THE DEVELOPMENT OF BINDERLESS, SMOKELESS BRIQUETTES FROM BITUMINOUS COLLIERY WASTE

TREVOR ENGLAND

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JOHANNESBURG 1993

Declaration

I declare that this project report is my own unaided work. It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

T. England

(Signature of candidate)

5th day of OCTOBER 1993

ABSTRACT

Superfines of less than 200 micron are generated when mining coal. They have not been successfully beneficiated in the past and are not acceptable to the consumer.

The superfines produced at Kleinkopje are from bituminous coal with a volatile matter content of 24%. They are currently stored in surface slimes dams which are a potential environmental problem.

A process has been developed whereby the superfines are beneficiated, briquetted without the use of binders and devolatilised to produce a premium smokeless briquette which will attract a premium price in the export market.
The capital cost of the project is estimated and an excellent payback period is predicted.

ACKNOWLEDGEMENTS

I wish to thank the following people and organisations:-

- Professor Horsfall for his support of my application to take part in the G.D.E. course and for his enthusiasm and support of the course work and papers.

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- To the Directors of Amcoal for permission to publish this paper.

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V.M.	Volatile matter
C.V.	Calorific value
I.M.	Inherent moisture
S	degree of saturation
Sr	residual degree of saturation
pc	cake permeability
pk	capillary pressure
t_2	dewatering time
ϵ	porosity
η	viscosity
k	cake thickness
p	pressure
R.D.	relative density
X	cake thickness
k	constant
R	solids rate
l	filter length
V	belt speed
W.G.	water guage
A	amps
Deg.	degree
f	function

The development of binderless, smokeless briquettes from bituminous colliery waste

CHAPTER 1

INTRODUCTION

South African coal was formed by the metamorphosis of vegetation over a time-span of 200 million years. In the process of coalification the organic material which is now coal was buried underneath soil, forming the coal seams which are mined today. Depending on the depth of cover, the coal is mined by either underground techniques or by opencast methods. Irrespective of which mining method is used a certain amount of superfine coal is produced, the amount of these superfines increasing over the years as mining has become more mechanised.

For various reasons the superfines, nominally minus 200 micron in size have had no commercial value and in fact have incurred costs in their disposal. Export steam coal contracts specify the maximum amount of minus 3mm and minus 0,5mm coal in the cargo. High transport costs from the mines to even the nearest power stations make it an uneconomical fuel for Eskom steam raising and high moisture content makes the material difficult to handle.

The author has been involved in testwork aimed at upgrading superfines to a saleable product over many years. The involvement has varied from hands-on operation in the case of briquetting to experiment design and result interpretation wit he practical testwork being carried out by mine technical staff. The degree of involvement has been indicated in the relevant sections.

This project report examines the use of the superfines to produce a premium smokeless briquette that is in big demand in England.

In order to produce a briquette of the required quality the techniques required are beneficiation or upgrading the quality of the coal, dewatering which allows the formation of a good briquette, briquetting and finally devolatilisation which renders the briquette smokeless.

Beneficiation of superfine coal is achieved by means of froth flotation or oil agglomeration and the various developments of the last five years are considered to determine a suitable process. Without a good yield of low ash content coal the project is not viable. The briquetting process requires a feedstock with a maximum moisture content of 5% whereas the product from the beneficiation stage contains 70% moisture. Two stages of dewatering are considered, the first stage being by either vacuum or pressure filtration, the second stage being by thermal drying. Several methods of thermal drying are considered including current research at the C.S.I.R. with regard to fluidised bed drying. The dried material is then briquetted in a conventional double roll briquette press but after initial trials using binders, binderless briquettes of good appearance and strength were produced. Binderless briquettes have been produced from bituminous coals by other workers but by means of heating the coal into the plastic stage and then briquetting. This hot briquetting requires great control to avoid fires and expensive presses to handle the hot feed stock.

The briquettes produced are not strong enough to allow distribution and marketing, are not waterproof to allow storage in the open and the high volatile content of the bituminous coal creates too much smoke to comply with smokeless fuel regulations. In order to remove the volatile matter the briquettes were carbonised in a test coke oven when it was found that not only were the briquettes rendered smokeless but that they also acquired acceptable handling strength and waterproof properties.

All the techniques of production were evaluated either at laboratory or pilot plant scale and the most successful or cheapest technique was selected to incorporate in a process flowsheet. Costing of the flowsheet was carried out using prices supplied by equipment manufacturers and installation and services costs factored from recent in-house projects. Estimates of production costs and selling prices were used to establish that a very good payback period could be achieved.

1.1 Availability of raw material

The Witbank coalfield is a major source of steam coal for the export market. Anglo American, through its wholly owned subsidiary Amcoal, operates four large mines in this area treating the Witbank No.2 seam. In the past these collieries have stored superfines in surface dams or have pumped them into old underground workings where they are effectively lost as a useful energy source.

The present stocks and annual production are as follows:-

Table 1.1 Availability of superfines

Colliery	Stored in Slimes Dams tons x 10^6	Annual Prod tons x 10^6
Kleinkopje	7,28	0,52
Goedehoop	2,0	0,20
Bank 2	NIL	0,15
Navigation	NIL	0,36
Total	9,28	1,23

The quality of the superfines from Goedehoop is good enough to allow them to be dried by vacuum filtration and utilised in the export steam coal. The superfines from Bank 2 are pumped underground and are not readily available for further beneficiation. The Navigation mine is in the process of commissioning and has produced very few fines to date. This leaves the fines from the Kleinkopje colliery as the obvious first choice to form the basis of a briquetting process. For the purpose of this project report it is assumed that the physical characteristics of the superfines from all the collieries are similar and that testwork carried out at one colliery will be applicable to another colliery. There is no doubt that this would apply to thermal drying testwork as the particle size distribution and total moisture content are very similar.

1.2 Source of superfines

A simplified flowsheet of the coal beneficiation process shows how the superfines are separated from the rest of the coal. The flowsheet is shown in Figure 1.1.

It can be seen that the superfines are not beneficiated in any way and therefore are usually of low calorific value.

1.3 Quality of Kleinkopje raw superfines

An average quality of the Kleinkopje thickener underflow solids is :-

Figure 1.1
SIMPLIFIED PLANT FLOWSHEET

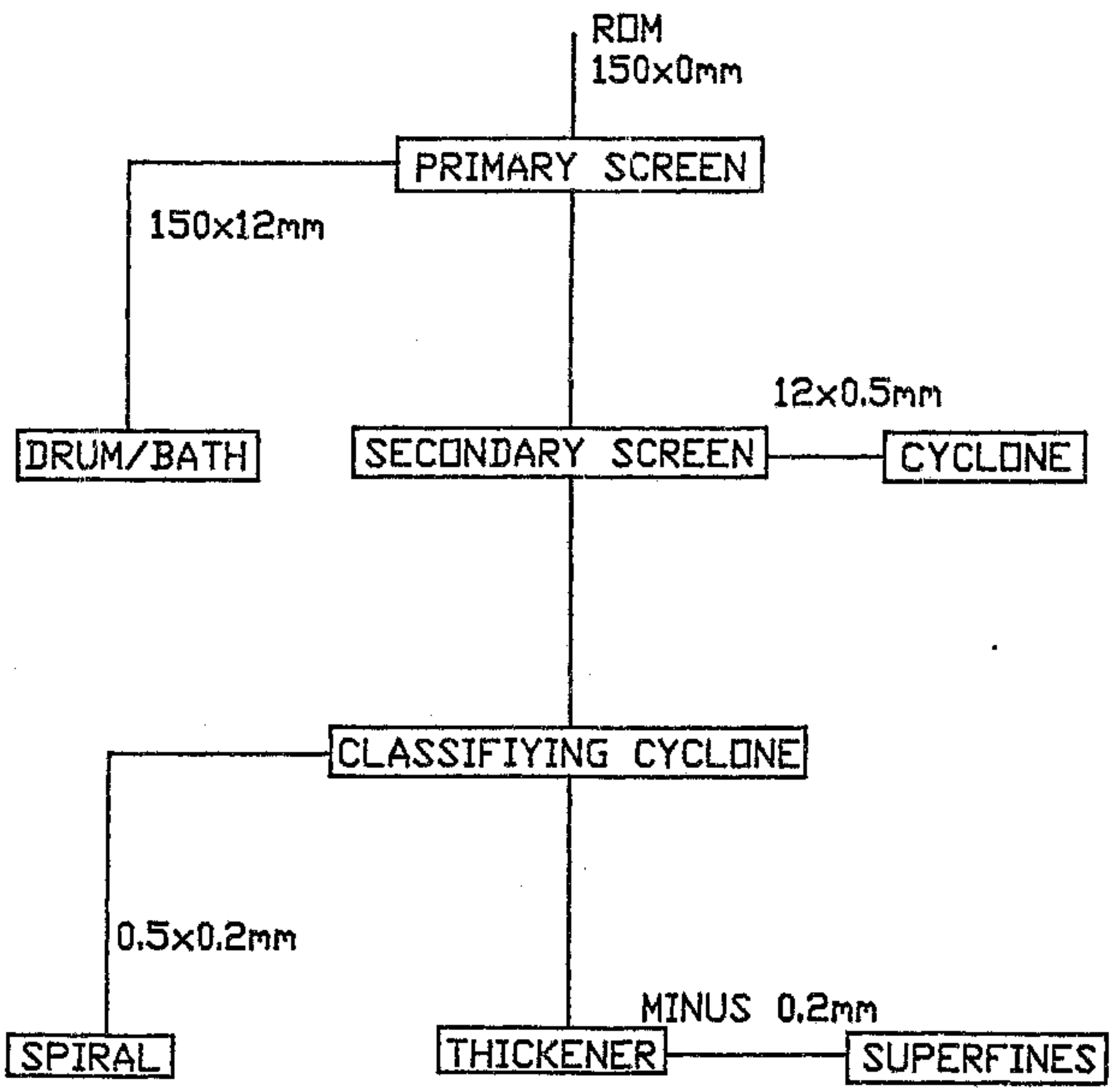


Table 1.2 Analysis of Kleinkopje superfines

air-dry basis				micron			
Ash %	VM %	CV MJ/kg	S%	+212	+106	+45	-45
24.0	22,9	23,9	0,55	9,1	36,4	22,7	31,8

1.4 Ideal qualities of a premium briquette fuel

A visit to England in 1990 confirmed that there was a significant demand for anthracite briquettes for closed stove domestic heating. The most popular briquettes were imported from Germany with a similar briquette being produced in Immingham using Welsh Anthracite. The desired properties are:-

- Low ash content - less than 10%
- Low volatile matter - Less than 5% - smokeless burning
- Good reactivity - easy to light and capable of burning at low combustion rates.
- Weather proof - must retain strength when wet
- Clean to handle - no dirt or fines produced
- No smell - no noticeable odour on burning

It can be seen from Para 4 that the raw Kleinkopje superfines do not meet the marketing requirement in terms of ash and volatile matter and that as a consequence of the high ash content the calorific value is also low.

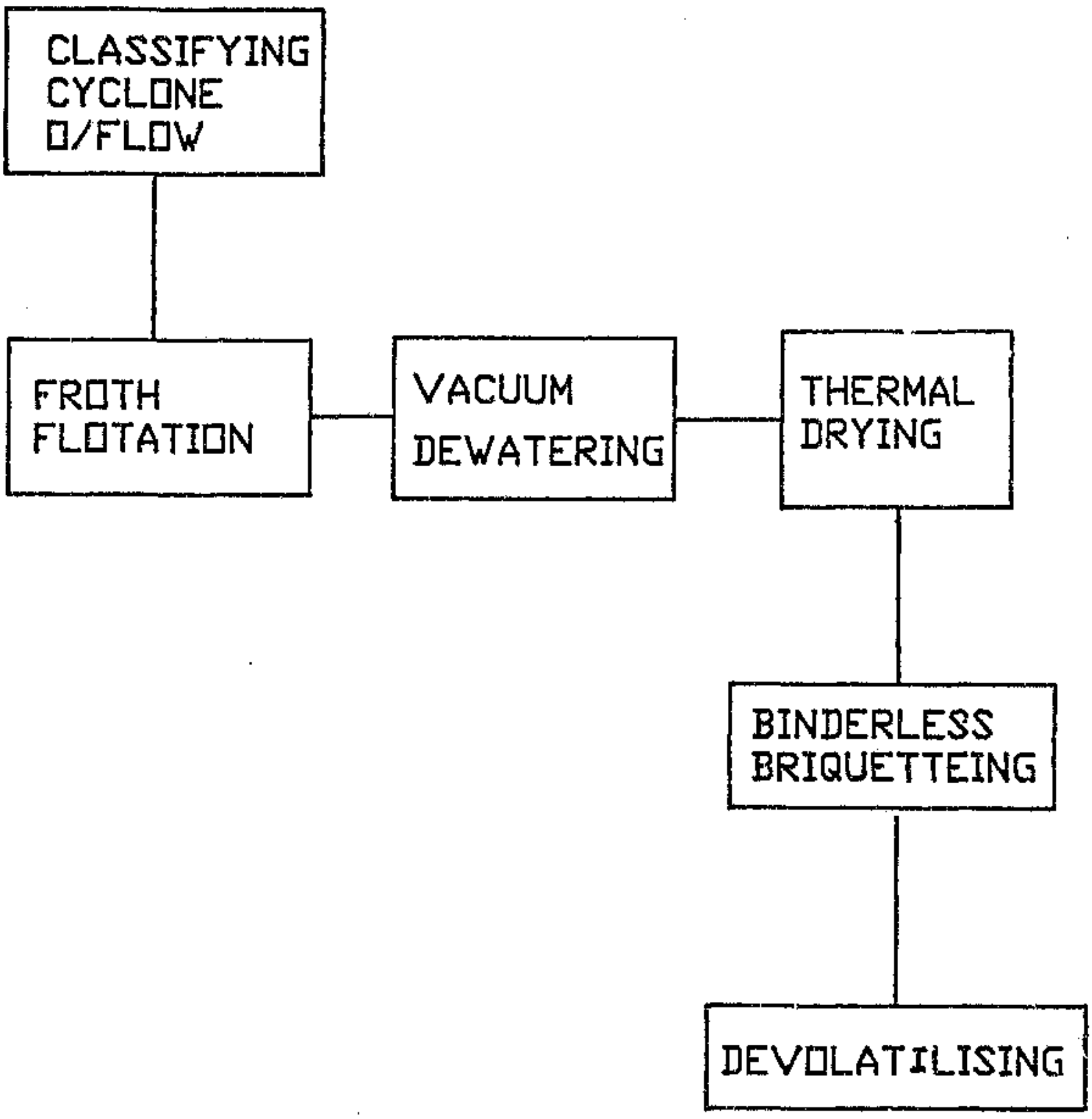
1.5 Process flowsheet to provide the required qualities

The first requirement is to reduce the ash content of the superfines and then to dry them in order to allow briquetting to be carried out. After briquetting the green briquettes must be devolatilised in order to make them smokeless.

The process requires five major coal processing steps, of which only vacuum filtration has been used commercially to treat Witbank 2 seam coal. Iscor carry out briquetting but only to produce coke. The flowsheet is shown in Figure 1.2.

Laboratory or pilot scale testwork has been conducted on Witbank 2 seam coal on all the required parameters to test the feasibility of the process. The results of the testwork will be detailed in the following sections.

Figure 1.2
PROCESS FLOWSHEET



CHAPTER 2

BENEFICIATION

The method of beneficiation practised in Europe and America for the 0,5 x 0mm coal fraction for many years has been froth flotation. In recent years oil agglomeration has been suggested as a means of fine coal beneficiation, and in particular a method developed by the National Research Council of Canada. Early attempts at beneficiating South African coal fines followed European practice in that sub-aeration techniques were used on the minus 0,5mm fine coal.

It was found that the minus 0,5mm Witbank No.2 seam coals were not amenable to flotation although some success was achieved with the coals of the Northern Natal coal fields.[1] With the introduction of spiral beneficiation of the 0,5 x 0,2mm fraction, attention was turned to the minus 0,2mm thickener underflow and good yields and qualities have been achieved by several froth flotation techniques and by a modified form of oil agglomeration.

2.1 Principles of Froth flotation

The difference in the surface wetting properties between coal and shale can be used to effect a separation. As shale is more readily wetted it is classed as being hydrophilic. Certain oils have an affinity for coal and make the coal more hydrophobic. These oils are referred to as collectors. If air is blown through a pulp, bubbles attach to the coal particles and carry the coal particle to the surface. The addition of frothers strengthens the bubble and allows the froth to be scraped from the surface of the vessel. An industry standard is to use Methyl Iso Butyl Carbinol (M.I.B.C.) as a frother and paraffin as a collector. Other reagents can and have been used which affects the yield of clean coal and the quality of the coal. Other factors affecting the efficiency of froth flotation are:-

(i) Particle size distribution

If the coal is particularly hydrophobic it is possible to float up to 0,5mm particles. In practice the Witbank 2 seam coals only float effectively up to 0,2mm which accounts for earlier failures.

(ii) Conditioning time

It is important to allow the reagent to collide with a coal particle. A conditioning tank giving a residence time of up to 5 minutes is provided for this purpose. The more dilute the suspension the better the chance of coal and reagent meeting and hence the classifying cyclone overflow at 5% solids is ideal as a froth flotation feed.

(iii) Residence time

Again time must be available for air-bubbles to attach themselves to the coal particle. Transfer of coal from the pulp phase to the froth phase is strongly time dependent.

(iv) pH

Changing the pH of the pulp can change the rate at which surface reactions take place.

(v) Aeration rate

A limited aeration rate can reduce the yield of concentrate. Fine bubbles are preferred to large bubbles.

(vi) Reagents

The type of reagents affect yield and quality as well as the manner in which reagent is added i.e. single stage addition or multiple stage addition.

2.2 Sub-aeration flotation at Landau

Sub-aeration flotation cells of the Wemco or Denver type have traditionally been used for coal flotation. A small pilot plant was set up at Landau III colliery to investigate the possibility of floating 2 seam coal using Denver cells.[2] The experimental design and interpretation of results were under the direction of the author with the practical work being carried out by the staff at Landau. The flowsheet is shown in Figure 2.1 and a typical cell in Figure 2.2. A 70 litre conditioning tank fitted with an agitator fed pulp to three 20 litre flotation cells in series giving 60 litre capacity in total. The froth was discharged by paddles into a launder, the froth height being controlled by a gate on the tailings discharge.

