## COALTECH 2020

# Task 4.4.1 – Phase 1

# A Review of Past and Present Work both Locally and Internationally

**by**

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# THE ECONOMIC AGGLOMERATION OF FINE COAL FOR INDUSTRIAL AND COMMERCIAL USE

## A REVIEW OF PAST AND PRESENT WORK BOTH LOCALLY AND INTERNATIONALLY

### 1 INTRODUCTION

Mining and processing of coal to provide a product to meet market requirements inevitably results in the formation of a fine coal fraction, which is not favoured by the user. In the early days of the industry, when steam trains burning large lumps of coal were the main form of industrial transport and power generation was achieved by burning coal on chain grate stokers, fine coal could be defined as being less than 6mm. Today coal burning power stations use pulverised fuel and accept a product down to 200 micron in size. The limitation on the bottom size as delivered is the high moisture content of the fine coal and the handleability of the coal. The fine coal, or more correctly the ultra fine coal can carry in the order of 20 % moisture and difficulty can be experienced in discharging feedstock containing this material from railway trucks and from power station stockpiles. In addition to the handling problem, the high moisture content reduces the "as received" calorific value and can reduce the capacity of pulverising mills at power stations due to the extra moisture that must be driven off.

The increased use of mechanised mining has increased the amount of fine coal generated, many mines reporting up to 6% of the run of mine coal as being in the minus 200 micron fraction. Until recently this material has been disposed of either underground in old workings or on surface in slimes dams. Both practices are environmentally unacceptable and are a cost against the profit of the mine.

During the 1990's there has been a move in South Africa to beneficiate the 200 micron material using froth flotation, which improves the calorific value of the product but still leaves the high moisture content to be dealt with. Thermal drying can reduce the moisture to an acceptable level but there is a concern that the fine coal can pick up moisture during transport and stockpiling and that it may even return to an equilibrium moisture in the 18 to 20 % region.

For the above reasons there is a renewed interest in the agglomeration of fine coal. In this context agglomeration means any method used to form the fine coal particles in to a cohesive mass that behaves essentially like a lump of the parent coal. The methods generally used are some form of briquetting, pelletising or spherical agglomeration.

This study will review the practices that have been used in the past in South Africa and in the coal producing countries of the world. Much of briquetting development has been involved with the briquetting of brown coal and lignite. As there are none of these coals in South Africa reference will only be made to brown coal briquetting where the method is also useful for hard coal briquetting.

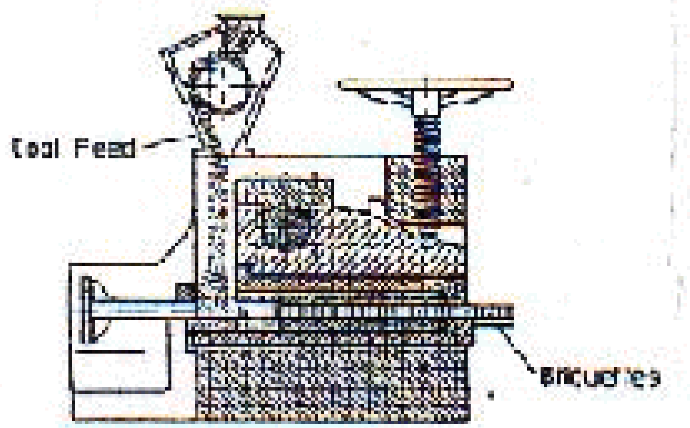
## 2 BRIQUETTING

Black coal briquettes were made in China during the 15th century. Clay and cow dung were used as a binders and the mixture was hand filled into a brick shaped mould, allowed to air dry and then used for domestic purposes. The bricks had a low calorific value and were too weak to transport any great distance. By 1850 mechanical methods of producing briquettes had been developed, brown coal and lignites using binderless methods and hard coals using binders. In 1848 William Easby[1] was granted a patent for :-

" The formation of small particles of any variety of coal into solid lumps by pressure".

This implies that only pressure was used, no binders being mentioned.

In 1855 Carl Exter[2] designed an extrusion press for peat which became the standard for lignite and peat for many years. It was also known as a " Ram Extrusion Press " or "Reciprocating Ram Press " and is shown in Fig 1.




Basic principle of the "Reciprocating Ram Press" (Exter).

Figure 1 Exter Ram Press

The first successful roller press was designed in Belgium by Louiseau in response for the need for a small briquette that could be transported over long distances. Roller presses are machines that achieve compaction of particulate matter by squeezing the material between two counter rotating rollers. Pockets formed in the working faces of the rollers form egg or pillow shaped briquettes that weigh in the order of 45 g each. Presses with capacities from 25 to 100 ton per hour can be constructed. Little has changed in the basic design of the presses, major improvements being in the way in which the pressure is applied to the rolls, the materials of construction to improve life and the ease of changing rolls and general maintenance.

Roller presses can also be used with fluted rolls to produce sheets of material that can then be broken up and screened to give a granular product. The granular material would be suitable for

mixing with power station feedstock and would solve the handling and moisture problems associated with fine coal.
Briquettes can be produced with the aid of binders or by the use of pressure only either at low temperature or at a temperature where the coal is in the plastic state. The introduction of the Clean Air Act in the U.K. in 1956 saw an increase in high temperature briquetting to produce smokeless fuels from bituminous coals. The advent of cheap North Sea natural gas saw the closure of these processes. Cheap gas and oil has caused a reduction of coal briquette production in most countries although development of briquetting technique has continued as a result of the need to agglomerate many other materials. Improvement in plant throughput has been achieved in a variety of industries by agglomerating the raw feed to the process. Notable uses have been in glass production, iron smelting, zinc refining and the fertiliser industry.

**2.1 Briquetting with binders**
Many binders have been proposed and used to produce hard coal briquettes. A review of binders published in 1969 by Waters[3] is shown in Appendix 1. The properties required of a binder are:-

(a) Produces a strong briquette.
(b) Produces a waterproof briquette.
(c) Does not detract from the quality of the coal.
(d) Does not interfere with the use of the coal.
(e) Is environmentally acceptable.
(f) Is economically viable.

The binders enjoying most success in the production of hard coal briquettes have been:-

Pitch
Bitumen
Lignosulphonates
Molasses
Starch

Pitch is highly carcinogenic and has largely been replaced by Bitumen.
Lignosulphonate, although at one time extensively used, is being replaced by Molasses as a result of environmental concern.
Molasses is modifed for use as a binder by the addition of either lime or Phosphoric Acid.
Starch, Molasses and Lignosulphonates must be treated at 200 to 300 degrees centigrade to develop the required strength and weather resistance.
All of the binders are expensive and are difficult to justify economically for use in South Africa.

Newly developed resin binders are showing promise. These are cold curing binders, often supplied in two parts, which when mixed together set chemically to form a strong weatherproof briquette. Anthracite briquettes are being made in this manner in the U.K. and sold under the name of Thermac. The cold curing binder is supplied by Du Pont and is a by-product from their nylon plant at Wilton, Middlesborough.

Almost all binders used commercially require that the total moisture of the feed is reduced to in the order of 10% in order to produce an acceptable briquette.

### 2.2.1 Binder Briquetting flow sheet

To produce a briquette using a binder the following steps are usually required: -

- Prepare the raw coal to give the correct size distribution.
- Dry the coal to the required moisture content.
- Mix the coal and binder.
- Briquette in press
- Condition the mixture if required.
- Post formation treatment heating or cooling dependent on binder used.

A typical flow sheet by Dr. Gunter[4] is shown in Fig. 2

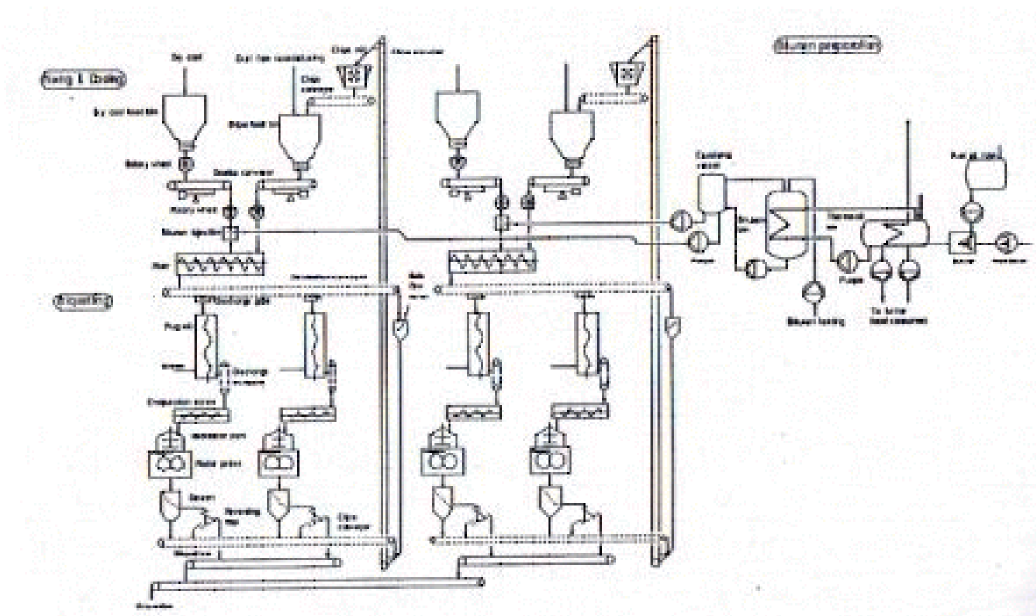


Figure 2 Typical Flowsheet - Briquetting with a Binder

Dry coal is blended with heated bitumen and then mixed with flashing and un-briquetted material from beneath the roller press. The mixture passes through a screw mixer and is further mixed in a pug mill. A screw feeder moves the material from the pug mill to the distributor of the roller press and then briquetted under pressure. The briquettes pass over a screen to remove undersize material, the briquettes being fed to a conveyor, initially to cool and then to storage.
A flow sheet of this type was used by the author[5] to produce smokeless briquettes from fine coke, using starch as a green strength binder, and either lignosulphonate or a phenol formaldehyde resin for handling and weatherproof properties. Curing of the binders was carried out in a gas-fired oven at about 400 degrees centigrade. This project failed economically due to the very poor life achieved on the rolls, mainly because the coke was in the order of 3mm top size and the roller press was acting as a crusher. In addition the coke was very abrasive compared to the types of coal normally

briquetted using roll presses.

Briquettes made with binders are usually formed using low pressure roller presses.
The pressure is defined as a specific force, which is the pressure applied to the rolls divided by the roller working width, the force being measured in kN/cm. Up to 50kN/cm is considered a low pressure operation. Early machines had two fixed rolls fitted horizontally in a frame with the material to be briquetted fed to the nip of the rolls from an overhead feed hopper. Modern machines have one fixed and one free roll, the rolls can be installed either horizontally or vertically. Further the rolls can be mounted symmetrically between the bearings or they can be mounted outside the bearings on a cantilevered shaft. The feed is forced into the nip of the rolls by means of a screw feeder that ensures even filling of the pockets.
In all cases in modern machines, pressure is applied to the moving roll by means of hydraulic cylinders. Oil displaced from the hydraulic cylinders is stored under pressure in a nitrogen filled accumulator which acts as a buffer against pressure surges.

