opportunities exist to capture the sulphur so released through preferential reactions with reagents specifically added to the reactor for that purpose. Several processes have been developed which capture the sulphur in the process. Almost all the processes encountered were however for combustion processes.

Limestone and dolomite can be added to the bed of a fluidised bed gasifier and act as sorbents to capture H_2S [Yrjas [55]]. In either the calcined (CaO) state or the uncalcined state ($CaCO_3$) limestone is able to react with H_2S to produce CaS and water. Simulations by Elseviers et al [56] show that there are energy efficiency benefits to be achieved in theory when limestone and/or dolomite is added to a gasifier in an Integrated Gasification Combine Cycle power generation complex. However, no mention could be found that this is indeed practiced at any of the IGCC complexes around the world.

Addition to a fixed bed gasifier is also possible. What should be observed carefully, however, is the effect of lime addition on the melting point behaviour of the ash. Certain processes are not designed to handle molten ash, and should melting occur, serious damage to the equipment may occur as well as prolonged operation stoppages.

From experience with fluidised bed boilers, in-bed capture is most effective with temperatures of below 850 °C. At higher temperatures the calcium-sulphur compounds will decompose again. Gasifiers typically operate at temperatures higher than 850 °C, and limestone addition therefore may not be that successful. This is particularly valid for the Sasol-Lurgi gasifier, since limestone added in the top part of the gasifier where the H_2S may be present, will move downwards and through the gasification zone and even hotter combustion zone before being rejected via the ash lock. When passing through the very hot combustion zone, the limestone or dolomite will release the captured sulphur again.

Even in entrained flow gasifiers the addition of Ca-based sorbents requires caution [INdC [57], Adanez [58]] . It was found that when injected into the hot gasification zones where the temperature can be as high as 1650 °C, the sorbents preferably reacted with the silicates in the slag rather than with the H_2S. Iron oxide particles injected here seem to react with the H_2S however. When injected lower in the gasifier where most of the slag has solidified, there is a better chance of sulphur capture.

Limestone/dolomite addition is only economical if the cost of these sorbents, delivered at site, is acceptable. With the location of most of South Africa's power generating capacity in the Eastern/South Eastern Highveld and Sasol Synfuel in Secunda, and the limestone in the Northwest province, transport costs may prove to be prohibitive. The feasibility of limestone addition from an availability point of view must also be considered: with more than 25 million ton coal to the Sasol Synfuel Secunda gasifiers per year, the dosage of just 5% on a mass basis would amount to 1,25 million ton of limestone. This is a large amount of material that needs to be handled in addition to all the coal. Also, at approx R 200/ton for the limestone, and transportation to Secunda ex Lichtenburg conservatively estimated at R400/ton, the additional financial burden on the process could be as high as R 750 million per year, or adding R 30/ton to the cost of coal.

Considering the coal tonnage as handled by the Sasol Synfuel gasifiers in Secunda, in-process sulphur capture in a gasifier environment appears to be potentially technically feasibly but economically not realistic.

In conclusion for this chapter, it is found that the only feasible approach to reduce the sulphur in the coal to the Sasol Synfuel gasifiers is through the application of density difference based beneficiation methods. All the other methods described require the communition of the coal to such small sizes for liberation or surface area enhancement purposes, that the coal is no longer acceptable to the Sasol-Lurgi gasifiers. In addition to the particle size issue, the other technologies are costly, technologically not proven on commercial scale, technically challenging and questions are raised whether the sum total of effort, energy and chemicals required for some of the technologies is not more detrimental to the environment than the sulphur itself.