Tests were run at varying residence times and at different % solids in the feed.

2.2.1 Residence time

Residence time was plotted against yield using a standard reagent addition in all cases. It can be seen from Fig. 2.3 that the yield is fairly stable after about 150 - 180 secs residence time.

2.2.2 Solids % in feed

% solids in the feed was plotted against yield using standard reagent addition. Figure 2.4 shows that yield drops off as the solids increase, 5% solids giving acceptable yields.

Figure 2.1

FROTH CIRCUIT LANDAU

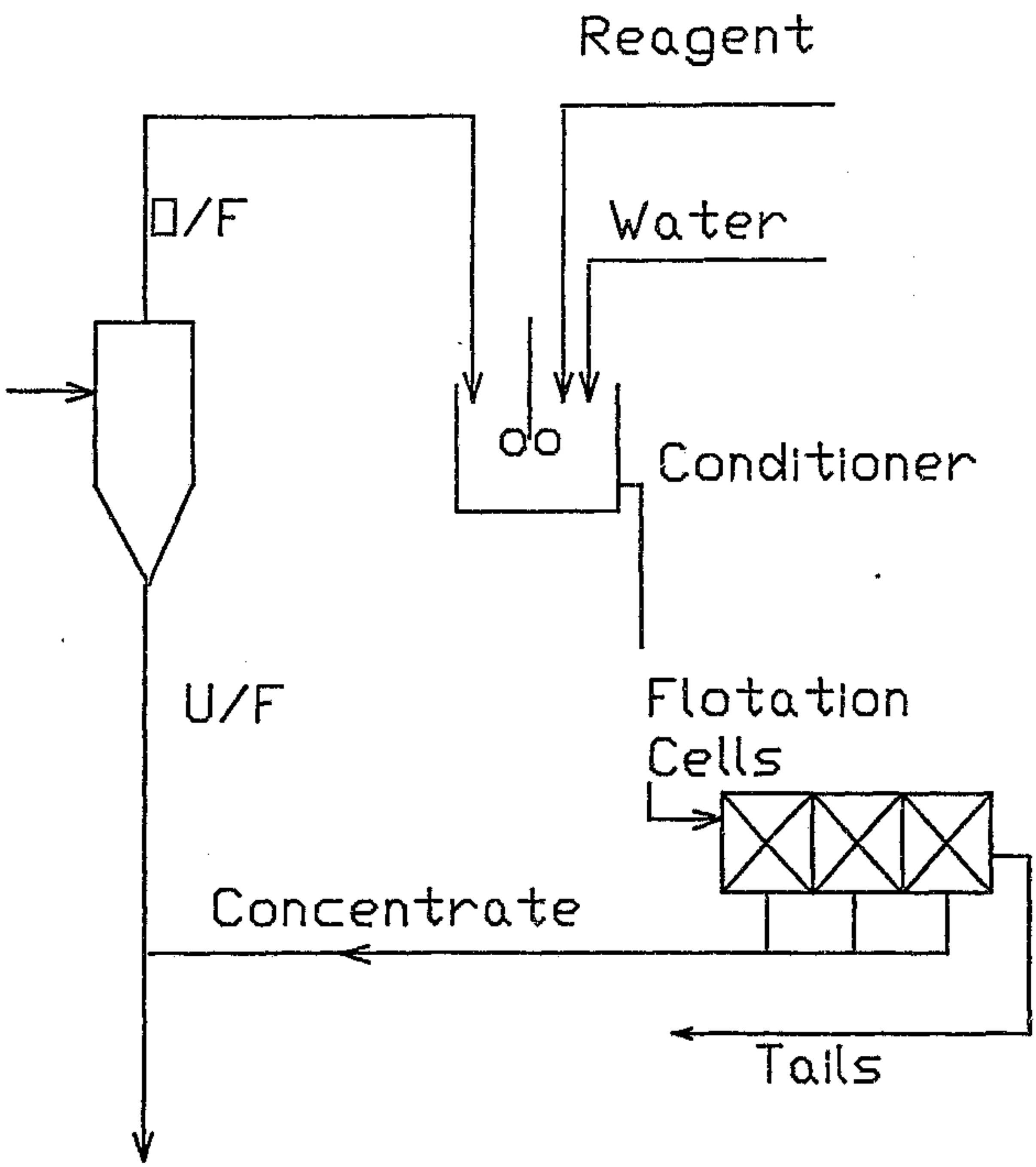


Figure 2.2

SUB-AERATION FLOTATION CELL

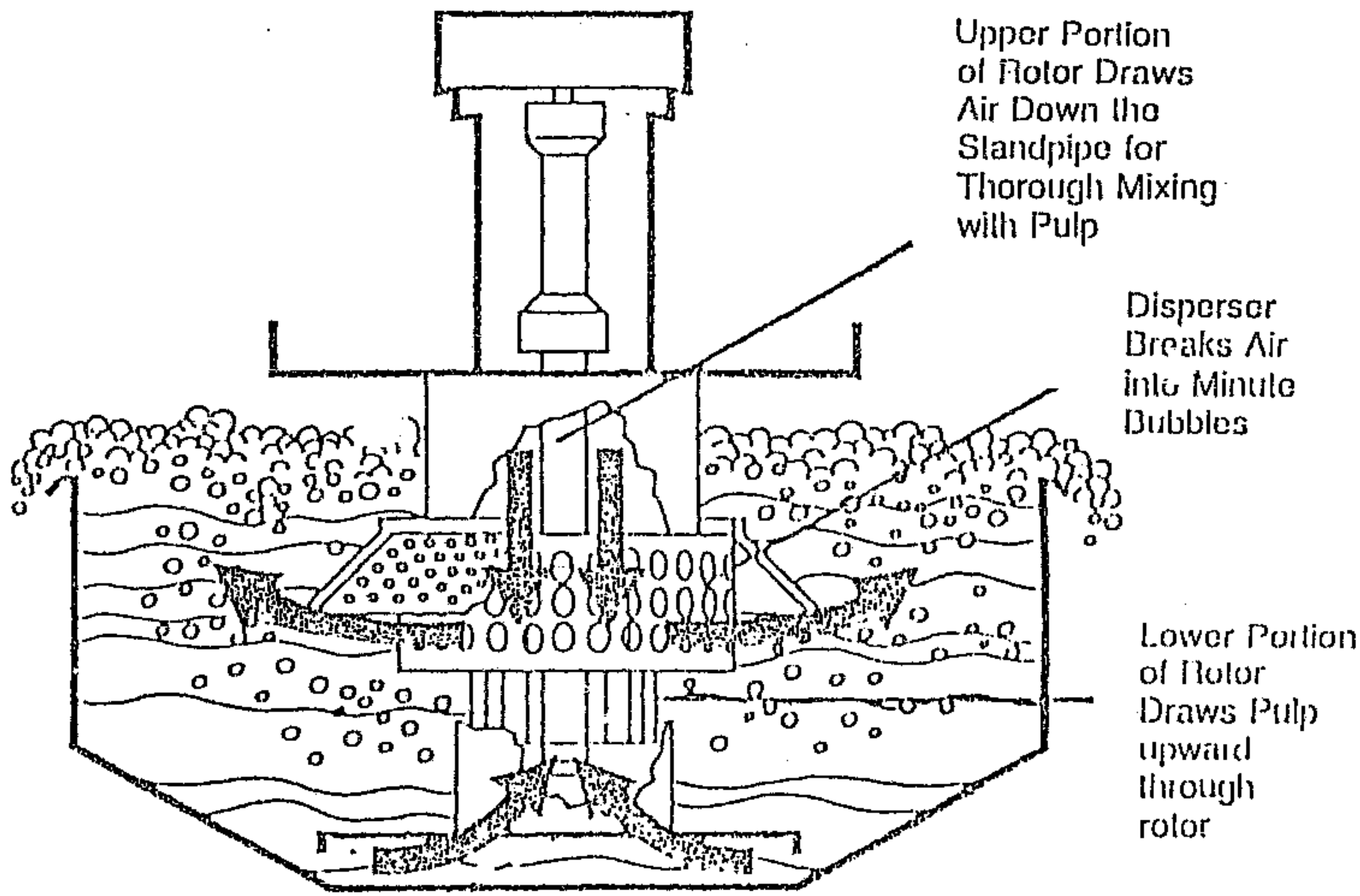


Figure 2.3

Residence time v. Yield

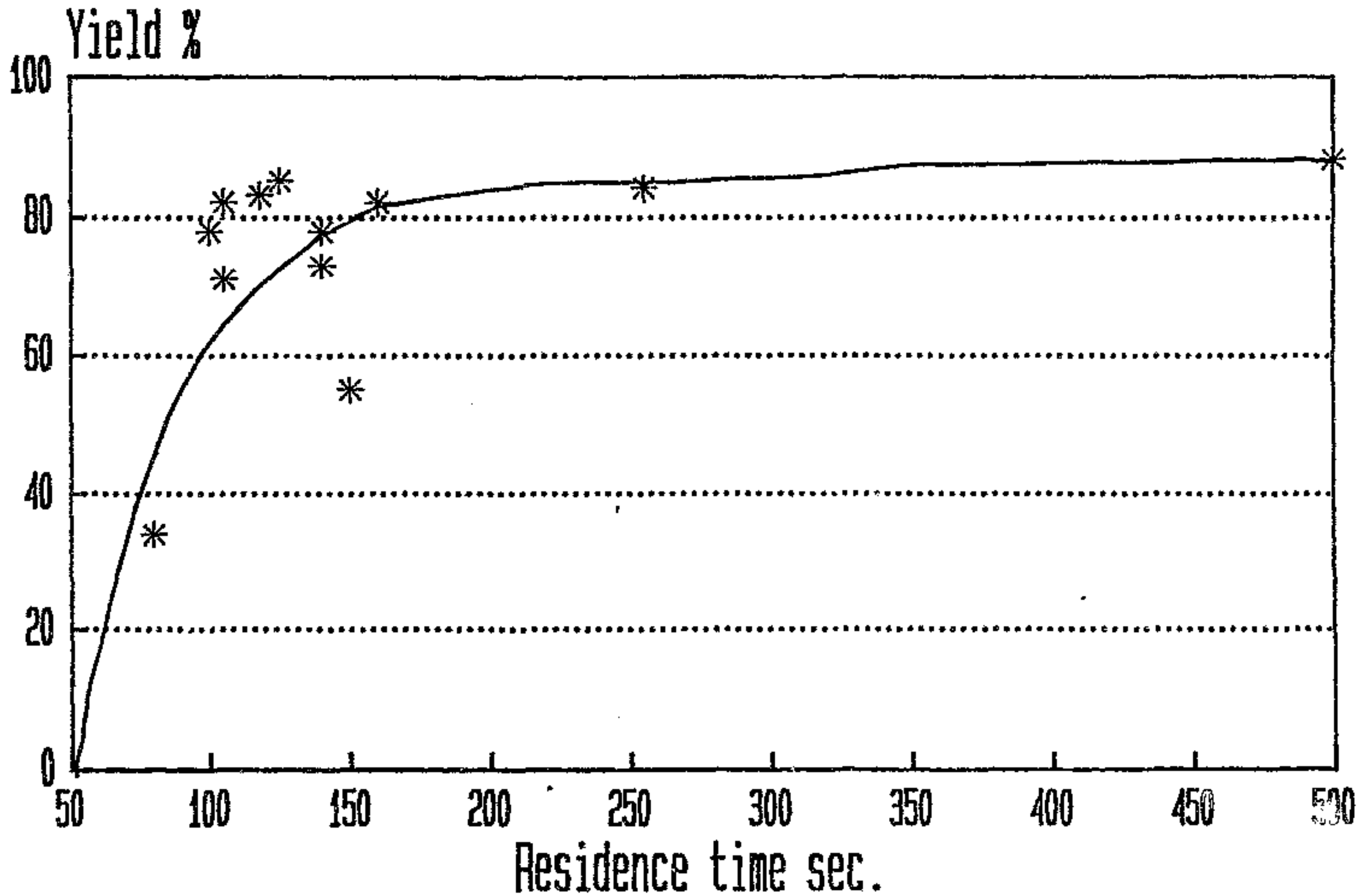
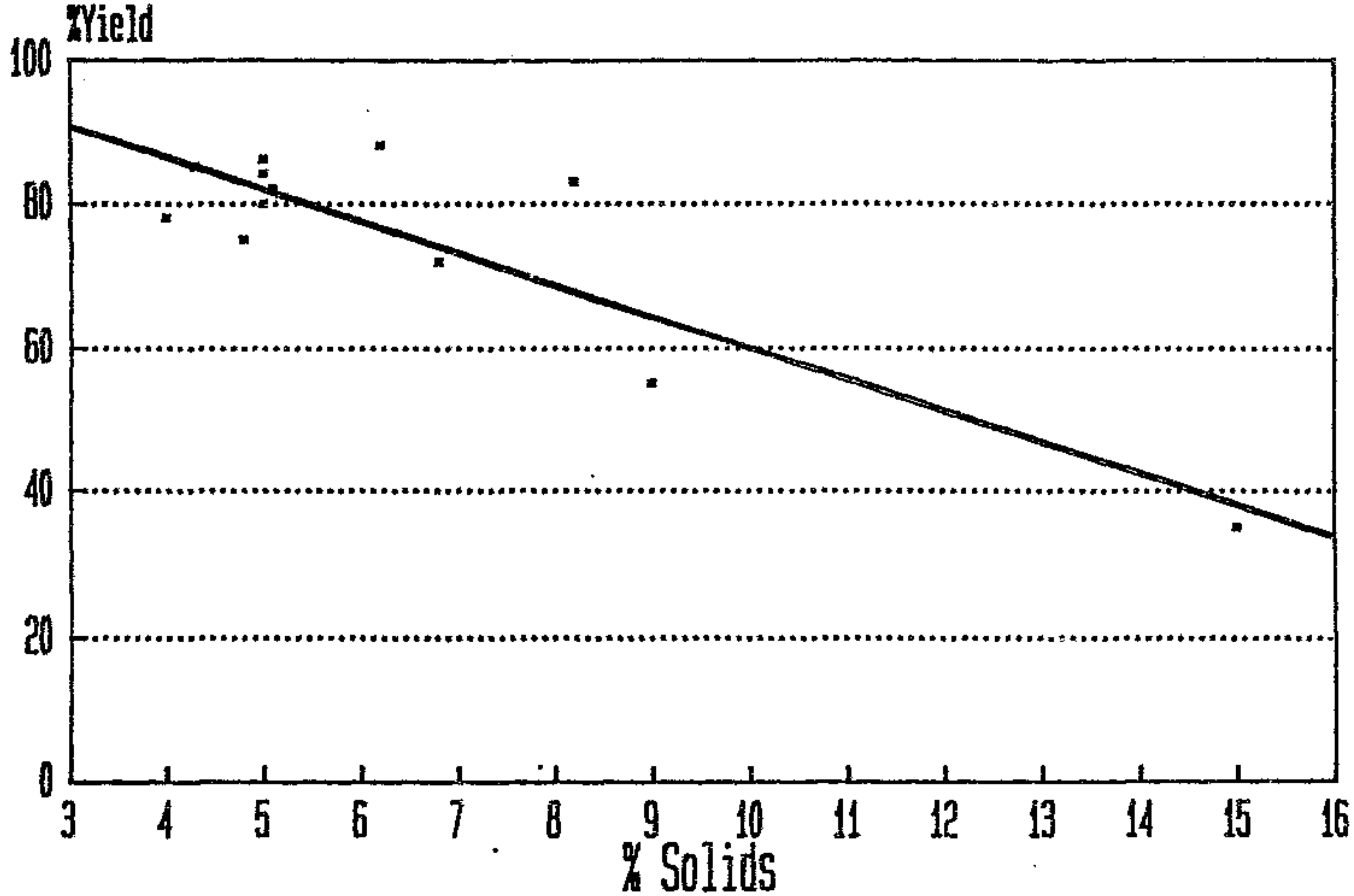


Figure 2.4
%Solids v. Yield



2.2.3 Amount of reagent

The amount of reagent used in litres/dry ton of solids was plotted against yield. Figure 2.5 shows that no increase in yield was found at addition in excess of 2,0 litre/ton.