There are only a few briquette machine manufacturers still in existence and they probably survive by producing machines for briquetting materials other than coal.
The major companies are: -

| | |
|---|---|
| Koppern | of Germany |
| Komarek | of United States of America |
| Sahut Conreur | of France |
| Zemag | former East Germany |
| Svedala | of Sweden |

Typical roller presses from some of these manufacturers are shown in Fig 3.[6,7,8]

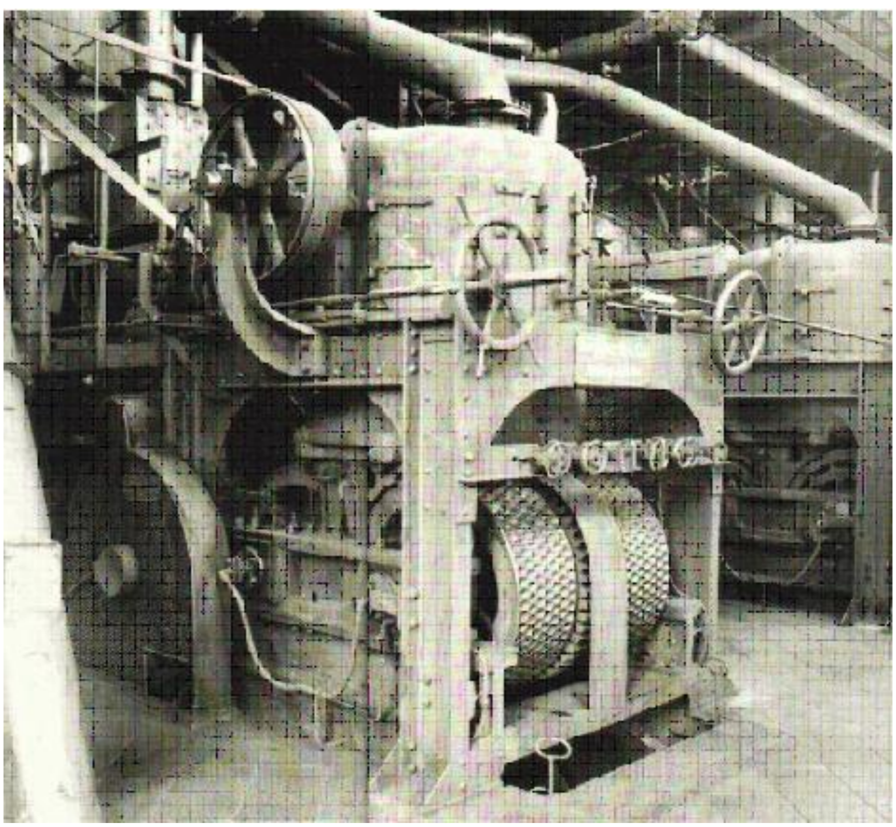


Figure 3a - Old Koppern Press

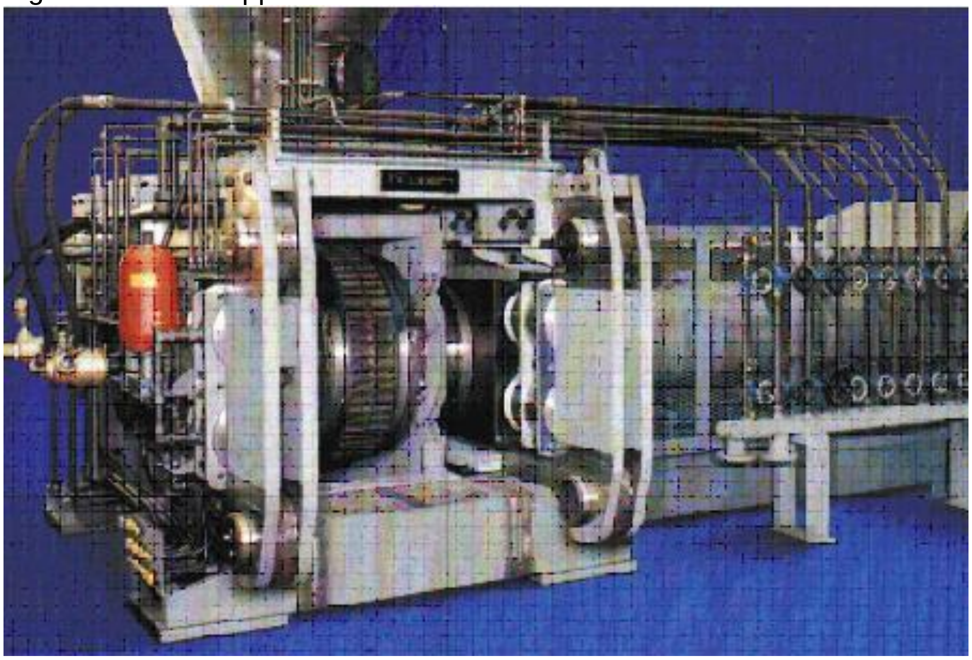


Fig 3b - Modern Koppern Press

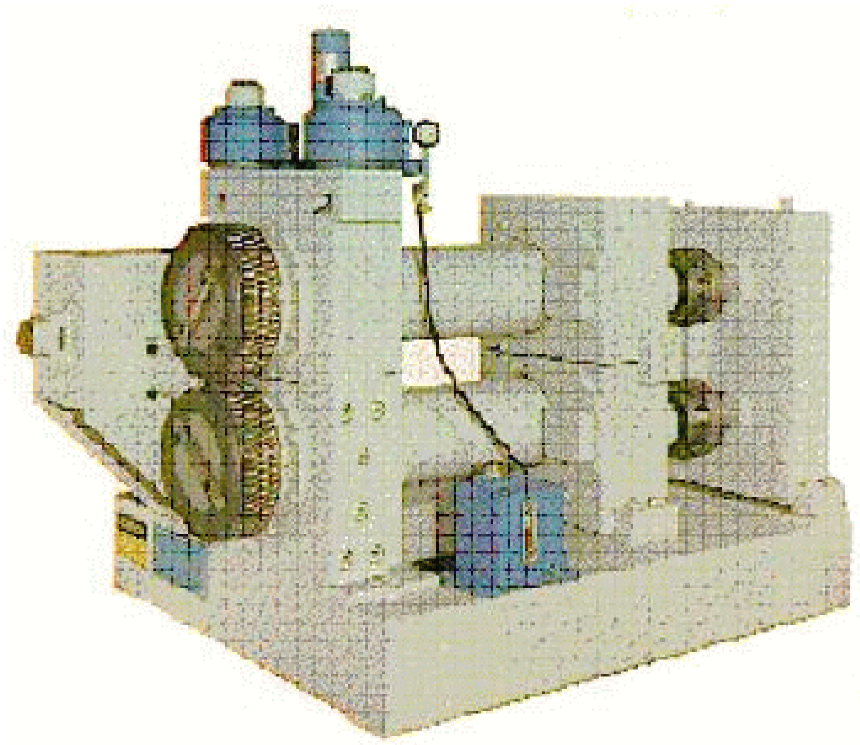


Figure 3c - Komarek Cantilevered Press

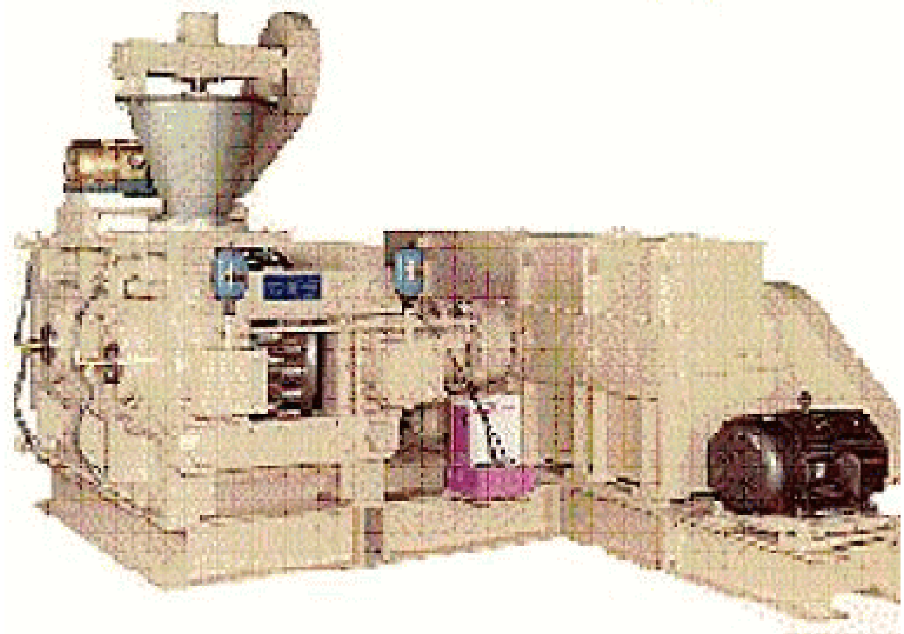


Figure 3d - Sahut Conreur Press

**2.2 Binderless Briquetting**

The cost of the binders results in briquette production being expensive, with the final product often being more expensive than the raw lump coal. Except for premium grade specialised fuels used in smoke controlled area in Europe, the cost of production precludes the use of briquettes for domestic heating purposes.

Binderless briquetting of brown coal and lignite has been practised for many years and a great deal of interest has been shown in briquetting hard coal without binders and using pressure only. Briquetting of coal at temperatures between 450 and 500 degrees centigrade which is above the softening point of coal has been practiced but is again expensive to prevent the oxidation of coal and deal with the emission of toxic waste.

The ideal practice would be to produce a briquette at ambient temperature using as low a roll pressure as possible, the briquette exhibiting the properties as previously discussed.

Honda[9] in Japan produced briquettes at between 100 and 200 degrees centigrade and Gregory[10] in England demonstrated that applying a shear force to the briquette during formation avoided the cracking due to expansion taking place when the briquette was released from the briquetting pressure. Komarek in America was able to produce binderless briquettes at 150 degrees centigrade due to the higher pressure obtainable with modern roll presses. K. Clark[11] of the Australian CSIRO produced binderless briquettes from some Australian coals at ambient temperature. A research programme was carried out to determine the coal properties that allowed low temperature binderless briquettes to be produced. Clark[12] et al produced binderless briquettes from sub bituminous coal in Western Australia. England[13] in South Africa produced binderless briquettes on a laboratory scale which were then devolatalised to produce a smokeless fuel for domestic use. Kalb[14] in Canada compared binderless briquetting of bituminous coal in a pilot plant with results obtained in the laboratory.

The main conclusion to be drawn from the above work is that the moisture content of the feed to the roll press is of the utmost importance. Many of the coals tested had a high Inherent Moisture with a consequent high Total Moisture. Reduction of the moisture content was by some means of thermal drying, either a rotary drier, fluidised bed or flash dryer being used. It was generally proposed that coal from the operating mine would be used as the heat source, even when other forms of energy were used for convenience during the test programme. The heat left in the dried coal was used in some instances to briquette at higher than ambient temperature. In one case the heat in the briquettes was utilised to pre heat the feed coal, at the same time cooling the briquettes to reduce the risk of spontaneous combustion taking place. Reference was made to a relationship between a high Hardgrove Index producing a stronger briquette, that is, the softer the coal the stronger the briquette.

This supports a theory that the strength of binderless briquettes is derived from deformation of vitrinite macerals at the surface of the briquette. Petrography has shown that the individual grains of vitrinite are broken down and converted into a continuous matrix which binds the other macerals together.

England referred to a relationship between volatile matter and the strength of the briquette.