2.2.4 Yield and quality

Table 2.1 Analysis of Feed and Products

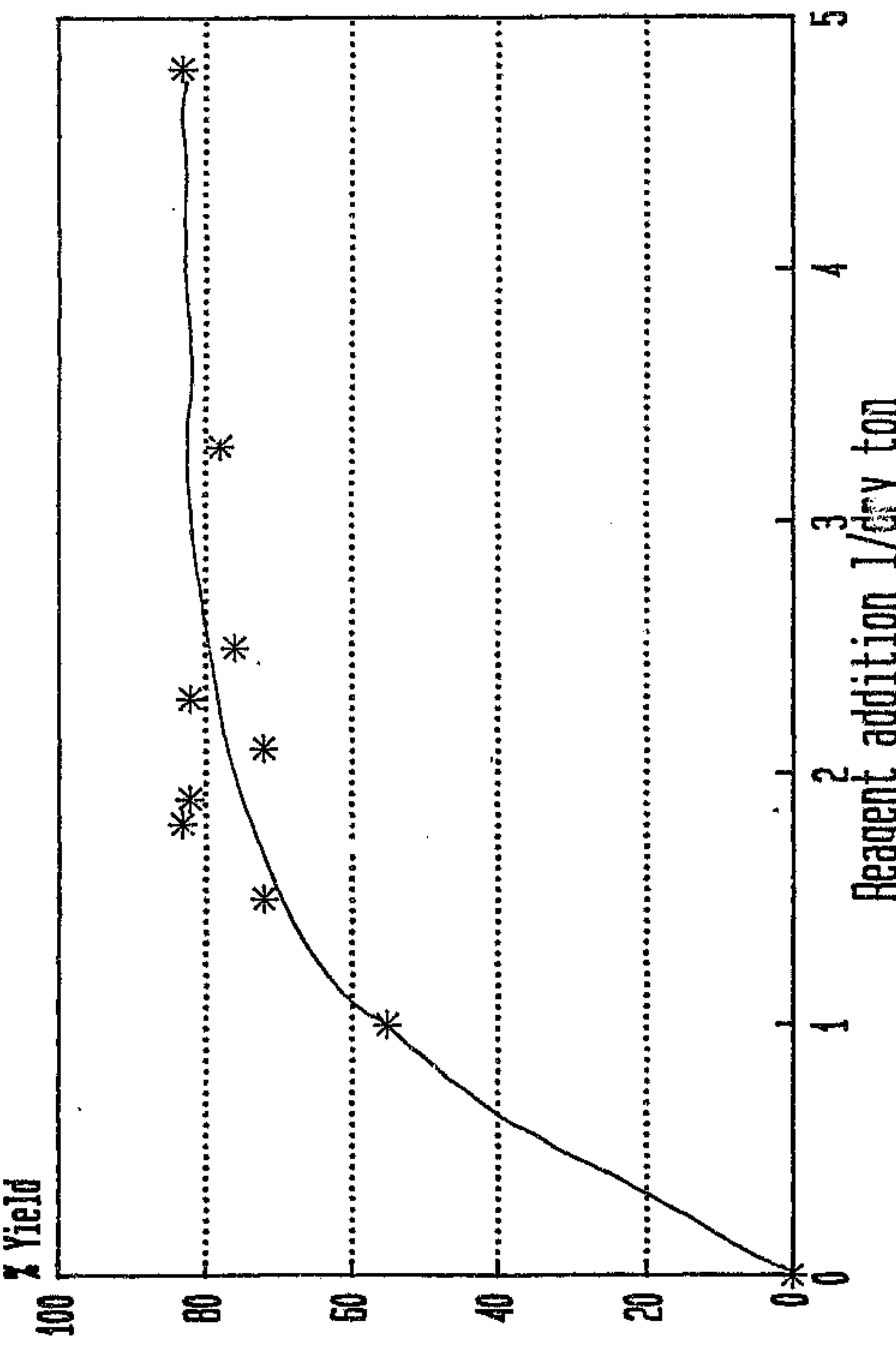
	I.M %	V.M. %	ASH %	C.V. MJ/kg	SULPHUR %
Feed	2,5	26,5	17,5	26,64	0,66
Product	3,0	26,4	10,2	29,69	0,61
Tails	2,1	25,4	41,2	15,71	0,69

This gives a yield of 76,5% determined by ash balance, at a product ash of 10,2%, showing that sub-aeration flotation gives an acceptable yield and quality.

2.3 Sub-aeration flotation at Kleinkopje

Sub-aeration testwork on Kleinkopje ultra fines was carried out using Wemco sub-aeration cells similar to those used at Landau.[3] Test work design and result interpretation was carried out by the author and staff of Kleinkopje and the physical testwork was carried out by the Kleinkopje

Figure 2.5
Reagent addition v. Yield



technical staff. Using M.I.B.C. and paraffin it was found that a product with 11% ash could be produced at a 36% yield. This yield is low compared to the Landau testwork and can be attributed to the fact that Kleinkopje is an opencast mine and treats three different seams i.e. 1 Seam and 2 upper for steam coal production and 2 select seam for a metallurgical coal and steam coal production. This work led to the consideration of using alternative flotation methods and reviewing the influence of reagents.

2.4 Pneumatic Cells - Ekof cell

The first pneumatic cell tested at Kleinkopje was the Uhde cell. The Uhde cell was developed in Germany in the 1970's but was found to be unsuitable for Kleinkopje because very low yields were obtained although at less than 10% ash.

The next pneumatic cell that was available for testing was the Ekof cell, again a German development. In pneumatic flotation, fine air bubbles are mixed with pulp which has previously been conditioned with reagents, external to the flotation cell. In the aerating units the hydrophobic particles adhere to the fine air bubbles. It is claimed that the air to slurry volume can be as high as 80% compared to 20% for sub-aeration units. The construction of the Ekof cell is shown in Figure 2.6 and 2.7.

Figure 2.6
EKOF CELL

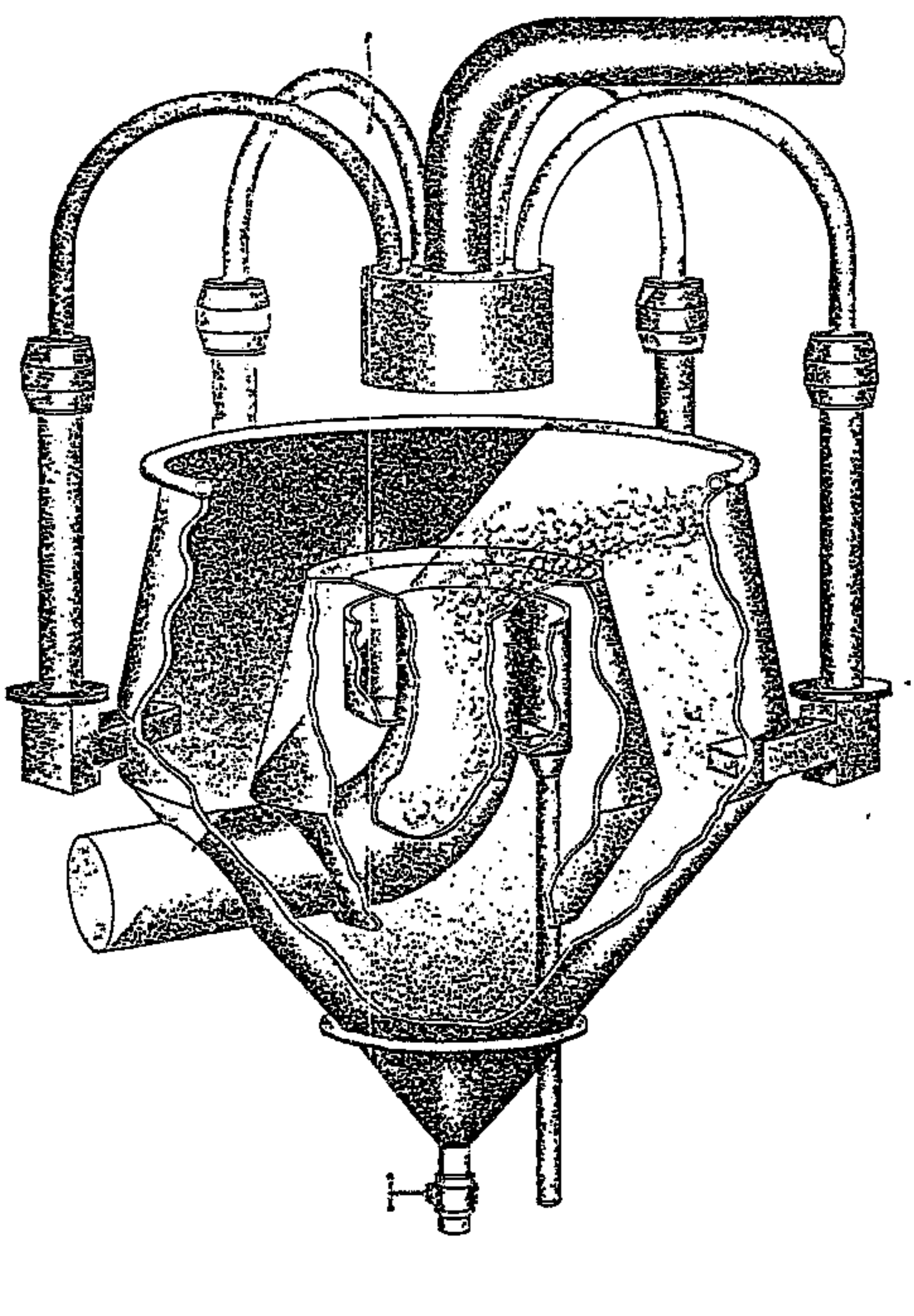
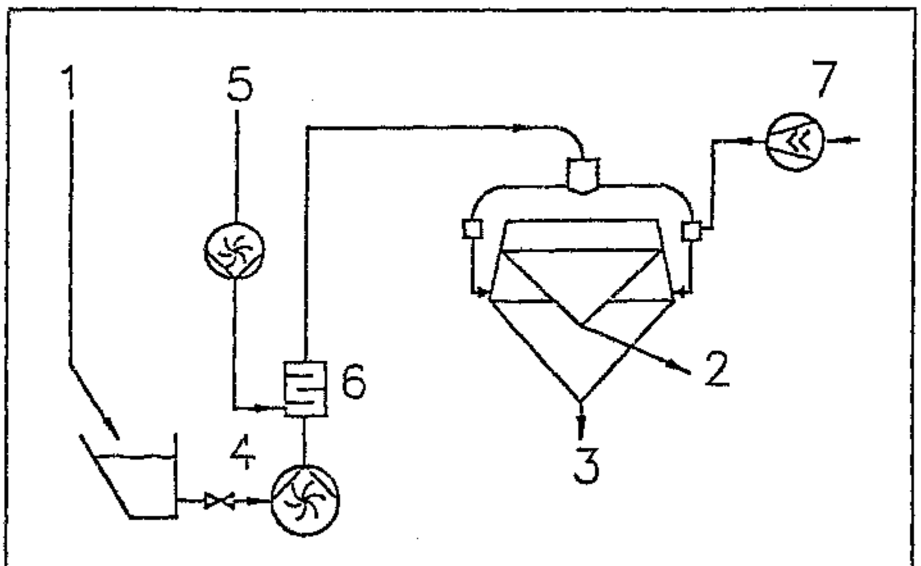


Figure 2.7
EKOF CELL FLOWSHEET



Connection diagram of an EKOFLOT unit

1. Pulp feed to pump sump
2. Concentrate
3. Tailings discharge
4. Pump sump with impeller pump
5. Feed regulation for reagents
6. Static mixer with injector
7. Air compressor

At the same time that the Ekof cell was being tested it was decided to evaluate different reagents and compare the performance of the Ekof cell with the Wemco sub-aeration cell.[4] The test programme was devised by the author, technical staff at Kleinkopje, the equipment manufacturers and the reagent suppliers. The flow circuits for the two cells were identical. Ten combinations of collectors and frothers were used, collectors CK10 and CK30 and frothers FK1, FK2, FK3 and FK4 all supplied by Betachem and combined frothers and collectors Cyanamid X5 and reagents from Sasolchem.

The results of these tests are given in appendix 2.1.

2.4.1 Results

The results of these tests are shown in Appendix 2.1. Tables 2.1 to 2.10.

From this series of tests it can be seen that the reagents CK10 + FK4 gave the lowest ashes. There is little difference in performance between the two cells, the Ekof cell tending to give higher ashes and yields for a given reagent dosage. Because of its simplicity of operation and installation the Ekof cell is considered a better choice than the Wemco cell to produce the required ash content.

A further study of the Kleinkopje thickener operation was carried out by F. Chidley of Betachem.[5] This study shows that to be certain of obtaining a 10% ash product a rougher and cleaner operation is required. To deal with the fluctuating feed quality of Kleinkopje coal this suggestion has a lot of merit even though capital cost is increased. The flowsheet used by Chidley in his testwork is shown in Figure 2.8. He showed that using thickener feed a yield of 53% at 10% ash could be obtained from the above circuit using CK10 and FK4 at a dosage rate of 2,3 litres/ton at a reagent cost of R3,50 ton. The yield versus ash content is shown in Figure 2.9.

2.5 Column Flotation

Conventional sub-aeration cells can trap gangue in the froth phase which reduces the quality of the product. In recent years a counter current flotation system has been developed which allows entrapped gangue to be washed from the froth phase. The term column flotation has been applied to this system, which was originated by D.A. Wheeler in 1963. Column flotation has been very successful in floating ores and the flotation of fine coal is a logical progression. The principle of operation of the column is shown in Figure 2.10. The feed slurry flows down the column and is met by an upward current of fine bubbles. Entrapped gangue is washed out of the froth zone by means of water sprays and leaves at the base of the

Figure2.8

DOUBLE STAGE FLOTATION FLOWSHEET

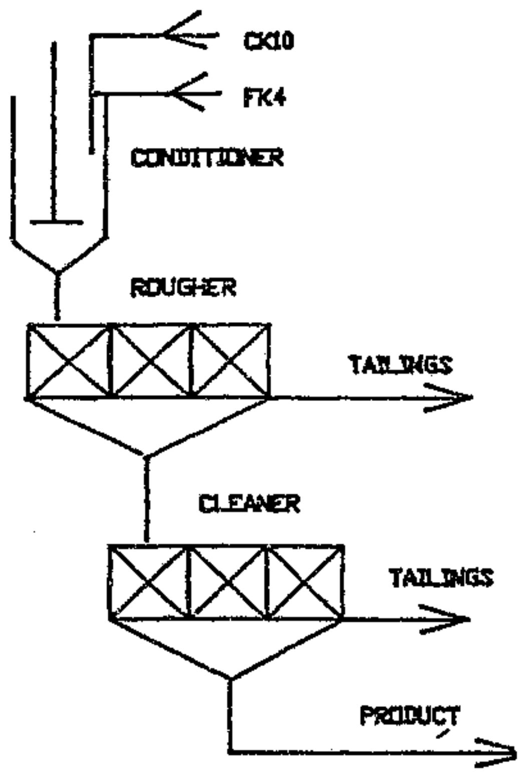


Figure 2.9 Ash/Yield relationship
Cleaner cell

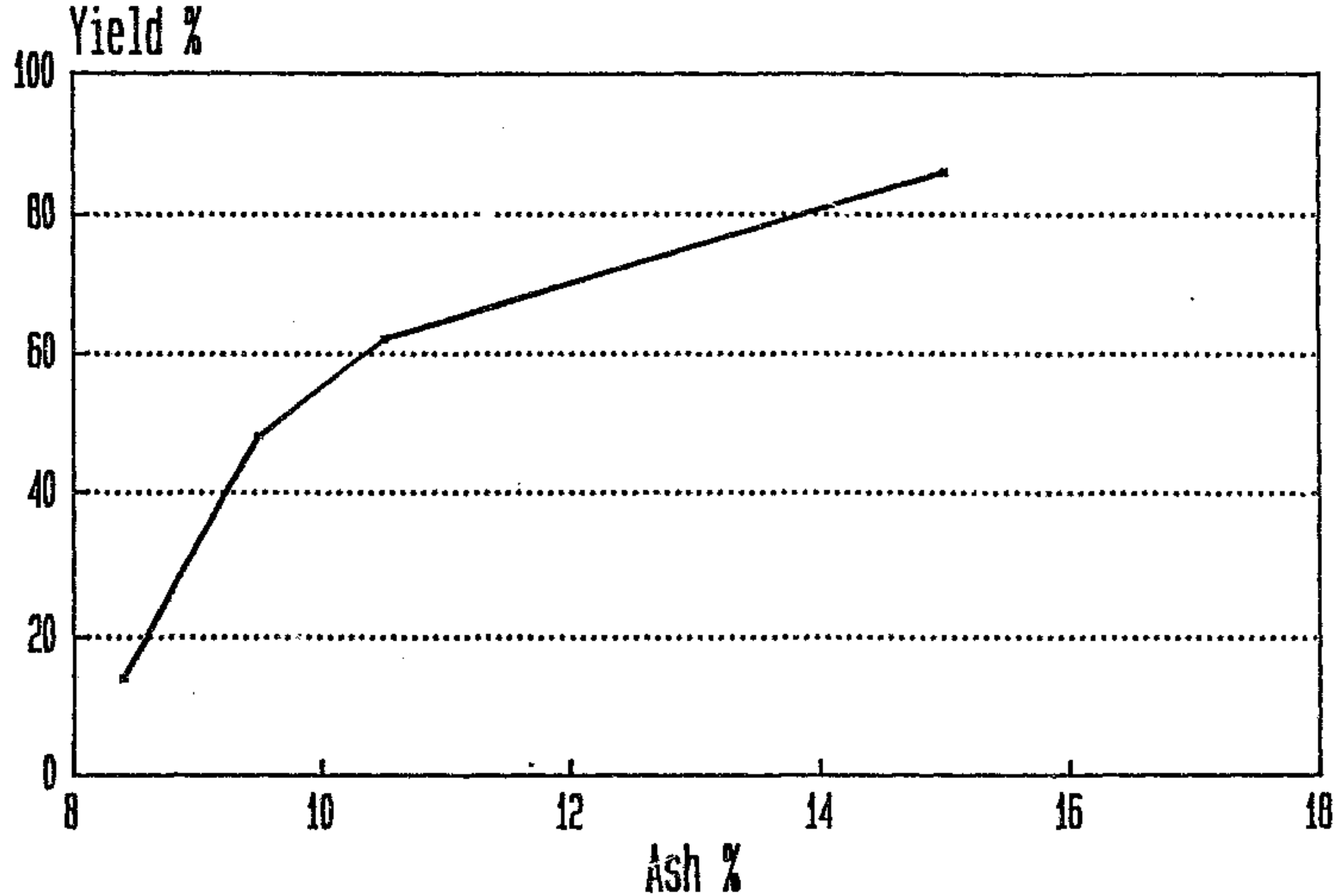
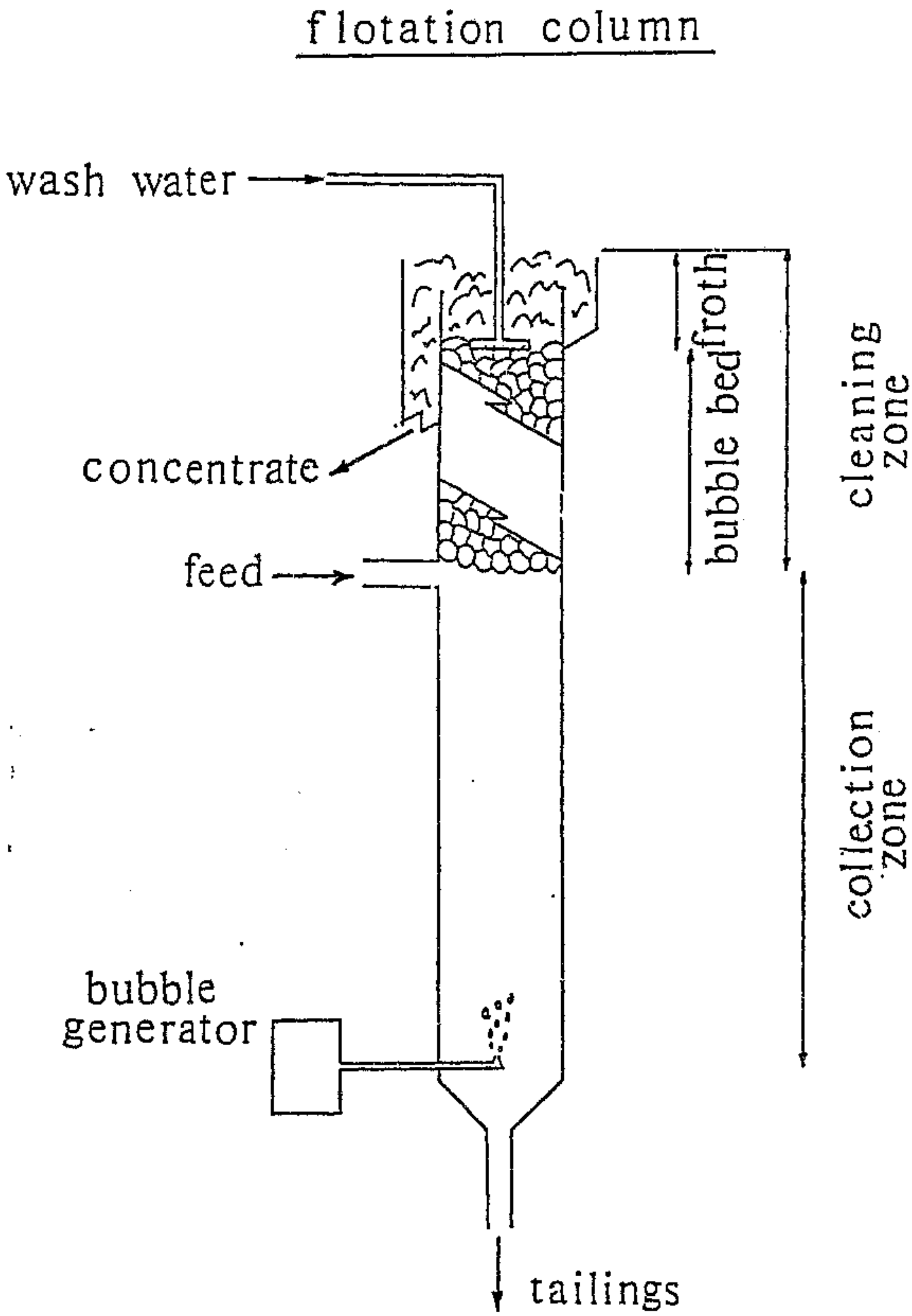


Figure 2.10 [27]
SCHEMATIC OF A FLOTATION COLUMN



column as tailings. Clean product overflows as a concentrate. Important parameters are the depth of the froth zone, the level of aeration and the extraction rate of the tailings.

Column flotation is claimed to have the following advantages over conventional cells:-

- A better product
- No loss of yield
- A reduction in the stages of operation
- Ability to handle a finer feed
- Simplicity in design with less moving parts
- Requires less floor space.

With these potential advantages column flotation trials were carried out at Goedehoop colliery in 1989.[6] The testwork was initiated by the Amcoal Consulting Metallurgist and the author liaised with U.C.T. in designing the test programm. The testwork was carried out by U.C.T. High recovery of low ash material was obtained although the sensitivity of columns to coarse feed material was observed. The results obtained were sufficiently encouraging to extend the testwork to Kleinkopje.[7]

2.5.1 Column Flotation at Kleinkopje

The pilot column consisted of four 1,5m long, 100mm I.D. sections of P.V.C. piping. The uppermost section was of clear P.V.C. to allow the pulp/froth interface to be

monitored. Two types of sparger, or bubble generator were used, these being a porous medium filter cloth sparger and a United States Bureau of Mine (USBM) sparger. The USBM sparger consists of pressurised air and a water/frother mixture being mixed in a packed bed chamber. The resulting mixture enters the column through a tube in which orifices have been drilled. The pressure drop across the orifices results in the generation of fine bubbles.
The feed to the column was from the thickener underflow and to protect the column from coarse material a linear screen was installed between the thickener underflow and the feed pulp tank.

The underflow from the linear screen was added to the feed tank and the pulp density adjusted to 8% solids m/v. Collector was added to the tank, the pulp being conditioned for 10 mins. The flowsheet is shown in Figure 2.11. Samples of feed, concentrate and tails were then taken when the column was operating at steady state. Shellsol A, a 95% aromatic oil which had been proved better than paraffin was used as the collector and Tri Ethoxy Butane, HTEB as the standard frother. HTEB was used as it produces a persistent stable froth.

It became apparent that high collector dosage rates were required to obtain an acceptable yield as shown in Table 2.2.

Figure 2.11

COLUMN CELL PILOT PLANT

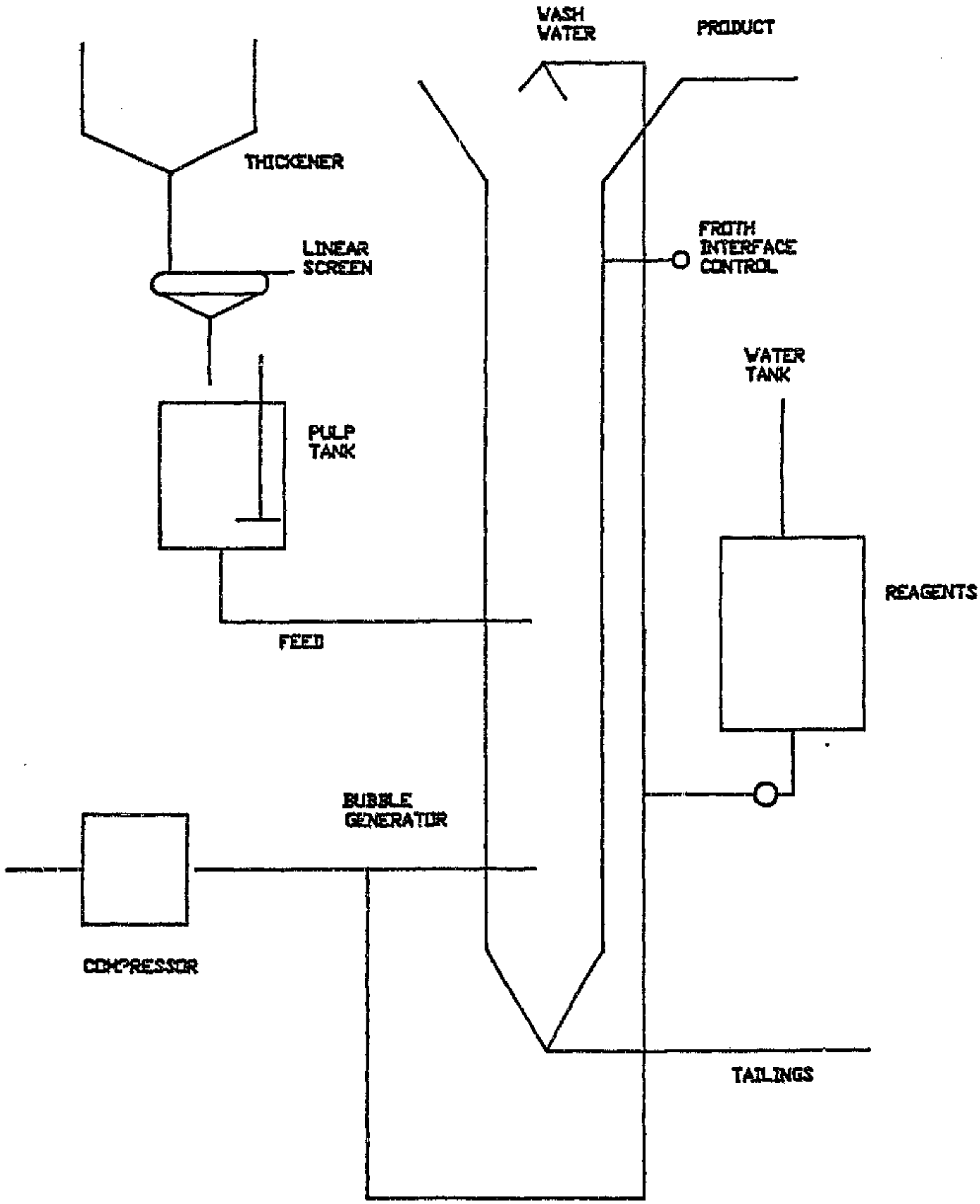


Table 2.2 Collectors dosage and yield

Collector dosage g/t	Average Yield %
<2500	25,4
2500 - 3400	44,8
3500 - 4600	37,6
5400 - 6000	44,8
6000	60,4

It was later demonstrated in laboratory tests that better conditioning results in lower consumption of collector.

A summary of Feed ash, Product ash and yield is shown in Appendix 2 in table 2.11.

These results indicate the variable nature of the Kleinkopje raw coal due to the different seams being treated i.e. 1 seam, 2 upper and 2 select. The different coals have different flotation characteristics resulting in a wide range of ash values and yields.

Column flotation has not proved better than pneumatic flotation in these tests mainly due to the high reagent consumption. Confirmation has perhaps been given that to achieve 10% ash, a second cleaner step is required. It is apparent from this work that columns have a low carrying capacity for coal, in the order of 1,5 tons/hr/m^2. If a 2 metre x 2 metre column is used giving 4m^2 per column then 20 columns would have to be installed to give the capacity required at Kleinkopje.

2.6 Other Flotation methods

Two other systems of flotation have recently found favour, these being the Jameson cell and the Leeds/Wemco cell. Neither have been tested on Witbank 2 seam although a pilot Jameson cell has just become available in South Africa.

The Jameson cell is a hybrid of the pneumatic cell i a short column. It was invented in Australia and is in use on several collieries there, notably at Newlands colliery. Mixing of solids, reagents and air is done outside the column and therefore only the wash part of the column is required.

The Leeds cell was developed by C. Dell in the 1950's at Leeds University. A conventional mechanical agitator at the base of the cell creates air bubbles which carries coal particles upwards. The bubbles meet a series of barriers consisting of low density rods and high density rods. As one rod tries to rise the other rod tries to sink thus producing a pinch effect on the froth. The squeezing force separates lightly bound gangue from the concentrate, an effect which can be amplified by the addition of wash water. As in column flotation an improvement in product quality compared to conventional flotation is experienced.

2.7 Oil Agglomeration

Oil agglomeration, sometimes referred to as spherical agglomeration, uses oil to collect fine coal particles which bind together to form a ball shaped agglomerate. In the process of coming together the coal particles disperse moisture, resulting in a drier product. Screening the agglomerate is all that is required to achieve dewatering.

The Trent process developed in 1920 used 20% to 30% of oil to achieve agglomeration, not a cost effective route at today's oil prices. The National Research Council of Canada developed the process to the point where 4% oil addition gave acceptable product yields and quality. Knowledge of the Canadian work lead to a joint venture being undertaken by Leys Engineering, Standard Bank and T.C.O.A. whereby four samples of ultra-fine coal were sent to Canada for laboratory scale oil agglomeration tests. One of the samples was of Greenside 2 seam and one was collected from a Kleinkopje slimes dam which was well weathered and should therefore have represented oxidised coal.[8]

Results of these tests showed:-

Table 2.3 Product quality and yield oil agglomeration

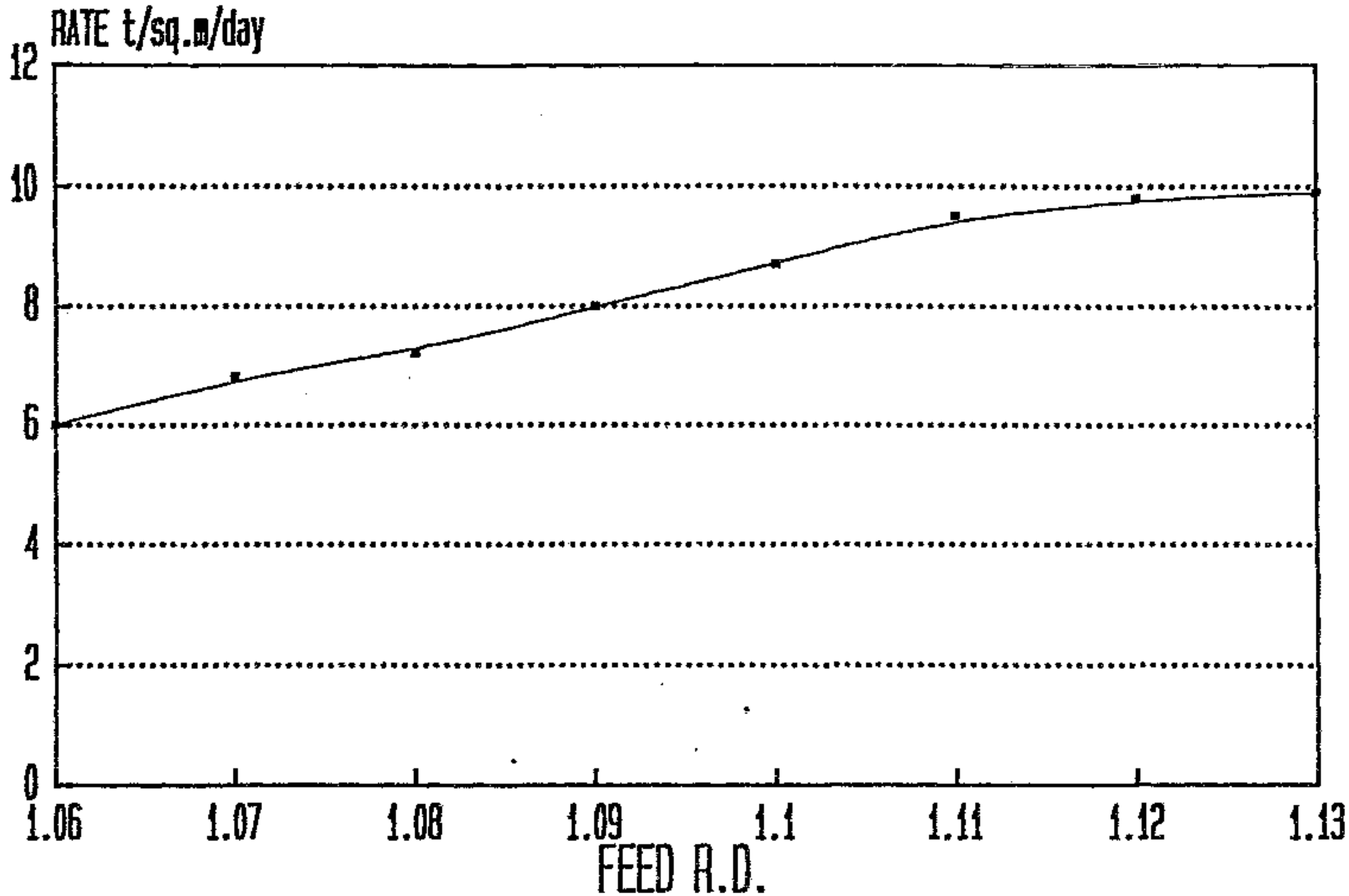
	Product ash	Yield %	Oil %
Greenside 2 seam	11,5	88,0	1,5
Kleinkopje dam	13,0	80,5	1,5

Leys Engineering acquired the South African patent rights for the Canadian process and eventually went into partnership with I.M.S. Process Plant to promote the scheme in South Africa.

I.M.S developed a trailer mounted pilot plant which was used at Rietspruit, Van Dyks Drift and Greenside collieries. No agglomeration testwork was carried out at Kleinkopje or any of the Amcoal mines. Visits were made to Van Dyks Drift to see the pilot plant working and laboratory tests were carried out on various Amcoal thickener underflows.

In a presentation on 23 October 1991 Mr. J. Whitehouse[9] of I.M.S. Process Plant gave details of yields and ashes obtained when treating Greenside No. 2 seam as shown in Figure 2.12. Using 1% oil a yield of 60 - 70% was obtained at 11 - 12% ash. It was claimed that the use of 1% oil resulted in lower moisture content when the

Figure3.3
EFFECT OF FEED R.D. ON THROUGHPUT



concentrate was vacuum filtered.

Observations of the tests being carried out at Van Dyks Drift showed that with 1% oil the unit was working as a froth flotation cell and there was no evidence of agglomeration of the product. I.M.S. have now renamed the process oil beneficiation as compared to oil agglomeration.

At this stage of development there appears no reason to believe that this is any different to froth flotation. Higher use of oil to achieve agglomeration is not justified on economic grounds.

It is of interest to note that Amcoal carried out oil agglomeration tests in 1982 when 0,8% oil resulted in a 70% yield at 10% ash. When this work was extended to pilot scale at Kleinkopje, Blair[10] achieved a nil yield after an exhaustive study of all the factors that could have influenced this result. Clearly there is an anomaly in the testwork.

2.8 Summary of fines beneficiation

The testwork has shown that superfines can be beneficiated in many different ways. The test results indicate that both the Wemco cells and the Ekof cell can produce a low ash product at a good yield. Of the two the Ekof is considered the better practical cell due to the lower volume and shorter residence time achieved by external mixing of pulp and air. Oil flotation requires too much oil for a given yield to be economically viable.

CHAPTER 3

DEWATERING

The concentrate from the froth flotation process contains 30% solids. To use the solids as a feedstock to a briquetting plant requires dewatering to 2% surface moisture. With the Kleinkopje ultrafines containing 2,5% - 3,0% inherent moisture it means that we are looking for a total moisture of 5%. Du Preez[11] reviewed the availability of dewatering equipment for different sizes of coal, although none of these methods produce a product with a low enough moisture content to allow briquetting. Therefore the cheapest and most reliable method which prepares the feed to a level acceptable for thermal drying is required.

For coal in the superfine range he regarded the horizontal belt filter and the pressure filter as being technically and economically suitable. Other equipment that can be used include the solid bowl centrifuge, which has had no success in South Africa, automatic filter presses and the Tube press, both of which are extremely expensive.

Horizontal belt filters are used at Goedehoop and New Vaal collieries to produce a 23% moisture product. Rotary drum filters are used at Vryheid Coronation to dewater a flotation product but they are extremely maintenance intensive.

The following sections will investigate the performance of the hyperbaric filter and the vacuum belt filter to determine which is the most suitable for preliminary dewatering.

3.1 Hyperbaric filter

The hyperbaric filter consists of a disc filter operating inside a pressure vessel. Using conventional vacuum filtration the differential pressure cannot exceed 0,8 bar. With Hyperbaric filtration the differential can be as high as 6 bar although 3 to 5 bar is usually sufficient for ultra fine coal. According to D'Arcy's formula, the cake thickness increases with the square root of the differential pressure.