### 2.2.1 Flow sheet for Binderless Briquetting

The flow sheet is similar to the previous flow sheet , the major difference being that the binder preparation system is replaced by a thermal drying section. Raw coal is fed to the thermal dryer, after being pre heated by the hot briquettes. The briquettes are at the same time cooled by the raw coal. The dried coal is then fed to the roll press for briquette formation. Collection of fines from the dryer by means of cyclones and bag filters is practiced, the recovered fines being recycled to the feed. The flow sheet is shown in Fig 4

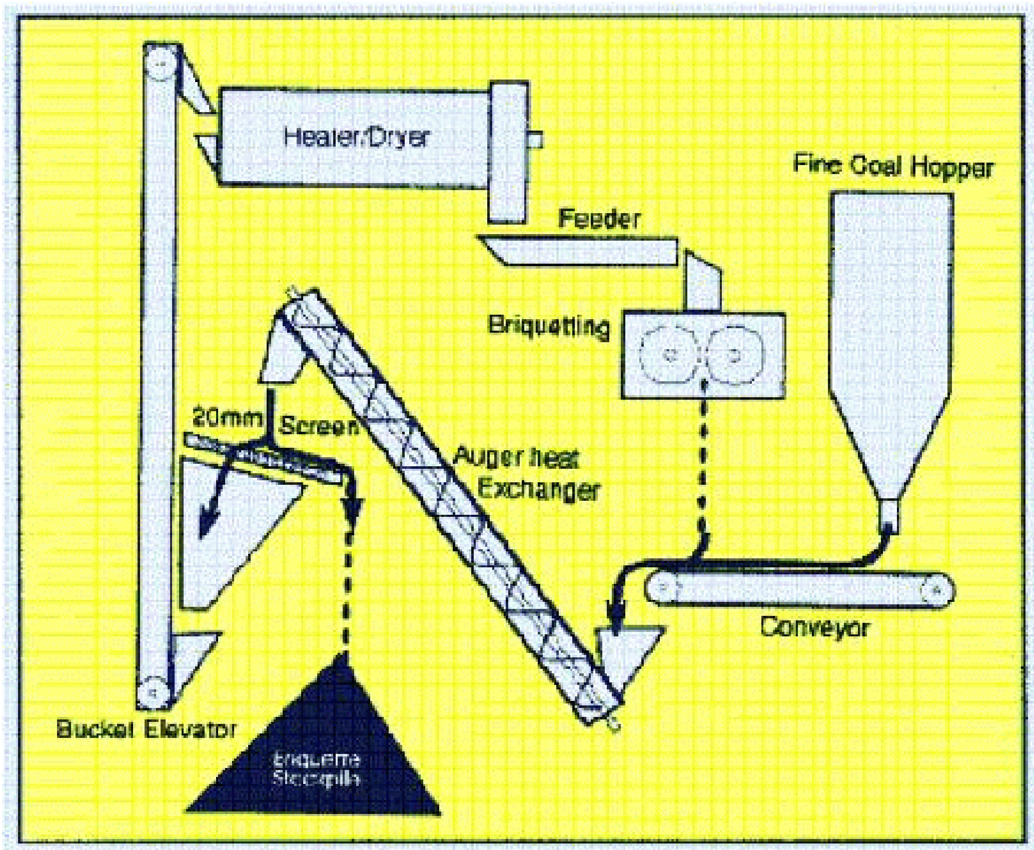



Figure 4 - Flowsheet for Binderless Briquetting

**3 HIGH TEMPERATURE BRIQUETTING**

The Clean Air Act of 1956 in the UK declared many urban areas smoke control zones and only authorised fuels could be burned. To meet the demand for smokeless fuels the National Coal Board ( Later National Smokeless Fuels )developed high temperature processes to drive off the volatiles from bituminous coal and either briquette or extrude the hot char into a suitable form for burning in domestic appliances.
Of the briquetting processes perhaps the best known was the Phurnacite[15] process wich produced pitch bound briquettes and then devolatalised them in a carbonising oven. The process was very dusty and eventually closed down due to environmental concerns. It was replaced by the German designed Ancit Process[16] which uses a three coal system, blending anthracite and coke breeze with a coking coal which acts as a binder. The blended coals are heated to 500 degree centigrade and hot briquetted. The briquettes are then transferred to a curing bunker before being quenched with water. The flow sheet is shown in Fig 5

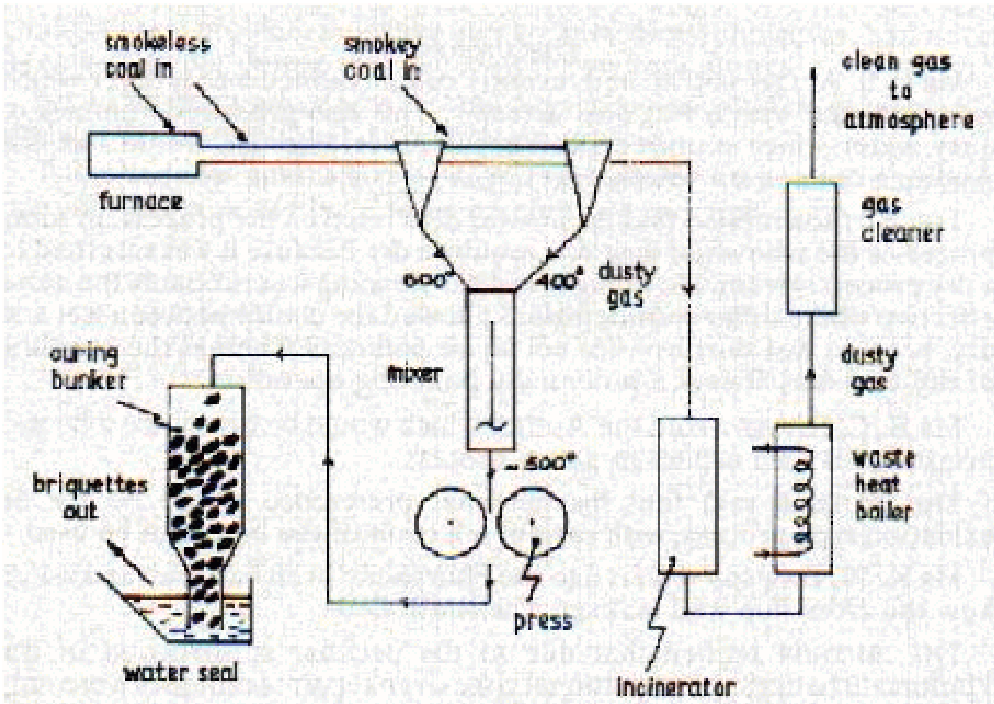



Figure 5 - Flowsheet of the Ancit Process

The Homefire[16] process used bituminous coal by crushing and drying the coal before carbonising it at 450 degree centigrade. The hot char is then briquetted , the briquettes being quenched in water. The flow sheet is shown in Fig 6

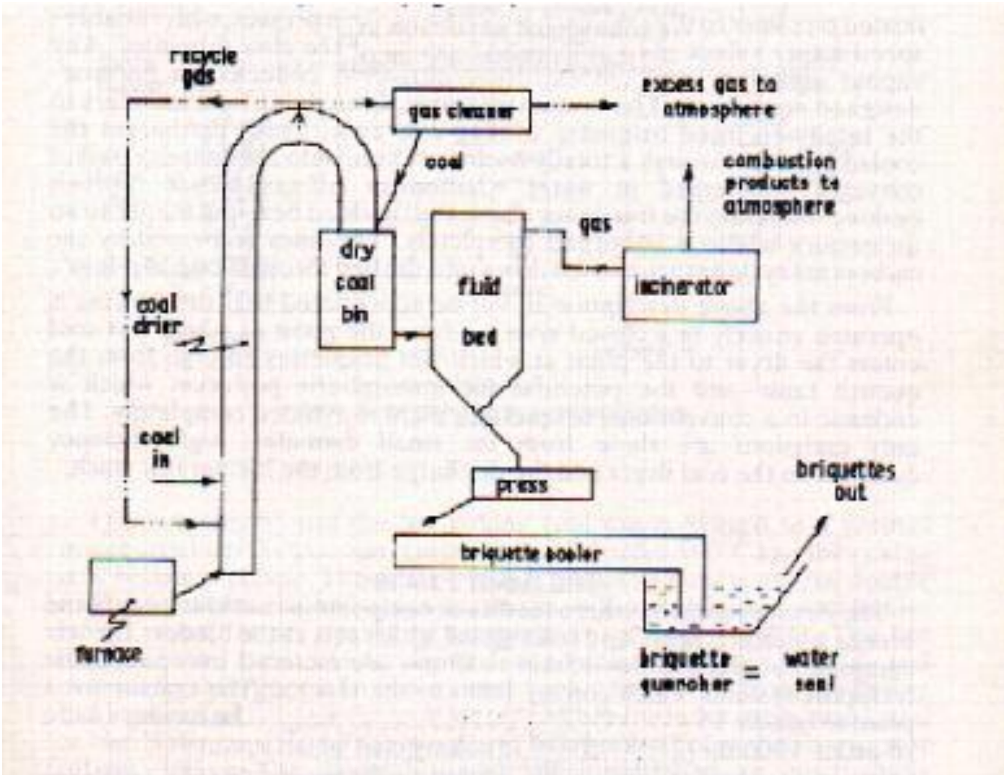



Figure 6 - Flowsheet for the Homefire Process

The plant is completely enclosed and is environmentally acceptable. Other processes such as Maxbrite[16] and Taybrite[16] make use of a so called oxidising oven which is a continuous operation and is self sustaining in that the released volatile matter is burned to heat the incoming coal. The oxygen percentage in the circulating gases is maintained at a low level to prevent combustion of the briquettes in the oven. As the briquettes pass along the oven they cool down and are finally quenched in water. The oxidising oven is shown in Fig 7.

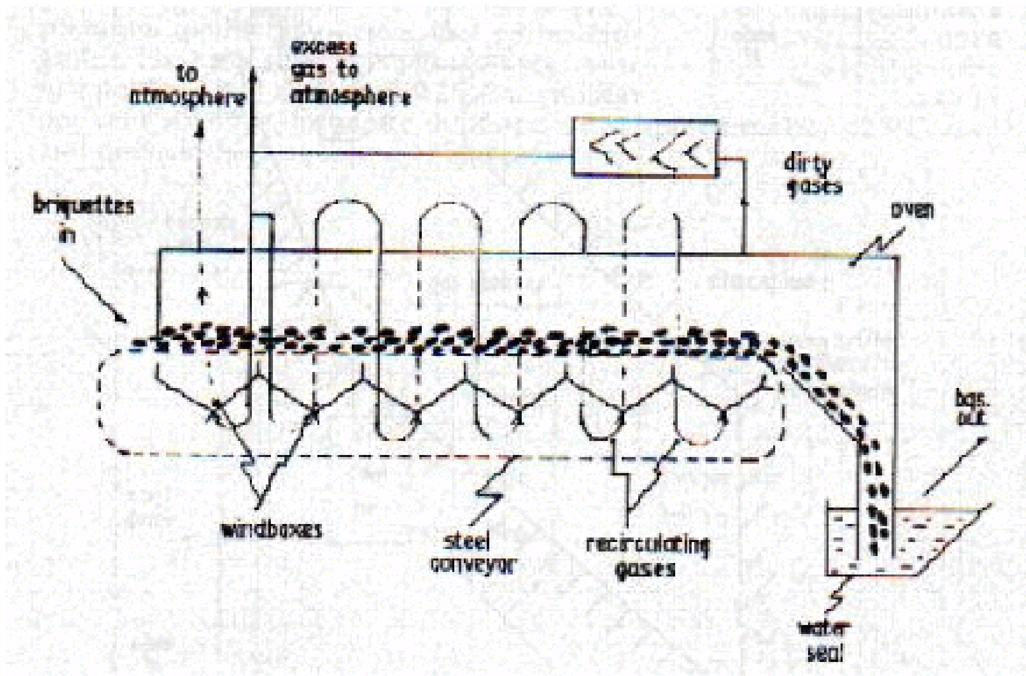



Figure 7 - Oxidising Curing Oven

The advent of relatively cheap, clean and convenient natural gas has seen the demise of many of these processes.

**4 PELLETISING**

Some industrial applications do not require the material feed to be the equivalent of solid lumps of coal. Modern coal burning power stations use pulverised coal that is less than 75 micron in size, much finer than the ultra fine coal that the mines discard. The reasons that the power stations will not accept the fine coal is because of the high moisture content lowering the heat value and making the coal difficult to handle. Agglomerates in the order of 6mm in size, and with about 10% moisture, would satisfy the requirements of the power station and allow them to utilise the fine coal. Agglomerates of this size can be produced by pelletising, the pellets being produced either in an inclined pan, by extrusion through a die or by means of a drum agglomerator.
It is thought that after pelletising the pellet will not pick up moisture on storage and that any propensity to spontaneous combustion will be substantially reduced.

**4.1 Pan pelletising**

The pan pelletiser consists of an inclined disc equipped with a rim to contain the charge. The rotational speed of the pan can be changed by means of a variable speed drive and the pan angle can be raised or lowered by operating a hydraulic cylinder. A normal operating range is between 45 and 50 degrees. The low pressure involved does not produce a strong, weatherproof pellet without the use of a binder. The same types of binders have been used in pan pelletising as in briquetting. The moisture content for a given coal feed and binder combination is critical and must be controlled within narrow limits. When using starch as a binder and fine coal the moisture range is from 18 to 25 %. The moisture level affects both the size and the strength of the pellet. Drying of the pellet

and curing of the binder is required as the last production stage, the actual temperature being dependent on the binder.
A flow sheet[17] for pan pelletising is shown in Fig 8.

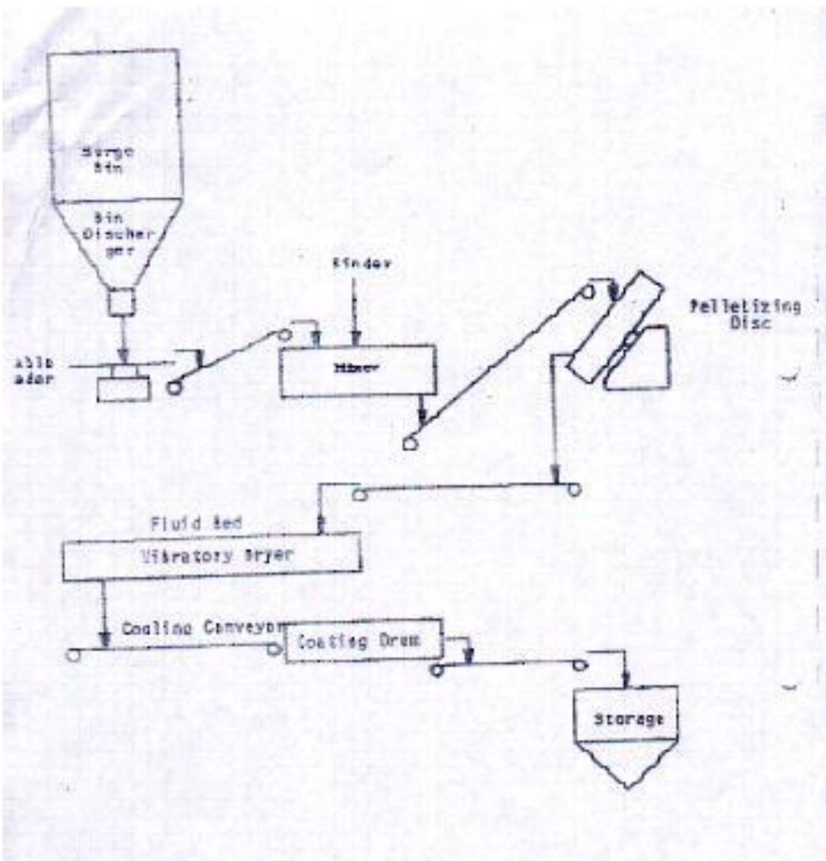



Figure 8 - Pan Pelletiser

### 4.2 Extrusion pelletising

Extrusion pelletising consists of mixing binder and coal, the use of a high shear mixer produces stronger pellets or reduces the amount of binder required. A screw-feeder introduces the mix to an extrusion chamber. The extrusion chamber has a base with multiple holes that are the diameter of the pellet required. Two roller wheels rotate on the base forcing the mixture through the die, the resistance of the material applying sufficient pressure to the particles to form adhesive bonds. A rotating knife below the die cuts the pellets to the required length. The pellets will then require heat treatment to form a weatherproof bond, the treatment being dependent on the binder used.
A flow sheet[18] is shown in Fig 9.

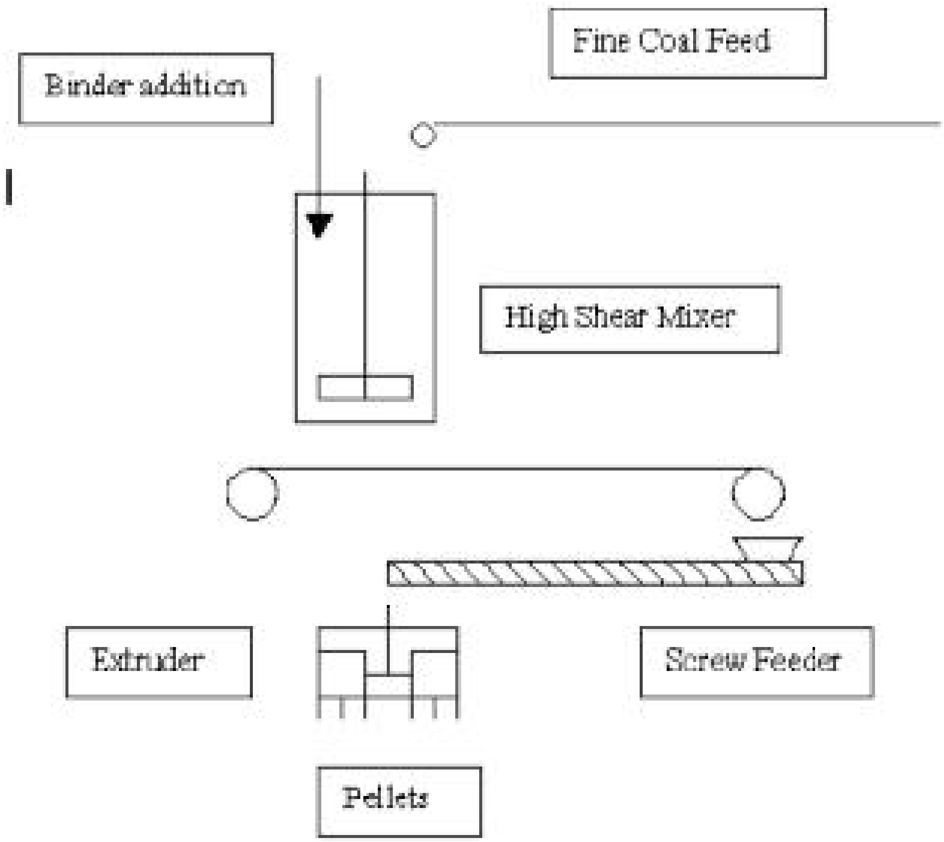



Figure 9 - Flowsheet for Extrusion Pelletising

**4.3 Drum agglomerator**

The drum agglomerator consists of an inclined rotary cylinder, the rotational speed being controlled by means of a variable speed motor. The angle of the drum, which is usually at about 10 degrees, is sufficient to cause movement of the material down the drum. The length of the drum is important as it is a factor affecting the size of the pellet produced. It has been observed that drums tend to produce more unpelletised material than pans and consequently a screen for undersize material is often fitted at the discharge end of a drum.
A drum agglomerator[19] flow sheet is shown in Fig 10.

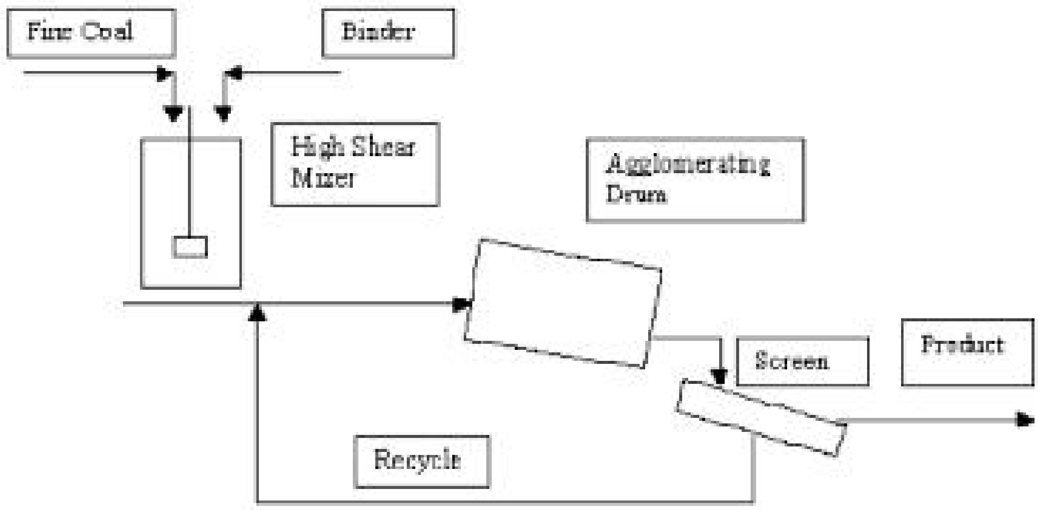



Figure 10 - Flowsheet for Drum Agglomeration

## 5 SPHERICAL AGGLOMERATION

Spherical agglomeration is achieved by adding oil to a fine coal slurry under high shear conditions. The coal particles become covered in oil and tend to combine together while the mineral matter impurities remain in the aqueous phase. This results in the beneficiation of the coal. The coal being lipophilic ( oil loving ) and hydrophobic ( water hating ), the oil coated coal particles draw closer together until they have achieved maximum repulsion of water The spherical agglomerates produced can be recovered by filtration and added to the coarse coal product. The first oil agglomeration application was the Trent process although much of modern day technology is based on the work carried out by Capes[20] at the National Research Council of Canada. At the 12$^{th}$ ICPC Blaschke[21] discussed work carried out by BHP Australia, the Aglofloat Process by the Alberta Research Council, the EERC process of the University of Dakota and the Otisca Process.
A flow sheet of the BHP pilot plant is shown as Fig 11

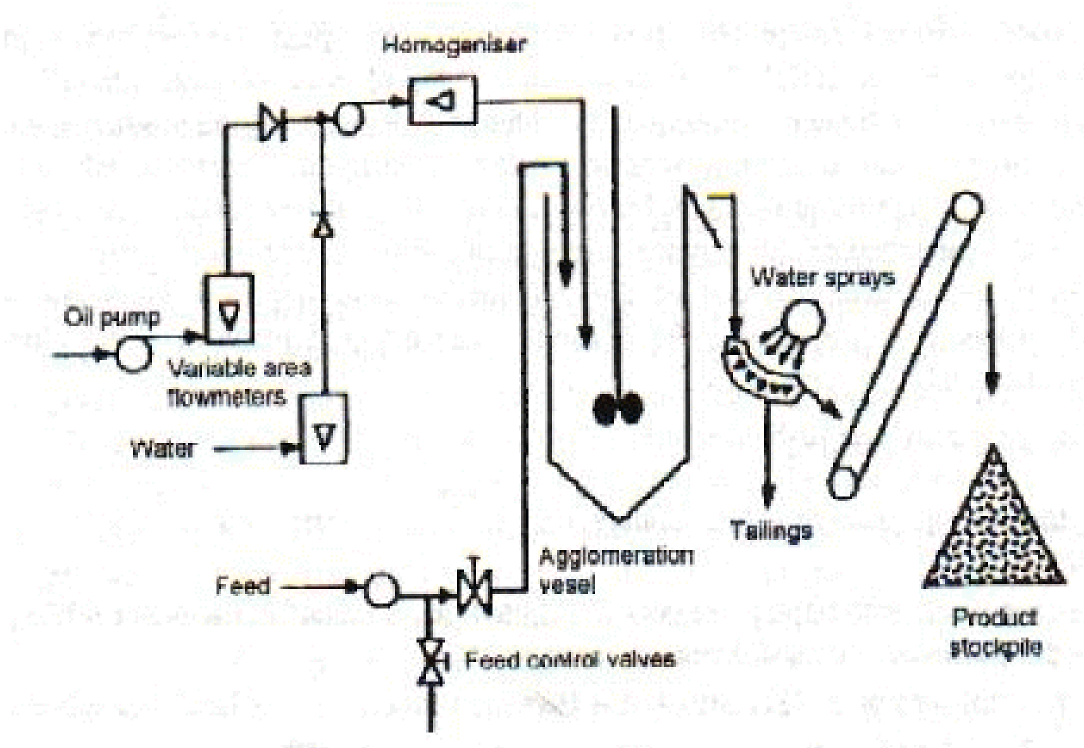



Fig 11 - Flowsheet for Oil Agglomeration

Blaschke also referred to a novel coagulation process that achieved agglomeration simply by lowering the pH value using only hydrophobic forces.
Donnelly[22] reported on the selective oil agglomeration process ( SOAP ) carried out at the Gunnedah mine in Australia. A 10 cubic meter pilot plant was operated on a continuous basis with good coal recovery. He stresses the need for high shear mixing and the use of the lowest oil consumption possible.
Although much research work has been carried out on oil agglomeration little has been achieved in the way of major operating plants. A major problem in most countries is the amount of oil required to achieve acceptably sized agglomerates strong enough to withstand handling. This is often in the order of 5% and results in oil heat units being sold at coal heat unit prices which is economically impractical. Attempts to operate at lower oil levels turns the process into a flotation process with little or no agglomeration and dewatering potential.