Schubert's theory states that a relative degree of saturation arises.

$$\frac{S-Sr}{1-Sr} = f \; \frac{pc}{\epsilon \cdot \eta (1-Sr)} \cdot \frac{(\Delta p - p_k) \cdot t_2}{h_K^2}$$

where S degree of saturation

Sr residual degree of saturation

pc cake permeability

pk capillary pressure

t_2 dewatering time

ϵ porosity

η viscosity

h_k cake thickness

p pressure

f function

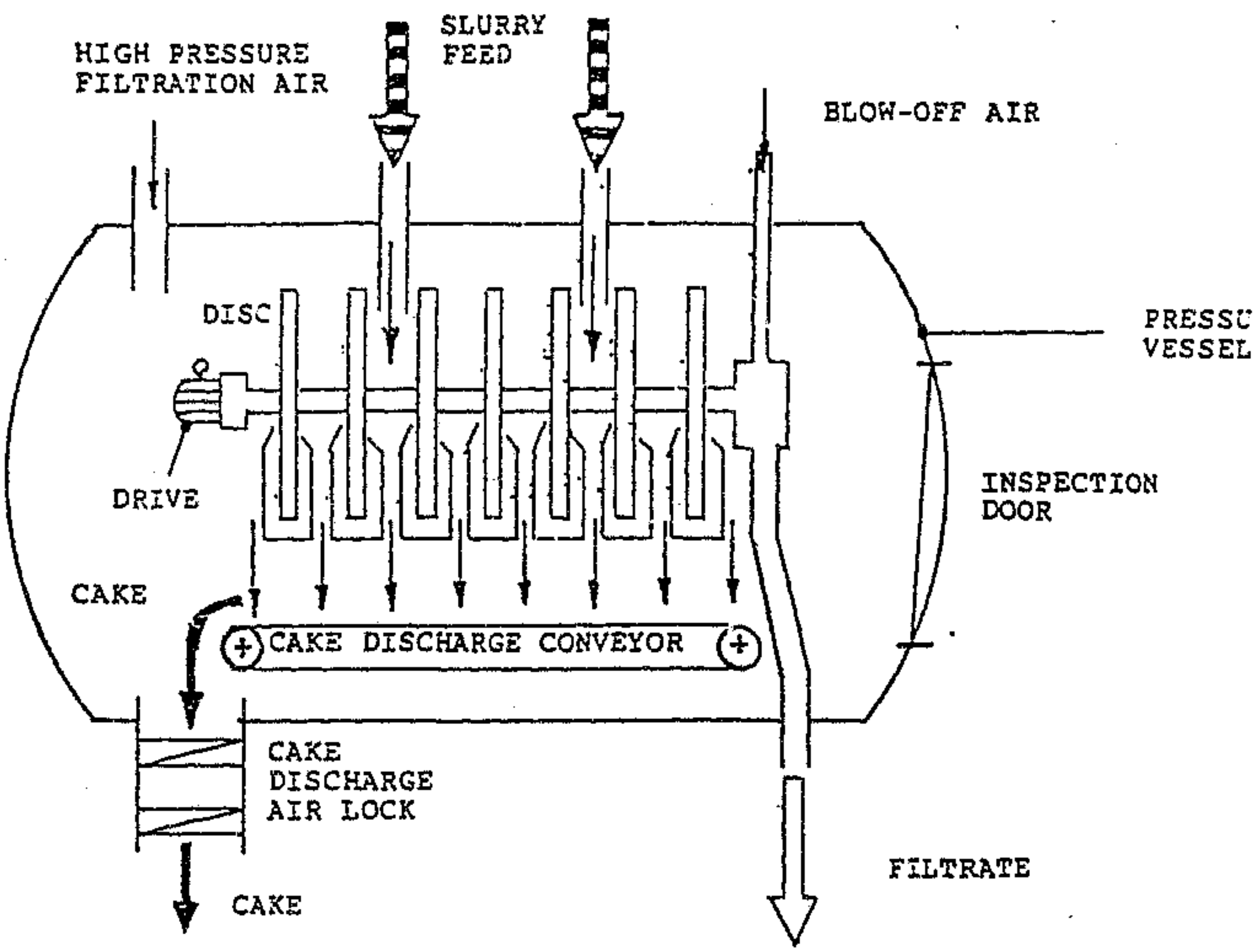
The residual moisture content of the cake drops

- with increasing effective pressure difference
- increase in dewatering time
- decrease in cake thickness

The higher effective differential pressure of the hyperbaric filter gives it a clear advantage over vacuum filters in achieving lower moistures.
The hyperbaric filter is shown in Figure 3.1.

The most important part after the disc filter is the discharge gate which has proved a problem area on other pressure filters. It must be able to discharge solids reliably and at the same time minimise the amount of air escaping from the pressure system. A double gate lock system has been developed to meet this requirement, the gate being lined with low friction material to avoid solids hang up and a pressure equalising line ensuring that the chambers are at the same pressure before the hydraulically operated lock opens which minimises air blow off. The gates are carried on inflatable seals and all maintenance can be done from the outside of the gate.

Figure 3.1
HYPERBARIC FILTER



3.1.1 Pilot Plant trials at the Collieries

A trailer mounted hyperbaric filter built by Andritz[12] was tested at New Vaal, Goedehoop and Kleinkopje. From these tests the projected performance of a full scale unit was calculated and is shown in table 3.1.

Table 3.1 Predicted performance of hyperbaric filter

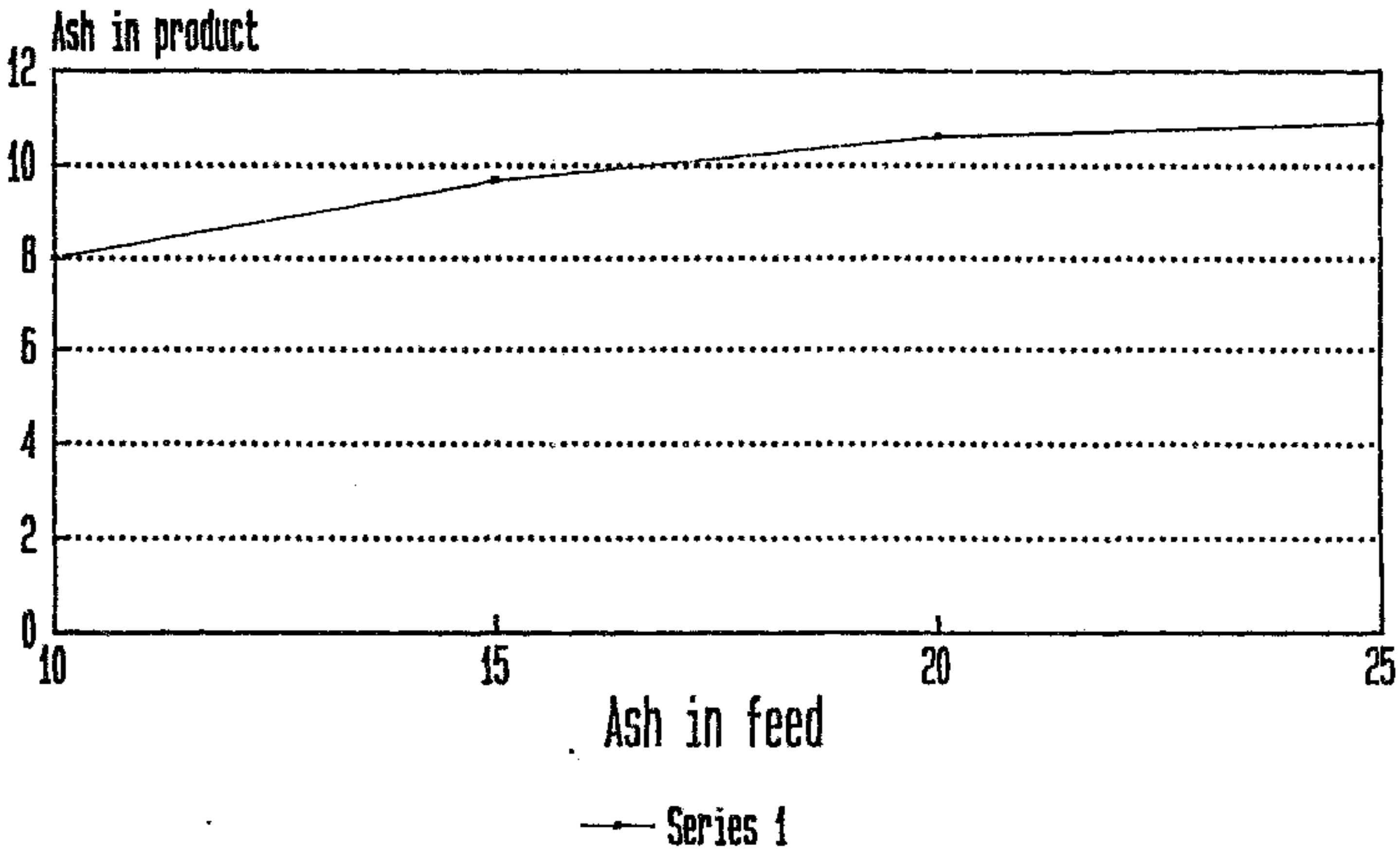
Parameter	Units	New Vaal	Goedehoop	Kleinkopje
Feed solids	% mass/mass	35-65	15-35	30-40
R.D. solids	-	1,16-1,35	1,06-1,16	1,14-1,19
Pressure	bar	4-5	4	5
Throughput	$kg/m^2/h$	450-550	500-700	500-700
Moisture	% mass/mass	26-29	17-18	18-19,5

The product from the belt filter at Goedehoop runs at 23% moisture compared to 17-18% by pressure filtration while at New Vaal the belt filter frequently discharges a suspension of solids in water.

3.1.2 Details of Kleinkopje testwork

Moisture in the product was determined at 3,4 and 5 bar pressure and for each pressure level varying feedrates were tested. The results are shown in Figure 3.2. The Andritz filter proved very reliable in operation and gave

Figure 2.12
Product ash v. Feed ash.
Greenside No.2 seam



lower moistures than a horizontal vacuum belt filter. (See 3.2)

3.2 Horizontal Vacuum Belt Filter

The horizontal vacuum belt filter is a top feed filter which has the advantage that the coarser material in the feed tends to form first on the bed thus preventing the filter cloth from becoming blinded. Lower moistures can be obtained compared to rotary drum filters, additional advantages being, according to Delkor[13]:-

. Flexibility between feed zone and drying zone
. Variable speed drive to control cycle times
. Continuous cleaning of filter cloth
. High filtration rates
. Low flocculant consumption
. Low power consumption
. High availability.

Simple laboratory tests can be used to determine the capacity required and scaling up presents no problems. The following factors were investigated in sizing the horizontal belt filter installed at Goedehoop Colliery:-

. Feed R.D. or % solids
. Flocculant type and dosage
. Effect of cycle time on product moisture
. Effect of cycle time on throughput

3.2.1 Effect of feed R.D.

This is illustrated in Figure 3.3.

It can be seen that as the feed R.D. increases the tons treated per square metre per day increases due to less water having to be removed.

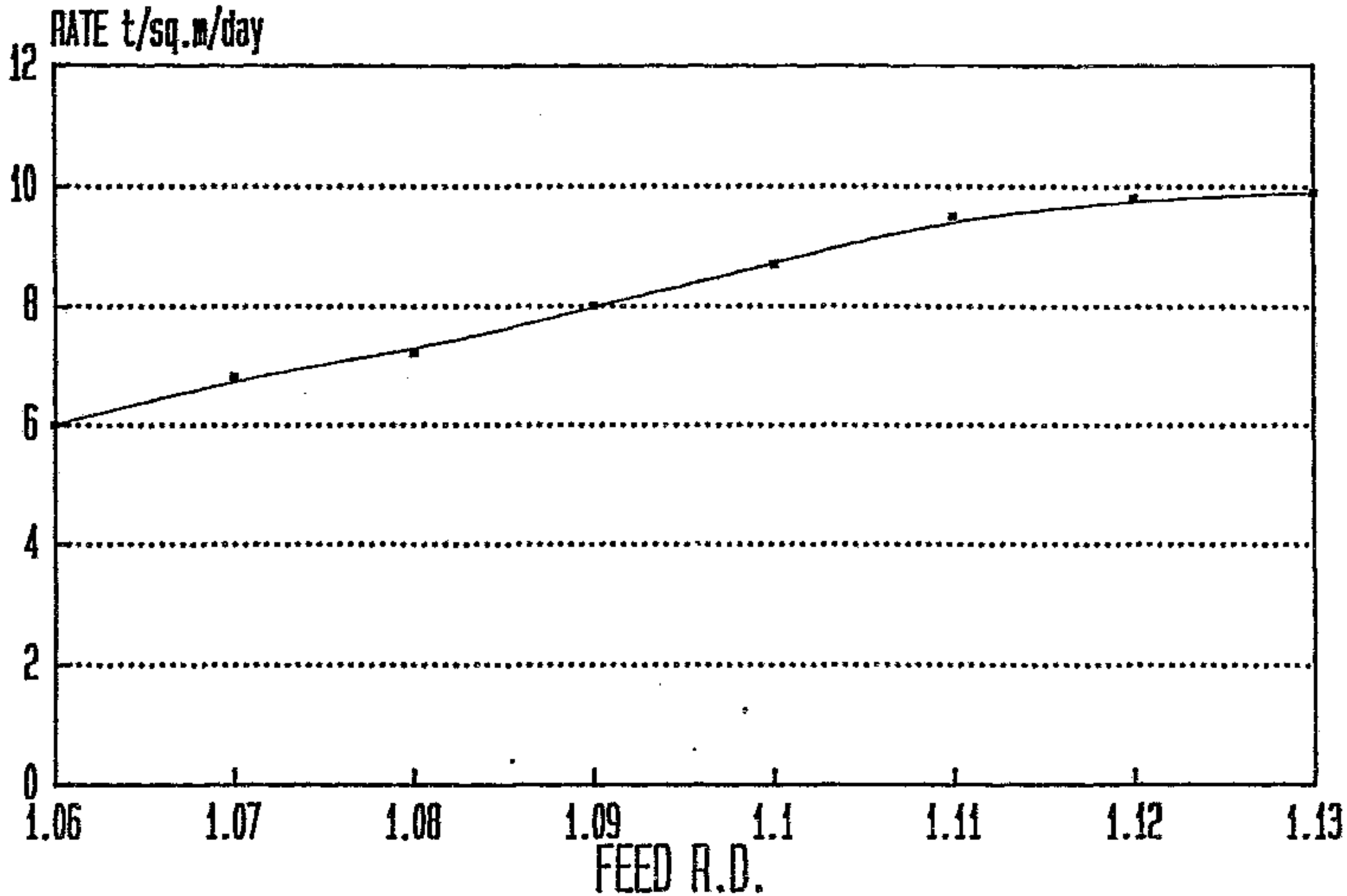
3.2.2 Flocculant type and dosage

The most effective flocculant type was determined by conventional settling rate tests. It is sometimes more convenient to use the same flocculant as is used in the thickener operation provided it gives acceptable results. It can be seen from Figure 3.4 that a small addition of flocculant results in a high increase in throughput, this effect becoming less pronounced at very high flocculant rates. A design point on the steep part of the curve at about 40g/t of solids would be selected as it gives a good compromise between capital cost and operating cost.

3.2.3 Effect of cycle time on moisture

For a given flocculant dosage, the effect of cycle time on product moisture is shown in Figure 3.5. With a fixed flocculant dosage the effect of increasing the cycle time