**6 THE MECHANISM OF BOND FORMATION**

A study by the Europeon Commission[23] for technical coal research showed that 7 coals of either bituminous or anthracite classification could be made into strong briquettes using binders. The surface chemistry of the coals had little or no effect on the strength of the briquette. An 8$^{th}$ coal however could not be briquetted, the major difference between this coal and the others tested was a high porosity and low crushing strength of the coal particles. The low crushing strength was due to deterioration of the vitrinite content by in situ heating of the coal by igneous intrusions.
Studies of acid modified molasses and ammonium sulphamate modified starch were conducted to attempt to establish optimum temperature and curing times.

The optimum temperature for molasses was found to be 250 degrees centigrade with a curing time of 30 minutes. This compares with 250 degrees centigrade used in practice but at a curing time of 90 minutes. The higher thermal capacity of commercial briquettes compared to the laboratory briquettes explains the difference in curing time.
Starch with the ammonium sulphamate modifier also cured at 250 degrees centigrade but required 60 mins in the laboratory. Unmodified starch required at least 300 degrees centigrade to cure and cross-linking was not as evident as with modified starch.
The bonding mechanism was the same for both molasses and starch, molasses consisting mainly of sucrose, a disaccharide and starch consisting of 20 % amylose and 80 % amylopectin, is a polysaccharide. Cross linking takes place by the formation of methylene bridges resulting in an increase of aliphatic carbon and a decrease in methoxy carbon.
Binderless bonding is believed to be achieved by the deformation of vitrinite. Petrographic sudies show complete loss of vitrinite grains on briquetting which are replaced by plates of vitrinite which bond the coal particles.

## 7 USES OF AGGLOMERATES IN SOUTH AFRICA

### 7.1 Iscor

The quality of coking coal in South Africa is generally inferior to the coals used in the northern hemisphere. Coke quality can be improved by briquetting these inferior coals before charging to the ovens, the increased density of the charge leading to better abrasion resistance and hot strength indices. The improved coke quality in turn improves the performance of the blast furnace. Iscor installed capacity to briquette 50 % of the charge at Newcastle using coal tar pitch as a binder, and obtained good increases in coke quality. A briquetting plant was also installed at Van der Byl Park[24].
With the better coking coals of Natal coming to an end, Iscor had to begin importing foreign coking coal and the better coking properties of the imported coals allowed the practices of briquetting the charge to be discontinued.

### 7.2 Export Steam Coal

With the introduction of froth flotation and the subsequent expected increase in moisture, Kleinkopje Colliery[25] is in the process of installing a pan pelletising system in order to add the fines to the steam coal without loss of as received calorific value.

### 7.3 Rand Mine Oil Agglomeration

Rand Mine carried out oil agglomeration test work at Rietspruit and Van Dyks Drift. Beneficiation of the fine coal was achieved but at 2 % oil addition very little agglomeration took place.

### 7.4 Sasol

The gasifying plants at Sasol can only accept a feedstock of plus 4mm. Although the minus 4 mm is used to raise process steam, excess fine coal is generated. The fine coal was successfully briquetted without binders and the briquettes performed well in the gasifiers but the cost of briquette production proved too high. Sasol took out patent number 93/6710 covering the briquetting of fine coal in 1993.[26]

## 8 EVALUATION OF THE ECONOMICS OF BRIQUETTING TECHNIQUES

The previous sections dealt with the technical requirements of producing agglomerates without regard to the financial viability of the process. This section will look at the capital and operating costs of the major processes to determine whether they are economically viable and if any one process offers a significantly better return on capital.
Estimated capital costs were obtained either from equipment suppliers or from current users. Costs are expressed in Rands in December 1999 money values.

### 8.1 Effect of moisture on the gross as received calorific value and revenue

The major application of agglomeration in South Africa will probably be in the treatment of flotation fines for addition to steam raising coal. Flotation fines can have an acceptable air dry C.V. but due to the high moisture content can have an as received CV too low for the market. Agglomeration can make the fines handleable and due to the nature of the process , the moisture content can be reduced to the extent that extra yield can be obtained in the coarser size fractions. Merely reducing the moisture content of the flotation product may not be sufficient as there is some doubt whether the ultra-fine coal will pick up moisture again during transit to the export port and in storage before loading on to a ship. The large exposed surface area of the ultra- fines can hold a large amount of water and after drying could increase back to 18 to 20 % moisture. Agglomerating the ultra-fine particles reduces the surface area and reduces the amount of water recaptured.
The following tables demonstrate the effect on yield and quality when treating coal in a processing plant to give a steam coal product. They are based on a Coaltech 2020 report prepared by J de Korte[27] of the CSIR.
Briefly the parameters are :-

| | | |
|---|---|---|
| Production | 5000000 Run of mine tons per annum (air dry basis ) | |
| | 417000 tons per month | |
| | | Dewatering screens |
| 50 x 1 mm | Dense Medium Cyclone | Basket centrifuge |
| 1 x 0.15 mm | Spiral | Dewatering-screen / |
| Screenbowl/thermal | | |
| Minus 0.15mm | Froth flotation | Various |
| Sales CV | 6100, 6150 and 6200kcal/kg GAR basis | |
| Base case | No flotation | |

The De Korte models are shown for 6100, 6150 and 6200 kcal/kg GAR demonstrating the effect of upgrading fines by flotation and by drying to different moisture levels by using a variety of dewareing techniques.
The results are shown graphically and will be discussed at the end of the section.

Dewatering - Evaluation of Options
Colliery exporting Steam Coal
Base = 6100 kcals GAR

| Case No : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base Case | Flotation + Belt Filter | Flotation + Screenbowl 18 % sf moist | Flotation + Screenbowl 14 % sf moist | Flotation + Screenbowl 10 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist | Flotation + Filter + Thermal Drying to 3 % sf moist | Flotation + Filter + Thermal Drying to 1 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 3 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 1 % sf moist + Pelletising |
| Per 100 tons of FTP : | | | | | | | | | | | |
| Tons ex Cyclone | 77.79 | 75.59 | 78.09 | 79.26 | 80.32 | 81.29 | 81.94 | 82.32 | 81.29 | 81.94 | 82.32 |
| Tons ex Spirals | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 |
| Tons ex Flotation | 0.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Total | 83.70 | 84.50 | 87.00 | 88.17 | 89.23 | 90.20 | 90.85 | 91.23 | 90.20 | 90.85 | 91.23 |
| CV ex Cyclone | 27.29 | 27.53 | 27.26 | 27.12 | 26.99 | 26.87 | 26.77 | 26.71 | 26.87 | 26.77 | 26.71 |
| CV ex Spirals | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 |
| CV ex Flotation | 0.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 |
| Combined MJ/kg AD | 27.27 | 27.51 | 27.27 | 27.14 | 27.03 | 26.91 | 26.83 | 26.77 | 26.91 | 26.83 | 26.77 |
| Moist ex Cyclone | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 |
| Moist ex Spirals | 26.00 | 26.00 | 20.05 | 16.15 | 12.25 | 8.35 | 5.43 | 3.48 | 8.35 | 5.43 | 3.48 |
| Moist ex Flotation | 0.00 | 30.00 | 20.05 | 16.15 | 12.25 | 8.35 | 5.43 | 3.48 | 8.35 | 5.43 | 3.48 |
| Combined | 8.69 | 9.49 | 8.68 | 8.27 | 7.87 | 7.48 | 7.19 | 7.00 | 7.48 | 7.19 | 7.00 |
| Combined - inherent moist | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| CV Kcals GAR | 6100 | 6100 | 6100 | 6100 | 6100 | 6100 | 6100 | 6100 | 6100 | 6100 | 6100 |
| FOB Price (R/t GAR) | R 118 | R 118 | R 118 | R 118 | R 118 | R 118 | R 118 | R 118 | R 118 | R 118 | R 118 |
| Tons railed per annum | 4469096 | 4551218 | 4644312 | 4685717 | 4721516 | 4752752 | 4772142 | 4782330 | 4752752 | 4772142 | 4782330 |
| Railage + Port fees per annum | R 245,800,260 | R 250,316,987 | R 255,437,164 | R 257,714,445 | R 259,683,388 | R 261,401,351 | R 262,467,793 | R 263,028,131 | R 261,401,351 | R 262,467,793 | R 263,028,131 |
| Revenue per annum | R 527,616,282 | | R 548,298,602 | R 553,184,621 | R 557,422,296 | R 561,112,578 | R 563,381,196 | R 564,591,005 | R 561,112,578 | R 563,381,196 | R 564,591,005 |
| Contribution per annum | R 281,816,022 | R 286,996,051 | R 292,861,437 | R 295,470,177 | R 297,738,907 | R 299,711,228 | R 300,913,403 | R 301,562,874 | R 299,711,228 | R 300,913,403 | R 301,562,874 |
| Variance from Base Case | R 0 | R 5,180,029 | R 11,045,415 | R 13,654,155 | R 15,922,885 | R 17,895,206 | R 19,097,381 | R 19,746,852 | R 17,895,206 | R 19,097,381 | R 19,746,852 |

| Case No : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base Case | Flotation + Belt Filter | Flotation + Screenbowl 18 % sf moist | Flotation + Screenbowl 14 % sf moist | Flotation + Screenbowl 10 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist | Flotation + Filter + Thermal Drying to 3 % sf moist | Flotation + Filter + Thermal Drying to 1 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 3 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 1 % sf moist + Pelletising |
| Tons per annum : | | | | | | | | | | | |
| Spiral Product | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 |
| Feed to Froth Flotation | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 |
| Froth Product | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 |
| Discards (Ultrafine) | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 |
| Discards (Coarse) | 764,850 | 724,850 | 599,950 | 541,400 | 488,350 | 439,800 | 407,350 | 388,350 | 439,800 | 407,350 | 388,350 |
| Tons per hour : | | | | | | | | | | | |
| Spiral Product | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 |
| Feed to Froth Flotation | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 |
| Froth Product | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 |
| Operating cost : | | | | | | | | | | | |
| Dewatering screen @ 10 c/t | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 |
| Screenbowl centrifuge @ 90c/t | R 0 | R 0 | R 400,950 | R 400,950 | R 400,950 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 |
| Horizontal Belt filter @ 95 c/t | R 0 | R 142,500 | R 0 | R 0 | R 0 | R 142,500 | R 142,500 | R 142,500 | R 142,500 | R 142,500 | R 142,500 |
| Hyperbaric Filter @ 300c/t | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 |
| Thermal Drying @ 400 c/t | R 0 | R 0 | R 0 | R 0 | R 0 | R 1,782,000 | R 1,782,000 | R 1,782,000 | R 1,782,000 | R 1,782,000 | R 1,782,000 |
| Pelletising | | | | | | | | | R 6,000,000 | R 6,000,000 | R 6,000,000 |
| Froth Flotation @ 1200 c/t | R 0 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 |
| Discard Disposal | R1,197,275 | R1,137,275 | R949,925 | R862,100 | R782,525 | R709,700 | R661,025 | R632,525 | R709,700 | R661,025 | R632,525 |
| Total | R1,197,275 | R3,679,775 | R3,750,875 | R3,663,050 | R3,583,475 | R5,034,200 | R4,985,525 | R4,957,025 | R11,034,200 | R10,985,525 | R10,957,025 |
| Net Contribution | R 280,618,747 | R 283,316,276 | R 289,110,562 | R 291,807,127 | R 294,155,432 | R 294,677,028 | R 295,927,878 | R 296,605,849 | R 288,677,028 | R 289,927,878 | R 290,605,849 |
| Variance from Base Case | R 0 | R 2,697,529 | R 8,491,815 | R 11,188,380 | R 13,536,685 | R 14,058,281 | R 15,309,131 | R 15,987,102 | R 8,058,281 | R 9,309,131 | R 9,987,102 |