Figure3.3
EFFECT OF FEED R.D. ON THROUGHPUT



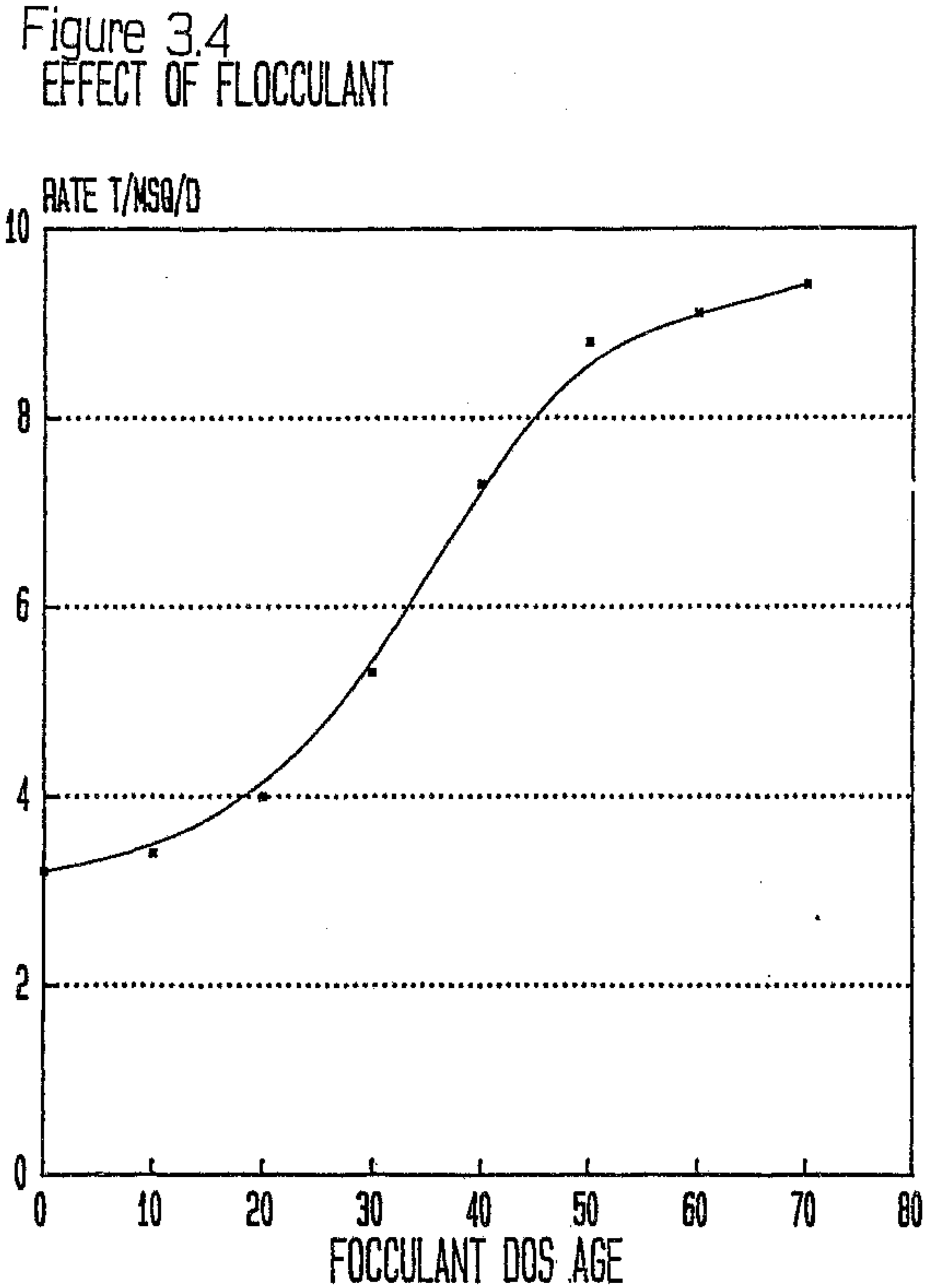
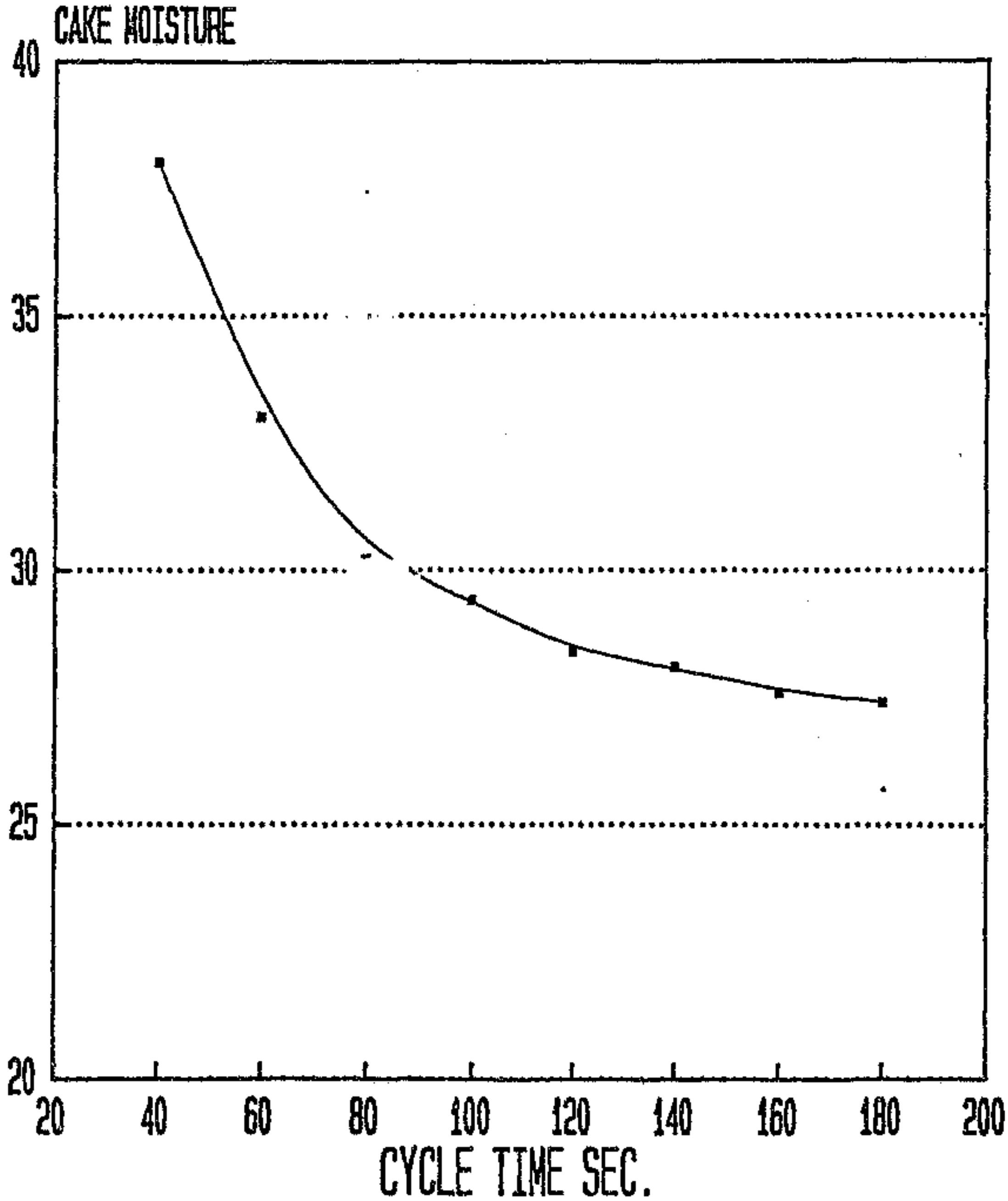


Figure 3.4
EFFECT OF FLOCCULANT
RATE T/MSQ/D
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
FOCCULANT DOS AGE

Figure 3.5

EFFECT OF CYCLE TIME ON MOISTURE



results in the cake thickness increasing according to the formula

$$t = k\ x^2$$

where t = cake forming time, x = cake thickness,

k = constant.

Solids rate is proportional to x/t

$$R = k^1 \quad x/t$$

$$R = k^{11} \quad \frac{\sqrt{t}}{t}$$

$$= \frac{k^{11}}{\sqrt{t}}$$

Since cycle time t = l/v, where l is the filter length and v is belt speed.

$$R = k^{111} \sqrt{v}$$

If the belt speed is doubled the tonnage would increase by a factor of √ 2 or 41%.

From these graphs the belt filter would be designed at a feed R.D. of 1,10 minimum, flocculant dosage of 40g/t of solids and a cycle time of 80 secs. which is equivalent to 9 tons/m^2 day at a moisture content of less than 30%.

Cycle time tests and filtering rates were determined in the laboratory using a 90mm Büchner funnel and experience has shown that these results can be scaled up t·· as large as a 120m^2 belt filter.

3.2.4 <u>Sizing of belt filter for Kleinkopje</u>

Assuming that Kleinkopje thickener underflow exhibits the same characteristics as Goedehoop then the size of belt filters for Kleinkopje can be calculated.

Kleinkopje treats 1450 tons/hour head feed of which 8% or 120 tons/hour reports to the thickener. If this feed is to be treated by froth flotation a yield of 60% would be achieved giving 72 tons per hour of dry concentrate. It is normal to allow 20% for surge factors when sizing equipment so that an 86 tons per hour capacity is required. The modular concept requires three belt filters, the nearest standard size is $28m^2$ which gives $84m^2$, close enough to the required area.

CHAPTER 4

THERMAL DRYING

Neither vacuum filtration nor hyperbaric filtration produces a low enough moisture content to allow briquette production. A technique has to be found to dry the ultrafines to 5% total moisture. Only thermal drying can achieve this low level. If it could be done directly from the froth concentrate so much the better, but it is probable that the cheaper methods of dewatering will have to be carried out as a primary stage.

There are three basic types of thermal drying to consider;

- Indirect
- Rotary Shell type
- Fluidised bed

4.1 Indirect Drying

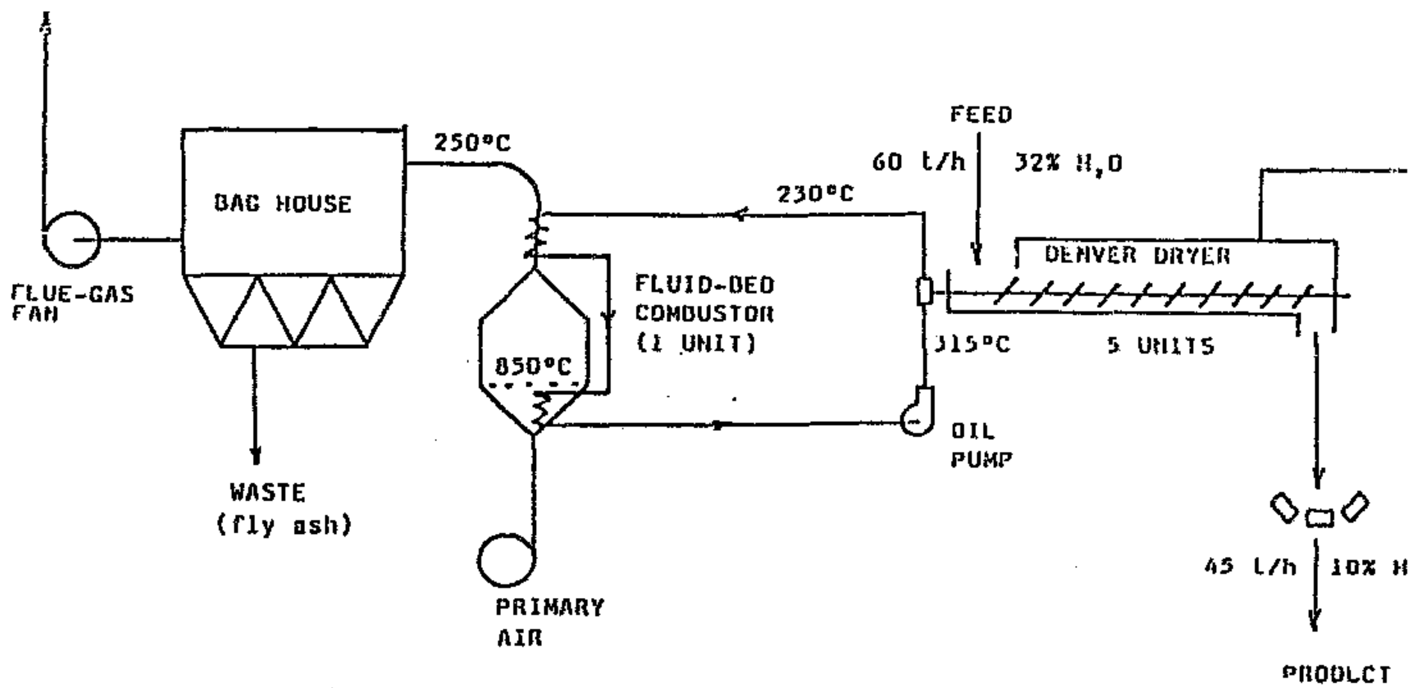
The most widely used indirect dryer is the Holo-Flite which was developed in America.[14] The Holo-Flite dryer consists of a hollow helicoid screw which conveys coal through the unit. A variable speed drive allows the throughput to be controlled. Hot oil at 315°C is pumped through the screw and the casing. A 610mm diameter screw, 7,23 metres long is capable of drying 4,5 tons per hour from 30% moisture down to 7% moisture. To treat the Kleinkopje concentrate would require 20 of these units which would be totally uneconomic. There are no Holo-flite dryers operating in South Africa on a coal application but the agents, Unique Engineering, claim that there is an installation working satisfactorily at a lime quarry. The flowsheet for an Holo-flite installation is shown in Figure 4.1 with a view of the machine in Figure 4.2. Details of the helicoil spiral are shown in Figure 4.3.

4.2 Rotary single shell dryers

The rotary single shell dryer consist of a rotating cylinder set with its axis at an angle and mounted on rollers to allow rotation. Coal is introduced at its highest end and by means of flights is passed to the lower or discharge end of the cylinder. Gas flow can be either co-current or counter-current. The rotary louvre dryer has a fixed cylindrical shell and an inner shell made of stainless steel louvres. Coal is supported and transported by the louvres while hot gases pass through the louvres. It is doubtful if this dryer would be suitable for the ultra fine coal.

I.M.S. developed a pilot scale rotary dryer which was used on Goedehoop thickener underflow after dewatering on a horizontal belt filter. In order not to interrupt plant operation the fines were recovered from the slurry pond and adjusted to the same moisture as the belt filter discharge. The objective was to ascertain if a thermal dryer would

Figure 4.1
HOLOFLITE FLOWSHEET



Installed motor kW = 650

Thermal efficiency = 81%

Figure 4.2
HOLOFLITE DRYER

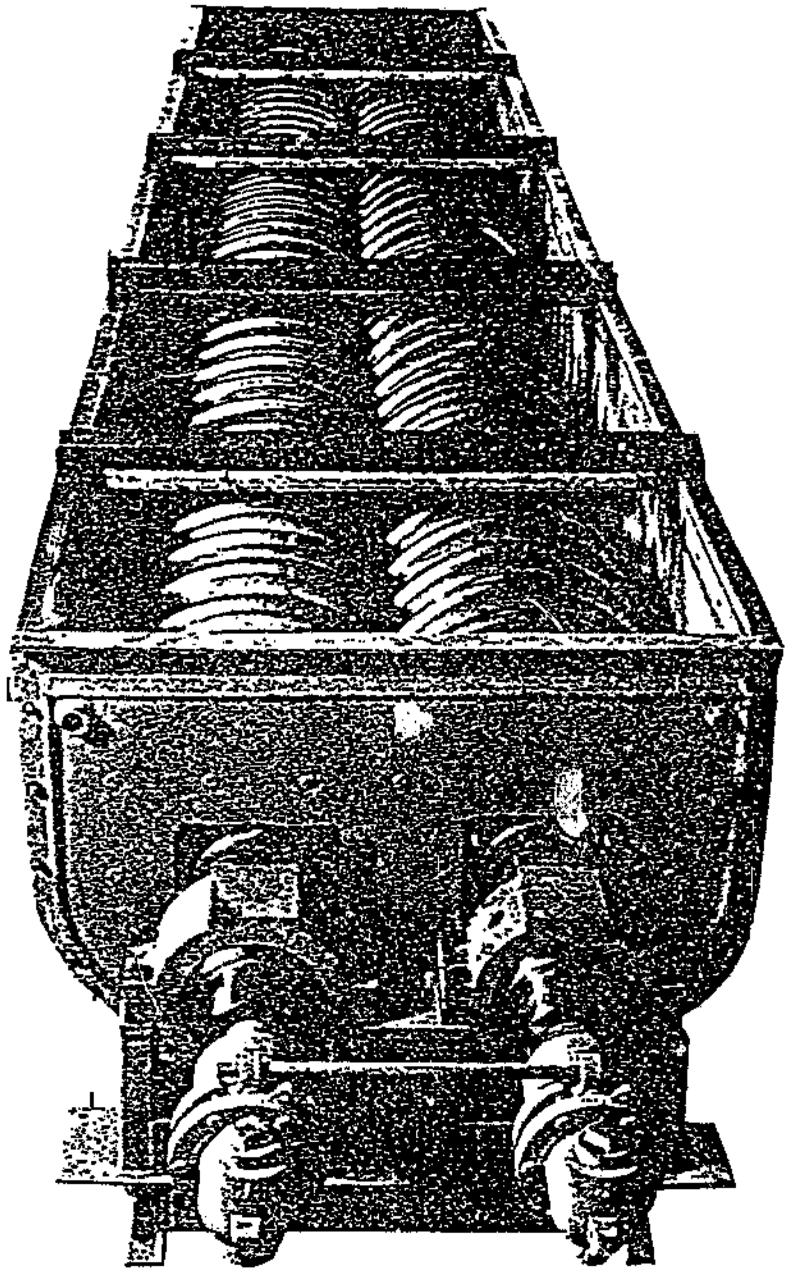
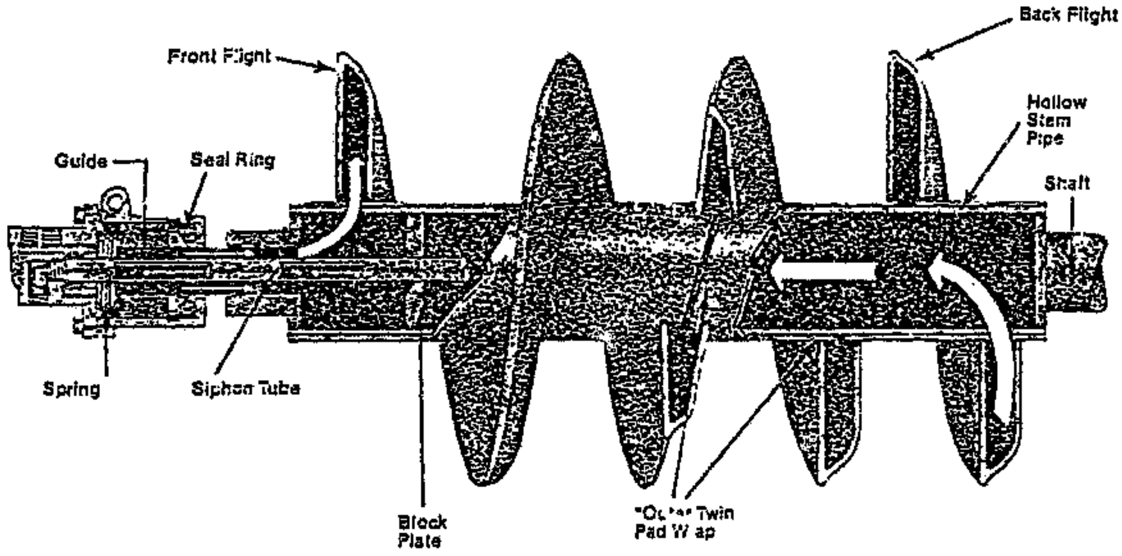