Dewatering - Evaluation of Options
Colliery exporting Steam Coal
Revised - Base = 6150 kcals GAR

| Case No : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base Case | Flotation + Belt Filter | Flotation + Screenbowl 18 % sf moist | Flotation + Screenbowl 14 % sf moist | Flotation + Screenbowl 10 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist | Flotation + Filter + Thermal Drying to 3 % sf moist | Flotation + Filter + Thermal Drying to 1 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 3 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 1 % sf moist + Pelletising |
| Per 100 tons of FTP : | | | | | | | | | | | |
| Tons ex Cyclone | 75.44 | 72.66 | 75.69 | 77.03 | 78.24 | 79.36 | 80.13 | 80.63 | 79.36 | 80.13 | 80.63 |
| Tons ex Spirals | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 |
| Tons ex Flotation | 0.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Total | 81.35 | 81.57 | 84.60 | 85.94 | 87.15 | 88.27 | 89.04 | 89.54 | 88.27 | 89.04 | 89.54 |
| CV ex Cyclone | 27.55 | 27.81 | 27.52 | 27.38 | 27.24 | 27.11 | 27.01 | 26.95 | 27.11 | 27.01 | 26.95 |
| CV ex Spirals | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 |
| CV ex Flotation | 0.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 |
| Combined MJ/kg AD | 27.51 | 27.76 | 27.50 | 27.37 | 27.25 | 27.13 | 27.05 | 26.99 | 27.13 | 27.05 | 26.99 |
| Moist ex Cyclone | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 |
| Moist ex Spirals | 26.00 | 26.00 | 20.05 | 16.15 | 12.25 | 8.35 | 5.43 | 3.48 | 8.35 | 5.43 | 3.48 |
| Moist ex Flotation | 0.00 | 30.00 | 20.05 | 16.15 | 12.25 | 8.35 | 5.43 | 3.48 | 8.35 | 5.43 | 3.48 |
| Combined | 8.73 | 9.56 | 8.71 | 8.29 | 7.88 | 7.48 | 7.18 | 6.99 | 7.48 | 7.18 | 6.99 |
| Combined - inherent moist | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| CV Kcals GAR | 6150 | 6150 | 6150 | 6150 | 6150 | 6150 | 6150 | 6150 | 6150 | 6150 | 6150 |
| FOB Price (R/t GAR) | R 120 | R 120 | R 120 | R 120 | R 120 | R 120 | R 120 | R 120 | R 120 | R 120 | R 120 |
| Tons railed per annum | 4345063 | 4397033 | 4517753 | 4568091 | 4611882 | 4650904 | 4676874 | 4693221 | 4650904 | 4676874 | 4693221 |
| Railage + Port fees per annum | R 238,978,453 | R 241,836,814 | R 248,476,393 | R 251,244,978 | R 253,653,498 | R 255,799,739 | R 257,228,059 | R 258,127,160 | R 255,799,739 | R 257,228,059 | R 258,127,160 |
| Revenue per annum | R 522,348,577 | R 528,598,897 | R 543,107,169 | R 549,168,904 | R 554,419,208 | R 559,108,308 | R 562,229,560 | R 564,196,875 | R 559,108,308 | R 562,229,560 | R 564,196,875 |
| Contribution per annum | R 283,370,124 | R 286,762,082 | R 294,630,776 | R 297,923,925 | R 300,765,710 | R 303,308,569 | R 305,001,501 | R 306,069,715 | R 303,308,569 | R 305,001,501 | R 306,069,715 |
| Variance from Base Case | R 0 | R 3,391,958 | R 11,260,652 | R 14,553,802 | R 17,395,586 | R 19,938,445 | R 21,631,377 | R 22,699,591 | R 19,938,445 | R 21,631,377 | R 22,699,591 |

| Case No : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base Case | Flotation + Belt Filter | Flotation + Screenbowl 18 % sf moist | Flotation + Screenbowl 14 % sf moist | Flotation + Screenbowl 10 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist | Flotation + Filter + Thermal Drying to 3 % sf moist | Flotation + Filter + Thermal Drying to 1 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 3 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 1 % sf moist + Pelletising |
| Tons per annum : | | | | | | | | | | | |
| Spiral | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 |
| Feed to Froth Flotation | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 |
| Froth Prod. | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 |
| Discards (Ultrafine) | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 |
| Discards (Coarse) | 882,700 | 871,400 | 720,200 | 653,150 | 592,500 | 536,550 | 497,850 | 473,000 | 536,550 | 497,850 | 473,000 |
| Tons per hour : | | | | | | | | | | | |
| Spiral Prod. | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 |
| Feed to Froth Flotation | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 |
| Froth Prod. | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 |
| Operating cost : | | | | | | | | | | | |
| Dewatering screen @ 10 c/t | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 |
| S/bowl cfuge @ 90c/t | R 0 | R 0 | R 400,950 | R 400,950 | R 400,950 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 |
| Horizontal Belt filter @ 95 c/t | R 0 | R 142,500 | R 0 | R 0 | R 0 | R 142,500 | R 142,500 | R 142,500 | R 142,500 | R 142,500 | R 142,500 |
| Hyperbaric Filter @ 300c/t | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 |
| Thermal Drying @ 400 c/t | R 0 | R 0 | R 0 | R 0 | R 0 | R 1,782,000 | R 1,782,000 | R 1,782,000 | R 1,782,000 | R 1,782,000 | R 1,782,000 |
| Pelletising | | | | | | | | | R 6,000,000 | R 6,000,000 | R 6,000,000 |
| Froth Flotation @ 1200 c/t | R 0 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 |
| Discard Disposal | R1,374,050 | R1,357,100 | R1,130,300 | R1,029,725 | R938,750 | R854,825 | R796,775 | R759,500 | R854,825 | R796,775 | R759,500 |
| Total | R1,374,050 | R3,899,600 | R3,931,250 | R3,830,675 | R3,739,700 | R5,179,325 | R5,121,275 | R5,084,000 | R11,179,325 | R11,121,275 | R11,084,000 |
| Net Contribution | R 281,996,074 | R 282,862,482 | R 290,699,526 | R 294,093,250 | R 297,026,010 | R 298,129,244 | R 299,880,226 | R 300,985,715 | R 292,129,244 | R 293,880,226 | R 294,985,715 |
| Variance from Base Case | R 0 | R 866,408 | R 8,703,452 | R 12,097,177 | R 15,029,936 | R 16,133,170 | R 17,884,152 | R 18,989,641 | R 10,133,170 | R 11,884,152 | R 12,989,641 |

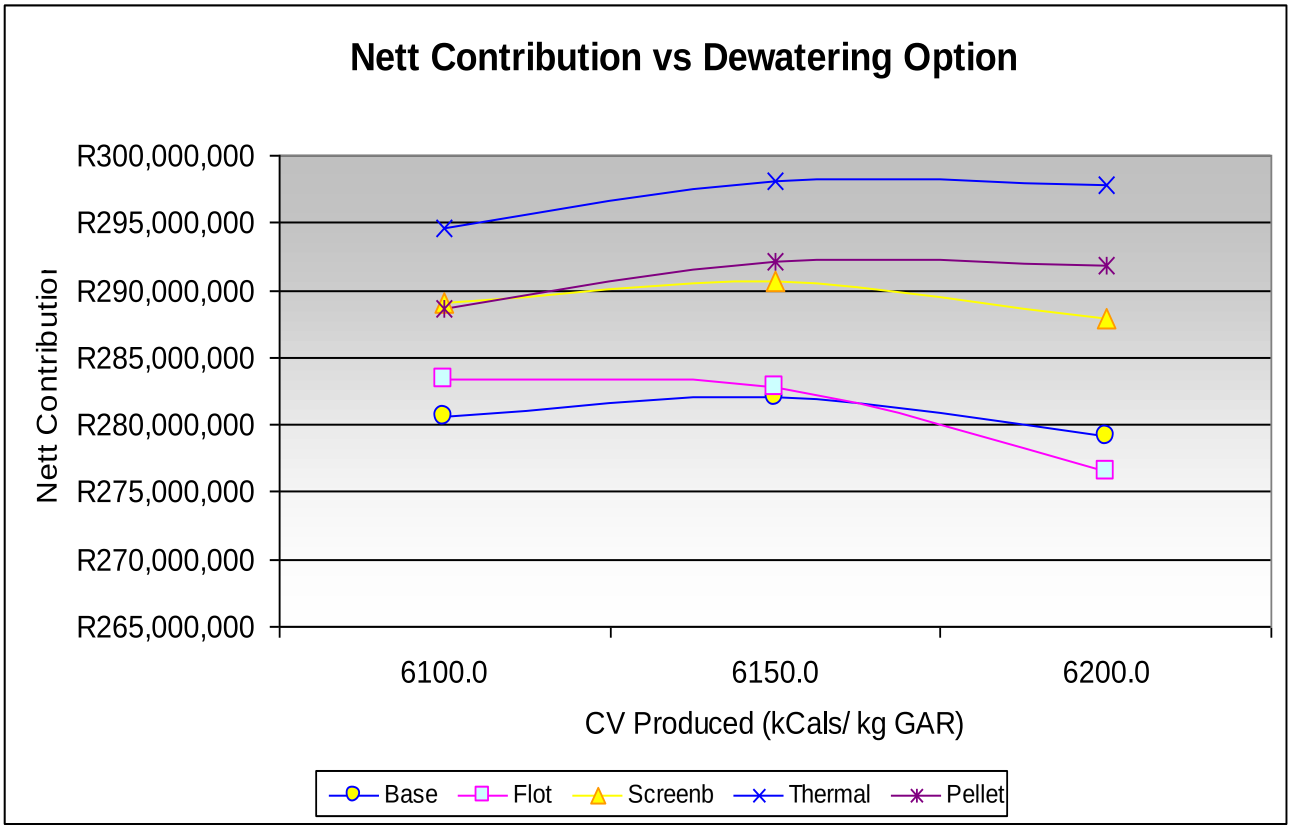
Dewatering - Evaluation of Options
Colliery exporting Steam Coal
Revised - Base = 6200 kcals GAR