Figure 4.3

HOLOFLITE HELICOIL SPIRAL



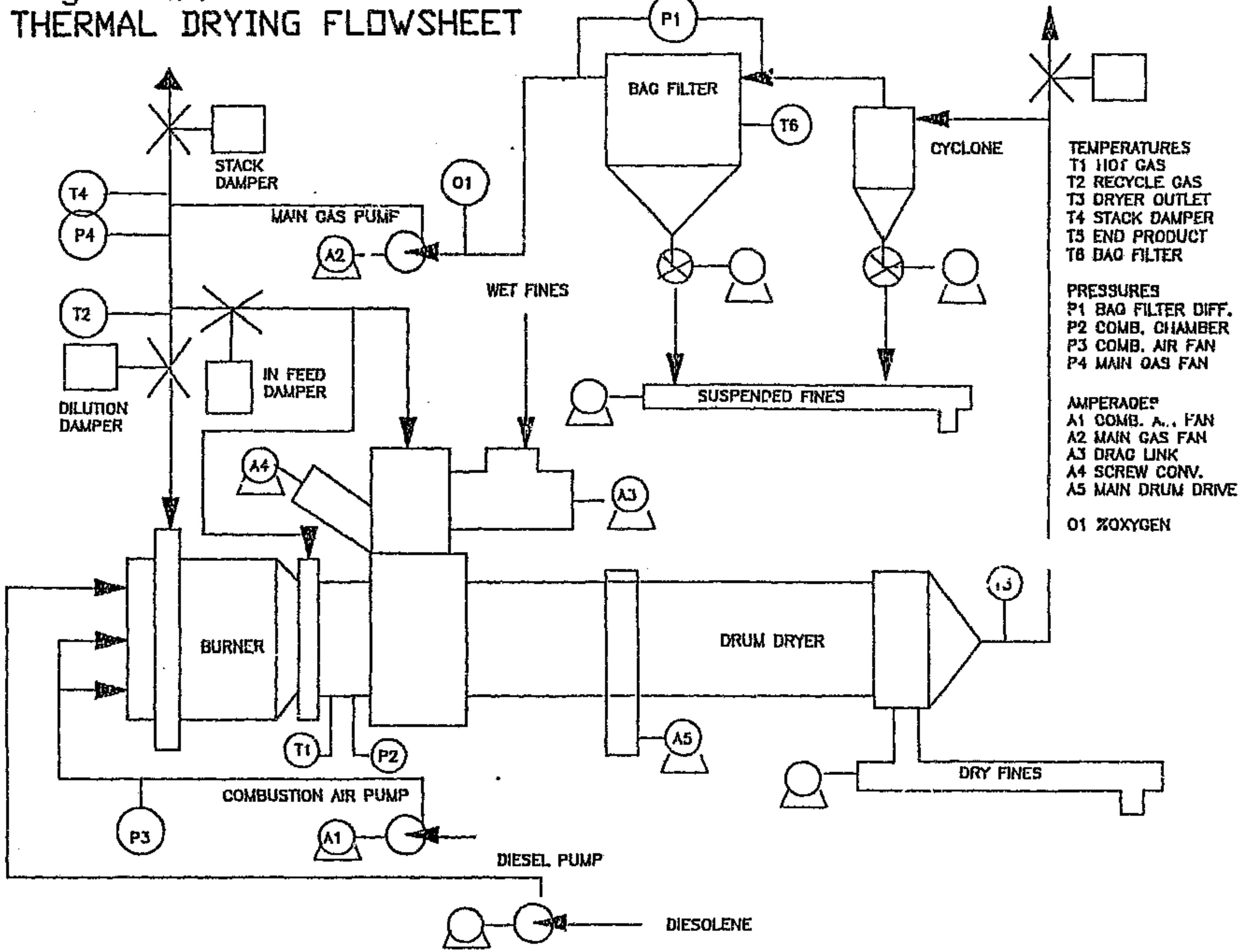
reduce the moisture content of Goedehoop thickener underflow to an acceptable sales limit at a financially viable cost. This work was reported by D.B.Nebbe.[15]

The basic flowsheet of the Goedehoop installation is shown in Figure 4.4.

The I.M.S. pilot rotary dryer is fired by diesel oil for convenience of operation at different sites. The source of heat could be any other form, at a colliery it could be from discard coal burned in a fluidised bed or from the cyclone and bag filter fines. The wet coal and hot gases enter the rotary shell together, making it a co-current operation. Some of the products of combustion are recycled which keeps the oxygen content low and reduces the risk of ignition of the dry fines. The recycled water in the form of steam also helps in this regard. Wet coal was fed to the dryer by a variable speed conveyor and then introduced into the dryer by means of a drag link conveyor followed by a screw conveyor. Product was removed by a screw conveyor into a container suspended on load cells which allowed the weight of product to be measured.

Emission of fines into the atmosphere was controlled by means of a cyclone followed by a bag filter, the solids from these units being brought back to the product. This gave an environmentally acceptable operation. The plant was well instrumented, the readings being taken every half

Figure 4.4
THERMAL DRYING FLOWSHEET



hour of operation being shown in Appendix 4.

Analysis of the fines is shown in Appendix 4.2 and a typical log sheet is shown in Appendix 4.3.

4.2.1 Sample collection

The following samples were collected every half hour of operation and analysed for moisture:-

Wet fines

Dry fines

Suspended fines

Each of the samples were composited over a run and analysed as follows:-

Calorific Value

Ash

Inherent Moisture

Volatile Matter

Size grading

4.4 Results

Table 4.1 Reduction of moisture

RUN	FEED MOISTURE	RECONSTITUTED FEED MOISTURE	PRODUCT TOTAL MOISTURE	COST OF DRYING WET FINES R/T
2	22,2	22,2	14,4	1,32
3	20,7	20,7	9,5	13,67
4	19,4	46,7	4,4	7,28
5	30,1	50,5	4,4	7,53
6	21,2	48,2	4,7	6,47
7	28,9	28,9	4,5	6,78
8	25,3	25,3	4,5	5,78

Runs 4, 5 and 6 required the addition of spray water to assist the fines into the drier. This water has been added to the feed water to give the reconstituted feed. Spray water would not be required on a full scale plant. The composite samples gave the following average values:-

Table 4.2 Analysis of wet and dry fines by size

ANALYSIS (AIR DRY)	WET FINES	DRY FINES	CYCLONE FINES	BAG FILTER FINES
CV MJ/kg	26,94	27,07	27,56	25,82
ASH %	16,2	16,00	14,4	19,7
VM %	25,9	26,00	26,6	23,7
IM %	2,2	2,0	1,8	1,5

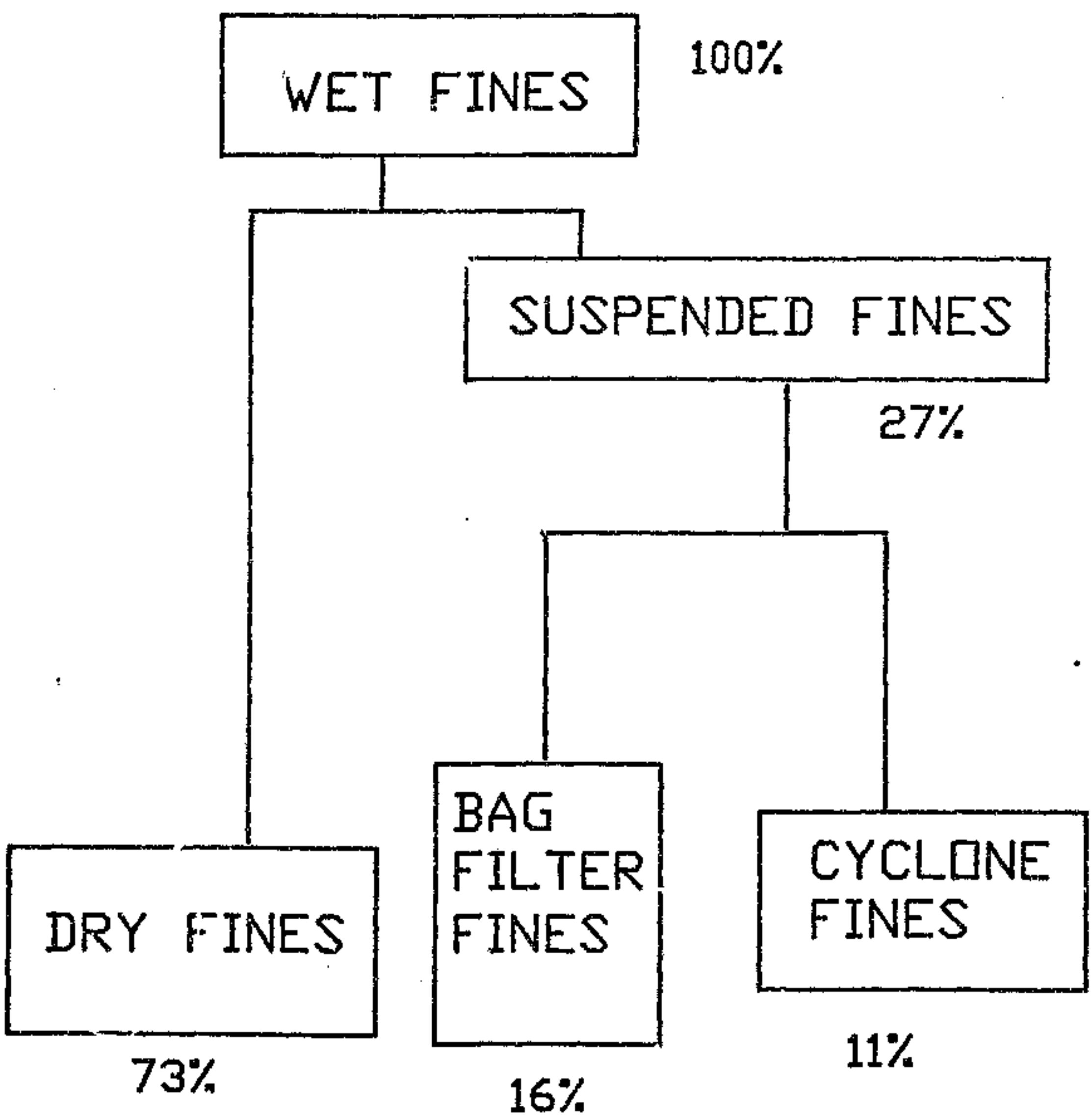
It can be seen that excellent moisture reduction was achieved with no loss of calorific value or volatile matter.

Distribution by size between dry fines, cyclone fines and bag fines can be seen in Figure 4.5.

The free moisture level at which the rotary dryer worked most efficiently and with no water injection is at exactly the expected discharge moisture from the belt filter.

Correspondence was carried out with Heyl and Patterson of the U.S.A. who offered an almost identical system to the I.M.S. proposal and at approximately the same price for a commercial plant capable of treating 60 tons/hour of wet feed.

Figure 4.5
PRODUCT SPLIT



4.3 Fluidized bed dryer

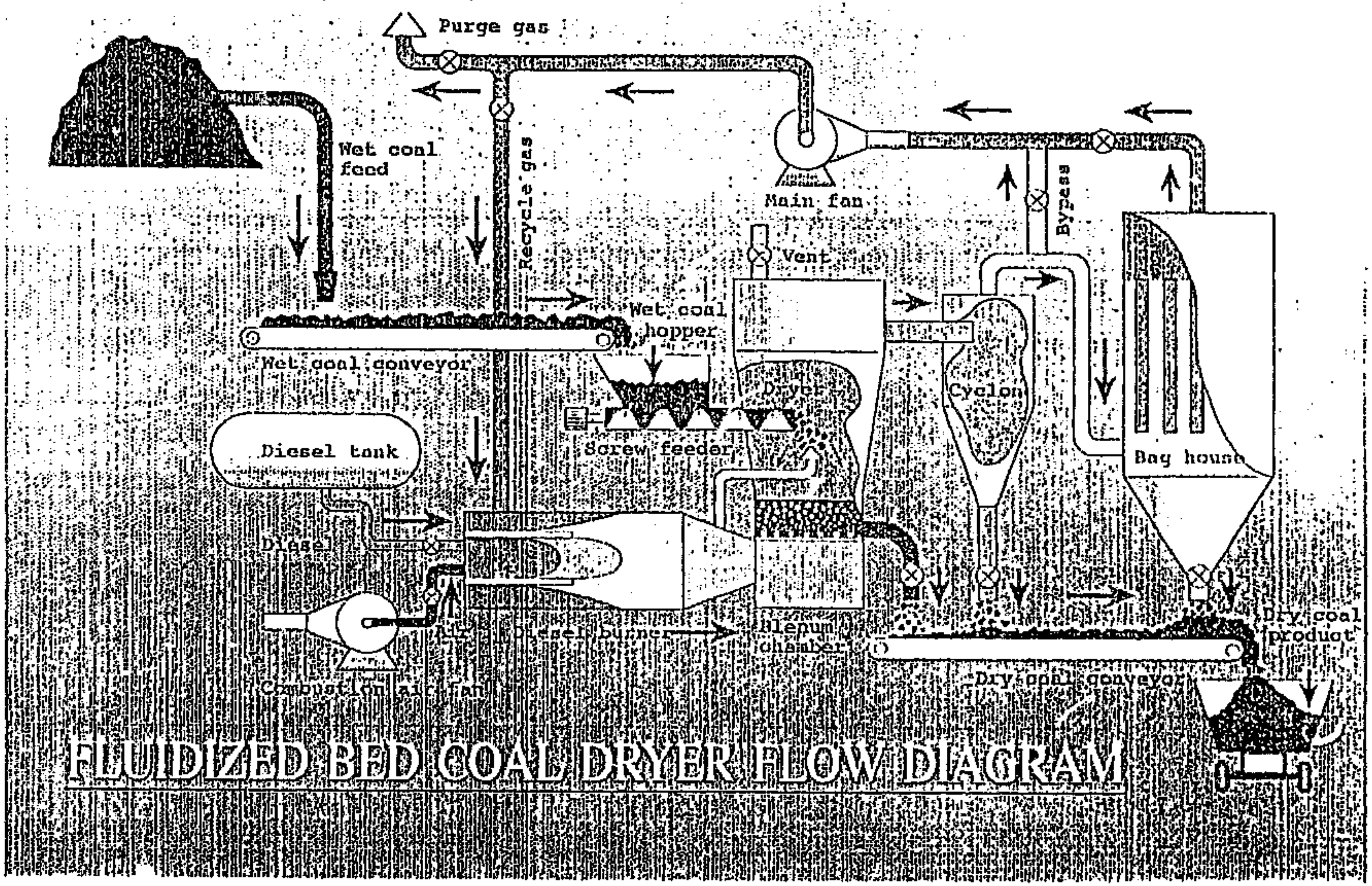
Fluidised bed techniques were developed in the petroleum industry to achieve intimate contact between fine solids and gases. The technique has been transferred to coal, first as a means of combustion of coal and then followed by its use for drying coal.

Fluidised bed drying is used widely in the U.S.A. and Heyl and Patterson quoted above manufacture large fluidised bed thermal dryers. For this application they considered the rotary dryer the better process route as fluidised bed dryers are usually used on slightly coarser coal.

Development work is being carried out on a pilot plant scale by the Division of Energy Technology of the C.S.I.R. in Pretoria of a fluidised bed dryer which is suitable for drying fine coal slurry[16]. Arrangements are being made to test Kleinkopje fines in this plant. The layout of the plant is shown in Figure 4.6.

Heat is supplied by means of a diesel burner and exhaust gases are recycled to maintain a combustion gas temperature of 420°C. As described in thermal drying the oxygen content is also reduced to a level where coal combustion cannot take place. Solids are fed into the fluidised bed by means of a screw conveyor .

Figure 4.6
C.S.I.R. FLUIDISED BED DRYER



The operation of the fluidised bed dryer relies on three control loops.

- Temperature is controlled by automatic burner modulation for a given recycle gas and material feed rate.
- Product is removed at a rate which maintains a specified pressure drop across the bed.
- Suction is controlled by regulating the induced draught fan.

Fines are recovered by means of a cyclone and a bag filter.

It can be seen that the flowsheet for the fluidised bed system is similar to the rotary dryer, the only difference being in the method of heat exchange.

Advantages quoted for fluidised bed drying are:-

- No moving parts - less maintenance
- Uniform mixing of material - no hot spots
- Residence time can be closely controlled.

The C.S.I.R. dryer is claimed to be able to evaporate 350 kg/h of water at a thermal efficiency of 80%. It has a bed area of 0,8m² and runs with a bed temperature of between 90 and 120°C.

From these figures it appears to run at a higher efficiency than the rotary shell dryer and at a much lower bed temperature.

There are indications that the flotation concentrate could be pumped directly into the fluidised bed dryer which would save the capital cost of a horizontal belt filter.

CHAPTER 5

BRIQUETTING

Briquetting of coal fines is an old industry, the first recorded installation being at St. Etienne, France in 1842. Management of Amcoal have long felt the need to make use of the discarded superfines and briquetting has been suggested as a favoured route. Consequently the Coal Processing Department has devoted time to developing a briquetting process. To this end a review of briquetting literature was carried out and briquetting operations were visited in England and Germany in 1990.

5.1 Briquetting with binders

Bituminous coal has traditionally been briquetted using pitch or bitumen as a binder. Pitch is used in Europe and bitumen in the U.S.A. As the process involves coating the coal particles with an adhesive, the mixing and heating of the coal and binder is of great importance. For a given coal, the finer the particle size the greater is the surface area and the amount of binder used to form a strong briquette must be increased. The limit of the top size of the coal is that it must not breakdown in the briquetting press thus exposing surfaces which have not been coated with binder. An accepted size range is 95% less than 1mm and 80% less than 0,5mm. The distribution within this size range should give a good packing density to limit voids within the briquette. Froth floated fines from Kleinkopje tend to have a smaller particle size than the ideal.

Figure 5.1 shows an ideal size distribution for briquetting with pitch as a binder as derived by Rogers and Homer[17] and shows the Kleinkopje superfines for comparison.

It has been shown by Broche and Nedelmann[18] that there is a relationship between the strength of the briquette produced and the volatile matter of the coal. In this instance the volatile matter can be taken as a measure of the rank of the coal. Figure 5.2 shows the relationship between volatile matter and strength.

The Kleinkopje coal falls in the area of greatest strength and should make a strong briquette.