| Case No : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base Case | Flotation + Belt Filter | Flotation + Screenbowl 18 % sf moist | Flotation + Screenbowl 14 % sf moist | Flotation + Screenbowl 10 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist | Flotation + Filter + Thermal Drying to 3 % sf moist | Flotation + Filter + Thermal Drying to 1 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 3 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 1 % sf moist + Pelletising |
| Per 100 tons of FTP : | | | | | | | | | | | |
| Tons ex Cyclone | 72.72 | 68.96 | 72.91 | 74.55 | 75.95 | 77.21 | 78.09 | 78.66 | 77.21 | 78.09 | 78.66 |
| Tons ex Spirals | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 | 5.91 |
| Tons ex Flotation | 0.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Total | 78.63 | 77.87 | 81.82 | 83.46 | 84.86 | 86.12 | 87.00 | 87.57 | 86.12 | 87.00 | 87.57 |
| CV ex Cyclone | 27.80 | 28.10 | 27.79 | 27.64 | 27.49 | 27.36 | 27.26 | 27.19 | 27.36 | 27.26 | 27.19 |
| CV ex Spirals | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 | 27.00 |
| CV ex Flotation | 0.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 |
| Combined MJ/kg AD | 27.74 | 28.02 | 27.74 | 27.60 | 27.48 | 27.35 | 27.27 | 27.21 | 27.35 | 27.27 | 27.21 |
| Moist ex Cyclone | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 | 7.38 |
| Moist ex Spirals | 26.00 | 26.00 | 20.05 | 16.15 | 12.25 | 8.35 | 5.43 | 3.48 | 8.35 | 5.43 | 3.48 |
| Moist ex Flotation | 0.00 | 30.00 | 20.05 | 16.15 | 12.25 | 8.35 | 5.43 | 3.48 | 8.35 | 5.43 | 3.48 |
| Combined | 8.78 | 9.66 | 8.76 | 8.32 | 7.89 | 7.48 | 7.18 | 6.98 | 7.48 | 7.18 | 6.98 |
| Combined - inherent moist | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| CV Kcals GAR | 6200 | 6200 | 6200 | 6200 | 6200 | 6200 | 6200 | 6200 | 6200 | 6200 | 6200 |
| FOB Price (R/t GAR) | R 122 | R 122 | R 122 | R 122 | R 122 | R 122 | R 122 | R 122 | R 122 | R 122 | R 122 |
| Tons railed per annum | 4202140 | 4202247 | 4371830 | 4437518 | 4491142 | 4538004 | 4569500 | 4589428 | 4538004 | 4569500 | 4589428 |
| Railage + Port fees per annum | R 231,117,712 | R 231,123,563 | R 240,450,629 | R 244,063,476 | R 247,012,813 | R 249,590,200 | R 251,322,503 | R 252,418,533 | R 249,590,200 | R 251,322,503 | R 252,418,533 |
| Revenue per annum | R 511,801,393 | R 511,812,630 | R 532,459,886 | R 540,464,411 | R 546,993,373 | R 552,708,237 | R 556,535,871 | R 558,967,884 | R 552,708,237 | R 556,535,871 | R 558,967,884 |
| Contribution per annum | R 280,683,681 | R 280,689,067 | R 292,009,257 | R 296,400,936 | R 299,980,560 | R 303,118,037 | R 305,213,367 | R 306,549,351 | R 303,118,037 | R 305,213,367 | R 306,549,351 |
| Variance from Base Case | R 0 | R 5,386 | R 11,325,576 | R 15,717,255 | R 19,296,879 | R 22,434,356 | R 24,529,686 | R 25,865,670 | R 22,434,356 | R 24,529,686 | R 25,865,670 |

| Case No : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base Case | Flotation + Belt Filter | Flotation + Screenbowl 18 % sf moist | Flotation + Screenbowl 14 % sf moist | Flotation + Screenbowl 10 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist | Flotation + Filter + Thermal Drying to 3 % sf moist | Flotation + Filter + Thermal Drying to 1 % sf moist | Flotation + Filter + Thermal Drying to 6 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 3 % sf moist + Pelletising | Flotation + Filter + Thermal Drying to 1 % sf moist + Pelletising |
| Tons per annum : | | | | | | | | | | | |
| Spiral Product | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 | 295,500 |
| Feed to Froth Flotation | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 |
| Froth Product | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 |
| Discards (Ultrafine) | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 |
| Discards (Coarse) | 1,018,500 | 1,056,550 | 858,850 | 777,200 | 707,200 | 643,800 | 599,850 | 571,600 | 643,800 | 599,850 | 571,600 |
| Tons per hour : | | | | | | | | | | | |
| Spiral Product | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 |
| Feed to Froth Flotation | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 |
| Froth Product | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 |
| Operating cost : | | | | | | | | | | | |
| Dewatering screen @ 10 c/t | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 |
| Screenbowl centrifuge @ 90c/t | R 0 | R 0 | R 400,950 | R 400,950 | R 400,950 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 |
| Horizontal Belt filter @ 95 c/t | R 0 | R 142,500 | R 0 | R 0 | R 0 | R 142,500 | R 142,500 | R 142,500 | R 142,500 | R 142,500 | R 142,500 |
| Hyperbaric Filter @ 300c/t | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 | R 0 |
| Thermal Drying @ 400 c/t | R 0 | R 0 | R 0 | R 0 | R 0 | R 1,782,000 | R 1,782,000 | R 1,782,000 | R 1,782,000 | R 1,782,000 | R 1,782,000 |
| Pelletising | | | | | | | | | R 6,000,000 | R 6,000,000 | R 6,000,000 |
| Froth Flotation @ 1200 c/t | R 0 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 | R 2,400,000 |
| Discard Disposal | R1,577,750 | R1,634,825 | R1,338,275 | R1,215,800 | R1,110,800 | R1,015,700 | R949,775 | R907,400 | R1,015,700 | R949,775 | R907,400 |
| Total | R1,577,750 | R4,177,325 | R4,139,225 | R4,016,750 | R3,911,750 | R5,340,200 | R5,274,275 | R5,231,900 | R11,340,200 | R11,274,275 | R11,231,900 |
| Net Contribution | R 279,105,931 | R 276,511,742 | R 287,870,032 | R 292,384,186 | R 296,068,810 | R 297,777,837 | R 299,939,092 | R 301,317,451 | R 291,777,837 | R 293,939,092 | R 295,317,451 |
| Variance from Base Case | R 0 | -R 2,594,189 | R 8,764,101 | R 13,278,255 | R 16,962,879 | R 18,671,906 | R 20,833,161 | R 22,211,520 | R 12,671,906 | R 14,833,161 | R 16,211,520 |

From the above tables it can be seen that the use of flotation and belt filters increases the the contribution to profit when producing a 6100 kcal/kg GAR product, is almost at break-even point at 6150 kcal/kg and results in a loss when producing a 6200kcal/kg product.
Screenbowl centrifuges drying the spiral and flotation product to 18 % moisture increases the revenue above the base case at all the Calorific Value levels.
Thermal drying increases the contribution the most but concern as previously been expressed regarding the possibility of moisture pick up between mine and customer. Agglomeration in the form

of pelletising reduces this risk and still gives a higher return than screenbowl centrifuges. These observations are shown graphically below.




## 8.1Capital costs

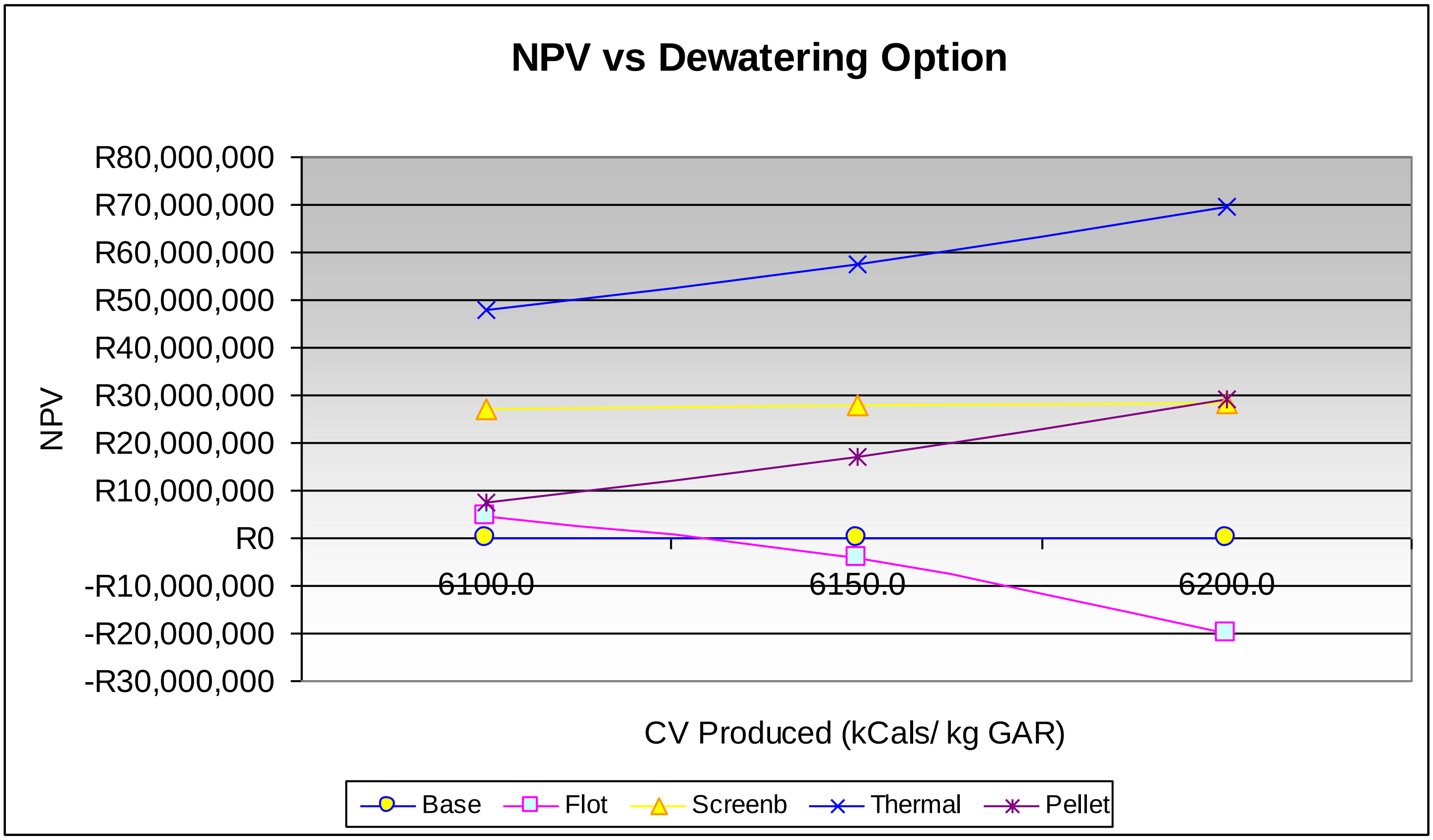
It has been demonstrated that thermal drying followed by agglomeration can increase the profitability of coal processing. However only operating costs were considered and the capital cost of the operation must now be reviewed. Quotes for briquetting presses and associated

equipment were obtained from two equipment suppliers while pan pelletising costs were obtained for a project under evaluation. No supplier of extrusion presses could be contacted and for the purpose of this report it is assumed that capital costs would be comparable to pan pelletising.
The operating costs are also shown below and it is clear that binderless briquetting has a cost advantage as binder costs are a major component of the total briquetting cost. Binderless briquetting is being practised in Australia and America and test work has shown that some South African coals are amenable to binderless briquetting. However it is also clear that even if binders are used, recovery of ultra fines by flotation,agglomeration and thermal drying is an economically feasible process.

Based on a 25 tph plant

| Cost of agglomeration | Briquetting ( Koppern ) | Briquetting ( Sahut Conreur) | Binderless Briquetting | Pelletising | Extrusion |
|---|---|---|---|---|---|
| CAPITAL COSTS | | | | | |
| Filtration | 10,000,000 | 10,000,000 | 10,000,000 | 10,000,000 | 10,000,000 |
| Thermal Drying | 9,500,000 | 9,500,000 | 9,500,000 | ) | |
| Binder add/control | 1,100,000 | 1,345,528 | 0 | ) | |
| Agglom. Equipment | 3,500,000 | 2,022,400 | 3,500,000 | ) 12,500,000 | 12,500,000 |
| Curing/Post treatment | 500,000 | 195,920 | 0 | ) 12,500,000 | 12,500,000 |
| Electrical | 900,000 | 628,914 | 617,647 | ) | |
| Civils & stuctures | 1,700,000 | 1,187,949 | 1,166,667 | ) | |
| Erection & installation | 2,200,000 | 1,537,346 | 1,509,804 | ) | |
| Total | 29,400,000 | 26,418,057 | 23.000,000 | 35,000,000 | 35,000,000 |
| Cost R/ton/hour | I,176,000 | 1,056,722 | 920,000 | 1,400,000 | 1,400,000 |
| | | | | | |
| OPERATING COSTS | | | | | |
| PER MONTH | | | | | |
| Labour | 57,600 | 57,600 | 57,600 | 57,600 | 57.600 |
| Maintenance | 212,500 | 197,440 | 196,814 | 291,667 | 291,667 |
| Binder | 531,250 | 531,250 | 0.0 | 286,875 | 286,875 |
| Energy | | | | | |
| TOTAL | 801350 | 786290 | 254414 | 636142 | 636142 |

Using these values J de Korte determined the NPV over 10 years at a 17 % interest rate.for the various drying methods used in conjunction with pelletising. The results are shown graphically :-




When the capital cost of equipment is taken into account it can be seen that thermal drying is still the best option but that pelletising gives a lower return than the screenbowl centrifuge until a product of 6200kcal/kg is produced. However a positive return is achieved at all levels and the improved handling characteristics of the product makes the agglomeration process worthy of consideration.

## 9 METHODS AND TECHNIQUES USED TO TEST BRIQUETTES

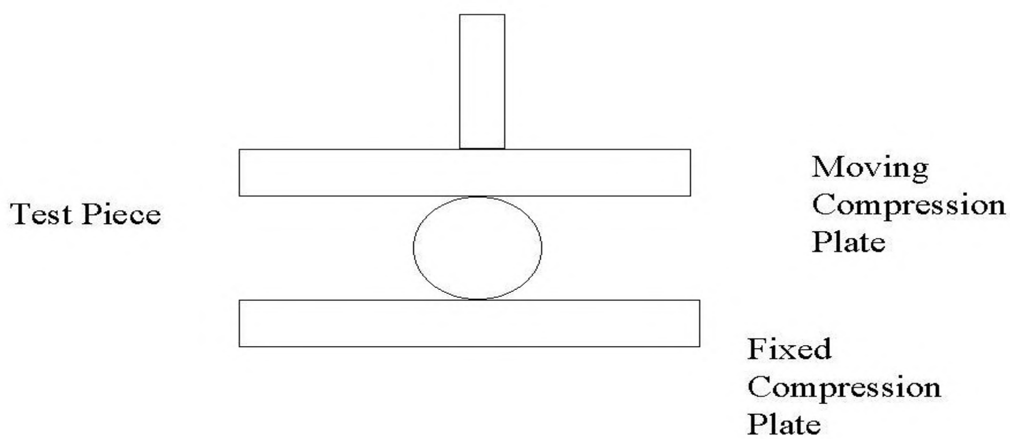
The producers and consumers of agglomerates require quality control procedures to ensure that the agglomerate will perform satisfactorily. Standard methods exist for testing solid fuels such as coal and coke but an exhaustive search has revealed the lack of international standards for commercial scale agglomerates. Japan has the most comprehensive standard, JP JIS Z 8841-1993, which deals with tests for crushing strength Tumbler strength and a Drop Shatter test. There are tests for charcoal briquettes for household use such as SABS 1399: 1999, which are not strictly applicable to industrial requirements. Clark and Meakins[28] acknowledge the lack of standards and give their opinion on the properties required of a briquette. The properties and test methods are discussed below.

**9.1 Strength**

Producers of agglomerates require a quick test to ensure that the process is operating well. The compressive strength is a good indication that sufficient binder is being used, that the briquetting pressure is adequate and that post curing treatment is being carried out correctly.

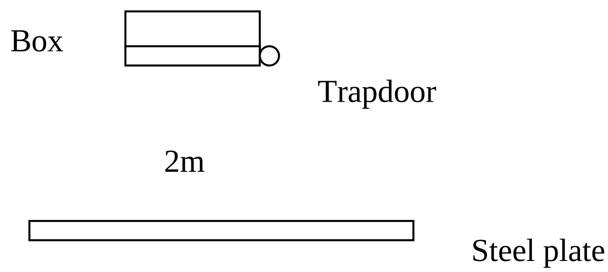
The Japanese Standard calls for a fixed compression plate on which the sample is placed and a moving compression plate to apply pressure to the test piece. The test piece can be between 2 and 20 mm in size. The compression plate moves at a speed of between 0.15 and 0.3 mm / second.

In order to compare agglomerates of different sizes the Australians calculate the Maximum Compressive Strength, which is the maximum compressive force divided by the cross sectional area over which the fracture occurs.



**9.2 Drop Shatter test**

The Drop Shatter Test is an indication of how the agglomerate will stand up to handling, particularly dropping from a height. A form of shatter test was used to measure the quality of blast furnace coke before the drum test became popular and is still to be found in many laboratories. A modification of this equipment could be used to determine the shatter index of agglomerates.
The Japanese version of the shatter test uses a sample of 400cubic centimetres which is then weighed. The sample is dropped 5 times from a tower from a height of 2 metres on to a steel plate. The sample is then screened on a screen about one fifth the size of the agglomerate and the over size weighed.




The Shatter Index is calculated from the formula :-

$$\text{Shatter Index} = \frac{Ms}{Mr} \times 100$$

Where Ms = mass of sample
Mr = mass of residue

**9.3 Tumbler Test**

The Tumbler Test is similar to the Micuum Test for coke , which gives a measure of the Abrasion Resistance and impact resistance of coke.
The Japanese method for agglomerates consists of a drum of 350mm internal diameter and 175 mm deep. 2 fins are welded inside the drum diametrically opposite each other to act as lifters. A 400 cubic centimetre sample is weighed and placed in the drum
The drum is rotated 200 times and the residue is screened at about one fifth of the size of the test piece. The residue is weighed and Tumble strength calculated using the formula :-

$$Ts = \frac{Ms}{Mr} \times 100$$

Where Ms = Mass of sample
and Mr = Mass of residue
The Australians did not propose a tumbler test.
The half micuum drum would probably be a good size for testing briquettes and testwork

should be carried out to see if it can be utilised for this purpose.

**9.4 Weathering**

The ability of an agglomerate to withstand exposure to changes in weather is of the utmost importance. The agglomerate can be stockpiled for some considerable time and can be exposed to repeated wetting by rain and snow followed by drying and high temperatures from direct sunlight. The agglomerate must remain strong and handleable under these conditions. There is no standard to test for weathering, many producers simply immerse the agglomerate in water for four hours and apply hand pressure to see if disintegration takes place. It is recommended that a cycle of wetting and drying is applied for a predetermined period of time and then a compressive strength test carried out to compare against the original strength. Where some organic binders such as starch are used, mould formation after a prolonged weathering has been reported. Addition of a bactericide may be required if mould is detected.

**9.5 Spontaneous combustion**

It has been observed that the absorption of atmospheric moisture is often a precursor to spontaneous combustion. The agglomerates have been dried and may pick up some water thus having the potential for starting the spontaneous combustion cycle. The fact that agglomeration has been carried out decreases the surface area and porosity of the fines and should reduce the propensity for spontaneous combustion. Bunker or furnace tests can be carried out to check this situation.

**9.6 Thermal degradation**

Some industrial applications subject the agglomerates to a rapid heating cycle. The Corex steel making process and the Sasol gasifiers are examples of this type of operation where even lump coal can disintegrate into small pieces. This is known as Thermal Degradation and agglomerates must be able to remain intact without breaking down into the original fine coal.

The test used to determine thermal degradation consists of plunging the agglomerate into an inert atmosphere furnace at 1400 degree centigrade and then measuring the remaining agglomerate. Clark[29] reports that binderless briquettes suffer little degradation but that briquettes made with binders suffer severe degradation.

**9.7 Other Properties**

The normal quality parameters used to measure the quality of coal and coke can be applied to agglomerates. Analysis for Ash content, Volatile Matter , Calorific Value and Sulphur can be carried out using the appropriate standards without modification.

## 10 THE MARKET POTENTIAL FOR COAL AGGLOMERATES

The use of briquettes and agglomerates to date was referred to in the review section and the experience gained in the past will be a guide to the possible use in the future.
ISCOR have briquetted part of the coke oven charge as a means of improving coke quality but no longer use the technique, supposedly because it is no longer cost effective. The ISCOR briquettes were pitch bound, the pitch being recovered as part of the coking cycle. It is unlikely that they will revert back to briquetting in the near future. Australians claim that binderless briquettes make a good feedstock for the COREX process and this is a use worth persuing.
It would appear that the ferro alloy industry is short of good reductant material and there is perhaps a potential market in this area.
SASOL have experimented with briquetting the fine coal which is surplus to steam raising requirements but which is too small to use in the gasifiers. Some success was reported, although other sources claim that the briquettes disintegrated in the retorts. It would appear that SASOL have lost interest in briquetting to produce a feedstock for the gasifiers.
The use of briquettes for domestic heating and cooking is unlikely due to the briquetting costs compared with the selling price of D grade coal. Unless smokeless fuels are made compulsory by law briquettes are not seen as viable for domestic use. Even if smokeless fuels were enforced the briquettes would have to go through a devolatalisation stage or anthracite would be required as the starting point.
In the established Europeon markets, where smokeless briquettes sell for R600 per ton, it would be possible to export smokeless briquettes at a reasonable profit.
The major use for agglomerates, probably in the form of pellets is in the steam raising market.
It has been demonstrated that froth flotation of the ultra fines combined with pelletisation and thermal drying is cost effective and this should provide an incentive for pelletisation plants to be installed.
The customer must be included in the decision to add pellets to the sized steam coal, he must be educated as to the reason for pelletising and assured that there will be no effect on his own production process.

## 11 THE RECOMMENDED ROUTE FORWARD

This report has reviewed past practice, looked at current techniques and costs and has indicated the potential markets for agglomerates. It has highlighted some areas where further research and development are required. These are :-

### 11.1 Binderless briquetting

The cost advantage of being able to carry out binderless briquetting justifies an intensive research effort. The cost section shows that the equipment cost for briquetting and pelletising is very much the same and therefore the saving in binder costs would make a significant contribution to the cost effectiveness of briquetting.
Parameters to be investigated would include :-

- Effect of coal composition
- Effect of briquette press design
- Effect of pressure
- Mechanism of bond formation

Conversion to smokeless fuel
Blending of coals to give maximum briquette strength

**11.2 Standardisation of quality tests**

In order to monitor the research results, standard tests for the parameters discussed in the report must be agreed. If there are no international tests then at least South African standards should be produced. It would be more useful to produce the test methods in cooperation with other interested parties in for example Australia and America than to go it alone.

**11.3 Moisture pick up on stockpiling**

Moisture pickup on stockpiling could easily be the motivating force for carrying out agglomeration. To date it is not known what the effect of stockpiling is when ultra fine coal has been thermally dried. It is essential that this question is answered with authority.

Acknowledgements

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