The quality of pitch used also affects the strength of the briquette, an acceptable pitch analysis being, according to Lloyd[19]:-

Figure 5.1

SIZE DISTRIBUTION OF PARTICLES

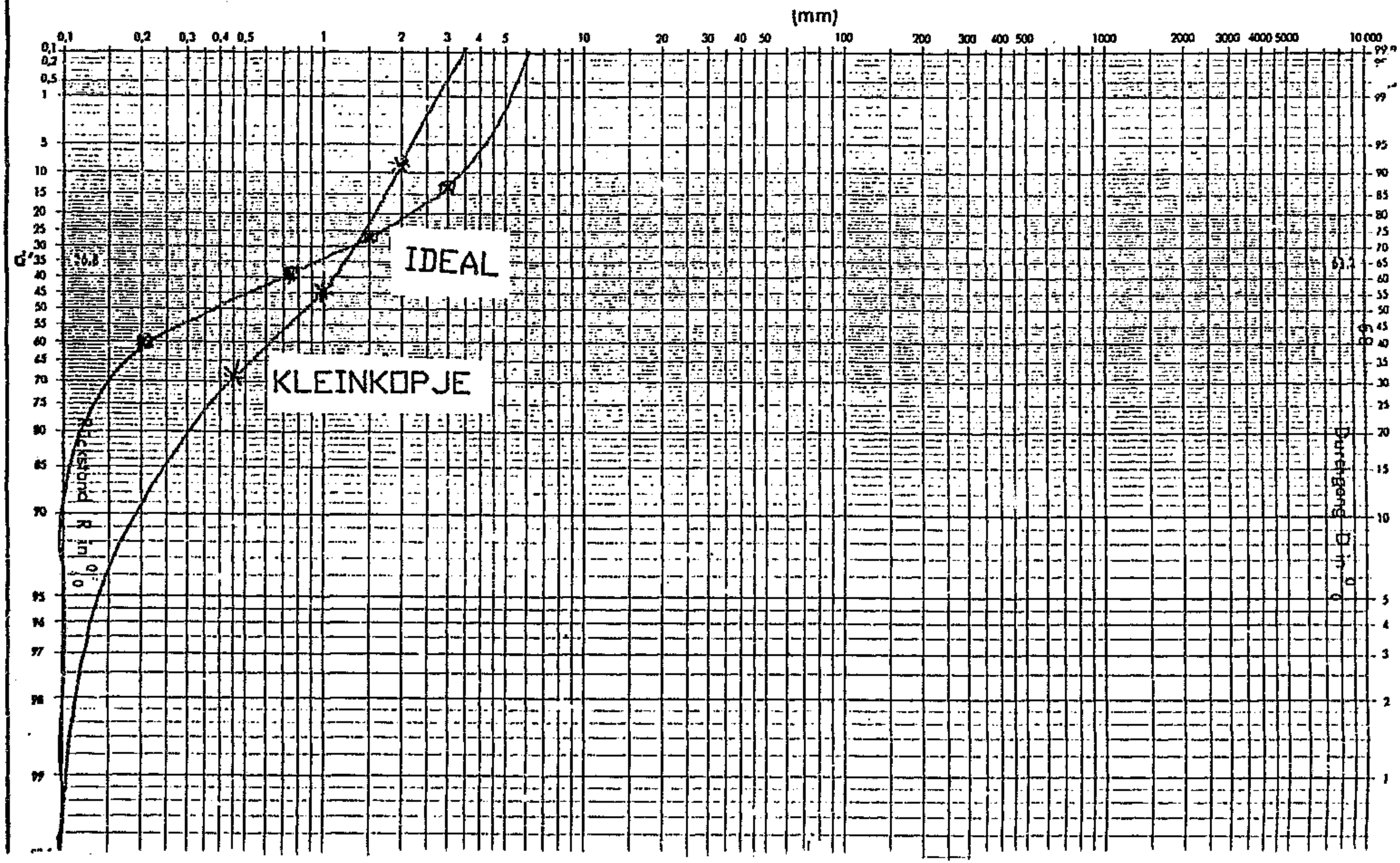


Figure 5.2
RELATIONSHIP BETWEEN V.M. AND STRENGTH

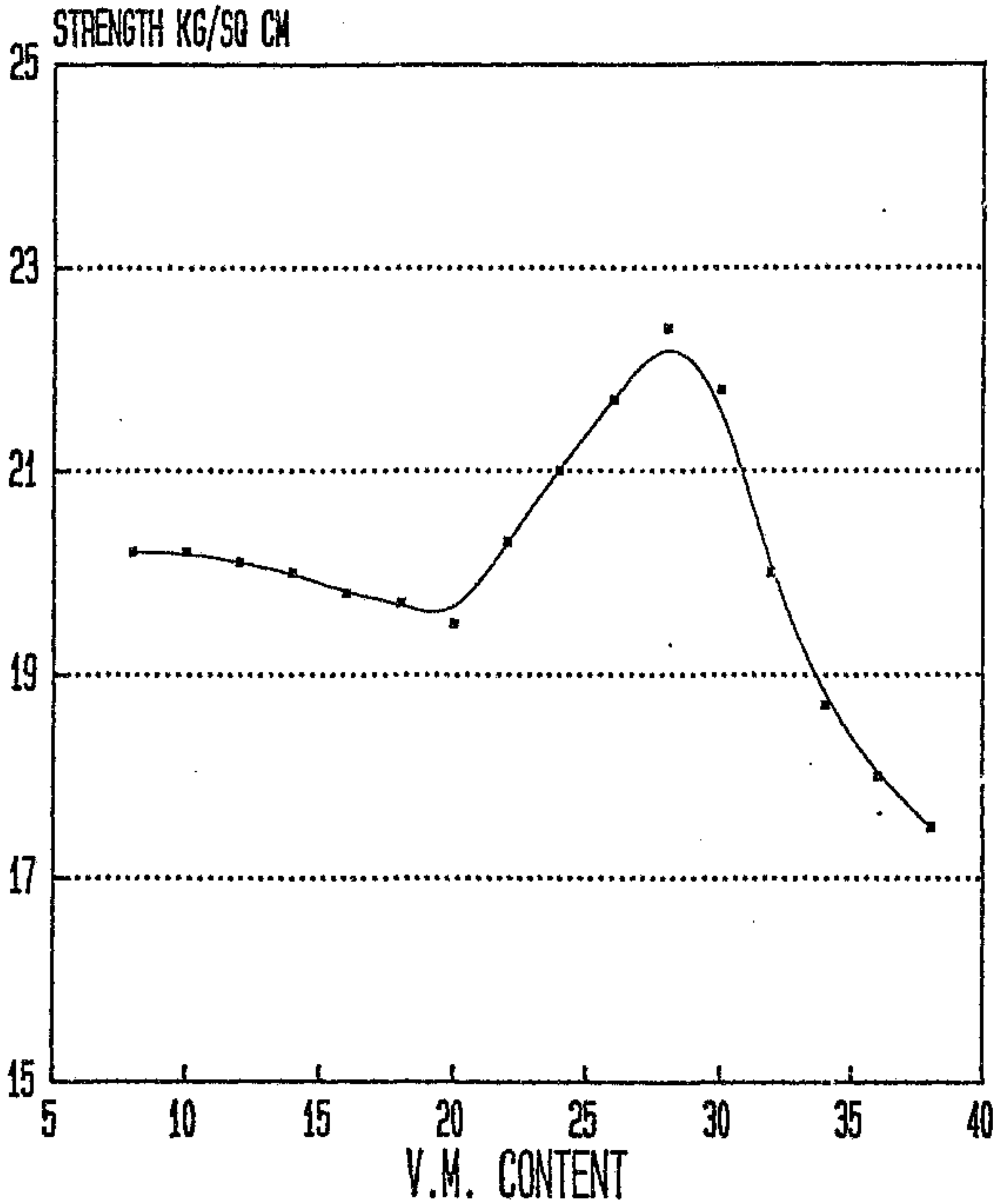


Table 5.1 Pitch analysis

Parameter	Range
Softening point °C	75 - 79
Free carbon %	14 - 21
Volatile matter %	65 - 75
Ash %	0,4

5.2 Pitch-bound briquettes from Kleinkopje underflow

As a starting point the author decided to produce pitch bound briquettes from the Kleinkopje thickener underflow material to demonstrate that a briquette could in fact be produced.

C.S.I.R. have a pilot briquetting plant which can produce pitch bound briquettes and 2 tons of thickener underflow material was transported to their site in Pretoria. The author assisted experienced C.S.I.R. operators to briquette the material. The material was steam dried in a Lödige mixer to 6% superficial moisture and then 10% pitch was added to the mixer and 100°C maintained for 10 minutes. The mixture was then briquetted in a Schuchtermann and Kremer - Braun double roll press at 24 MPa. The briquettes were allowed to air cool on a wire mesh conveyor.

An extremely strong smooth briquette was produced which subsequently proved to be totally waterproof. Immersion in water for 14 days did not weaken the briquette.

This was an encouraging test as there was concern that the fineness of the material could cause sticking in the briquette rolls. Further tests were carried out at 4%, 6% and 8% pitch but the yields of good briquettes were low and it was accepted that at least 10% pitch was required.

5.3 Alternative Binders

Pitch is in short supply in South Africa and alternative binders were considered. The binders which have been used with the most success overseas are modified molasses using lime or phosphoric acid and either the calcium or sodium form of ligno-sulphonate.

5.3.1 Molasses binder

A lime modified binder was obtained and a batch of briquettes produced using the same C.S.I.R. equipment as for pitch briquettes. The molasses briquettes are self curing to form a calcium succinate bond. Although these briquettes were strong and handleable the author established that they had very poor waterproof properties and disintegrated within minutes when immersed in water.

5.3.2 Ligno-sulphonate binder

Ligno-Sulphonate binders are used extensively in Europe to produce a premium smokeless briquette. The material is in very short supply in South Africa and therefore no testwork has been carried out.

5.4 The reason why binders are not desirable

The briquettes produced by the C.S.I.R. press are ovoid in shape and weigh 45gm. They are of a size and quality that would displace D grade coal from the domestic market. This coal has an ash content of 20% and a volatile matter of 24% and is not a smokeless fuel. It is priced at about R25 per ton at the mine.

Any briquette produced for this market must compete with the price of D grade coal. The binders considered above are priced as follows:-

Pitch	R650/ton
Molasses	R250/ton
Ligno-sulphonate	R350/ton

Used at 10% this adds between R25 - 65 per ton to the briquette cost which is more than the price of D grade coal.

5.4.1 Briquette strength

Strength tests, which involve crushing the briquettes between two parallel steel plates were carried out on the briquettes. The molasses/lime briquettes were the strongest in the air dry state, if they were waterproof they would have had adequate strength and would be better than the 10% pitch briquettes.

Table 5.2 Briquette strength

Binder	Air Dry Strength kg
4% pitch	13,4
6% pitch	18,8
8% pitch	51,5
10% pitch	80,7
Molasses/lime	87,5

5.5 Binderless briquettes

It was at this stage that it was decided to attempt to produce binderless briquettes in order to reduce the final product cost.

5.5.1 Historical review of binderless briquetting

Millions of tons of brown coal briquettes are produced annually in Germany and Australia. The brown coal is of little value as mined due to having up to 60% moisture and being small in size. Briquetting of brown coal is carried out without binders, pressure alone converts the coal into briquettes.

Numerous attempts have been made to briquette bituminous coal without a binder. An early process was the Sutcliffe process[20]. The patent claims that dry, finely comminuted bituminous coal can be compressed into lump coal, the difficulty being ridding the powder of air. Methods of expelling air were developed such as using moulds with slots and using double stage compression, as in the Ten Bosch press. Moulds were designed to allow lateral as well as linear discharge. The Sutcliffe works are still briquetting bituminous coals to make activated charcoal.

In 1953 Rhys Jones and Gregory[21] registered British patent 807433 which introduced a new concept into briquetting. They found while working at the Coal Research Establishment that the strength of binderless briquettes could be improved by introducing a shear strain while the briquette was under maximum load. It was thought that at full load forces are set up in the powder and between the mould walls and the powder that prevents intimate contact of the particles. If high shear strains are applied while under pressure, these internal arching systems are disrupted, internal frictional forces are reduced and plastic deformation occurs. The increase in briquette strength by applying shear strain is shown in Figure 5.3. A device for applying shear strain while the briquette is under load is shown in Figure 5.4. At maximum load the mould is rotated inducing shear strain in the briquette.

There has been no commercial development of this process.

5.5.2 Binderless briquetting at C.S.I.R

Against this historical background there seemed little chance of producing a binderless briquette by means of a conventional double roll press. However as binders made the cost of production too high for local briquette use and having a high pressure laboratory briquetting press available it was decided to see what happened when the Kleinkopje thickener underflow material was briquetted without a binder.

The briquetting press available was a Komarek B100 model as shown in Figure 5.5.

Figure 5.3
EFFECT OF SHEARING STRAIN ON STRENGTH

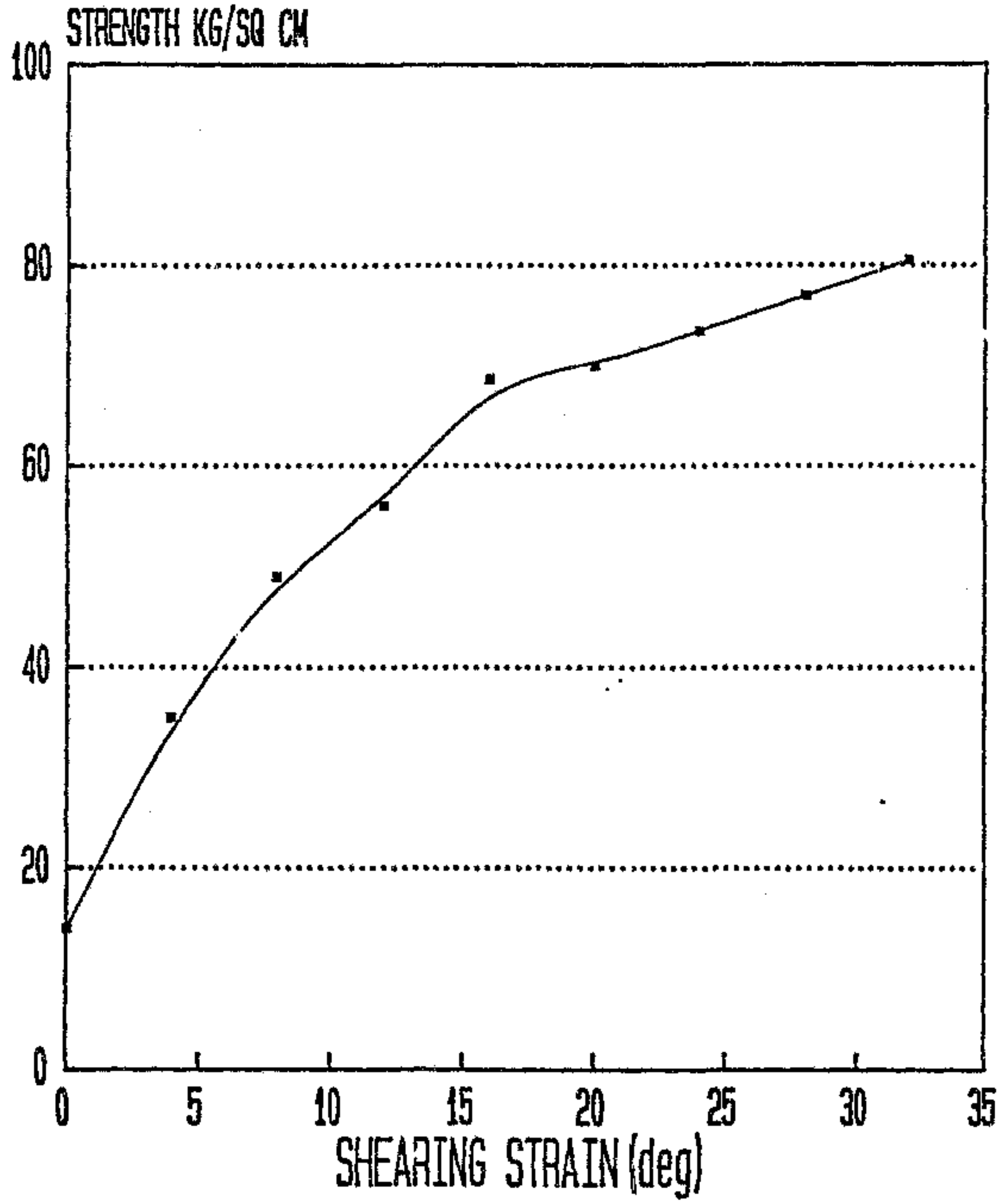


Figure 5.4

DEVICE FOR APPLYING SHEAR STRAIN

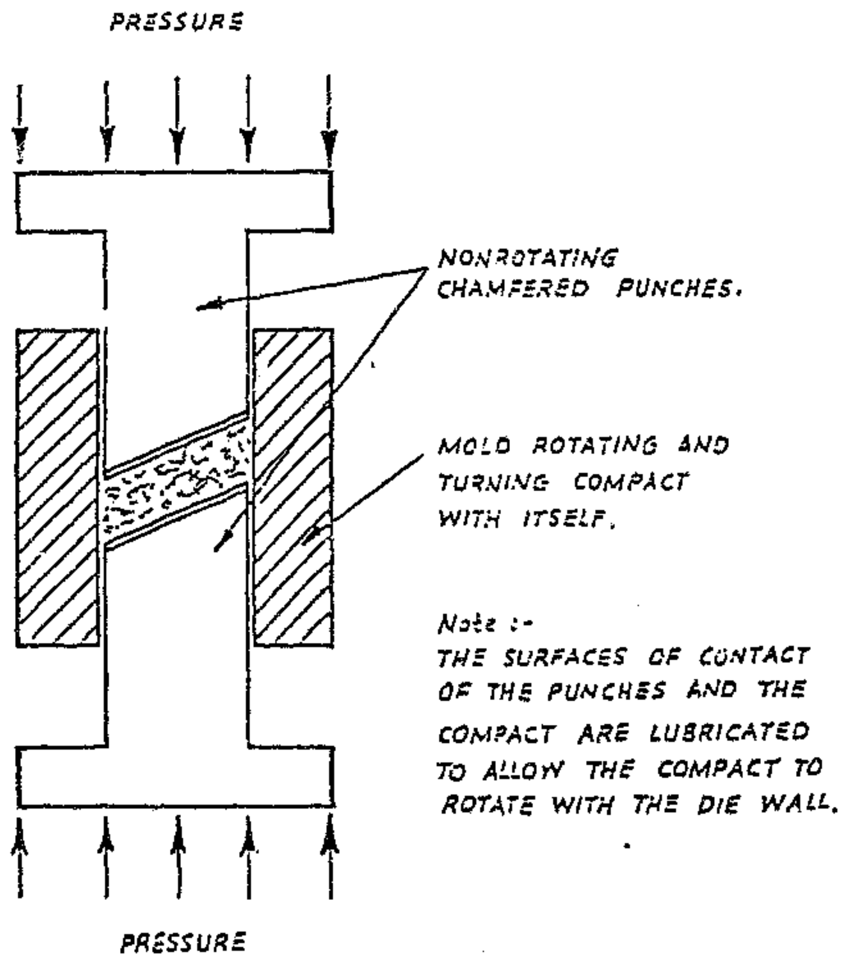
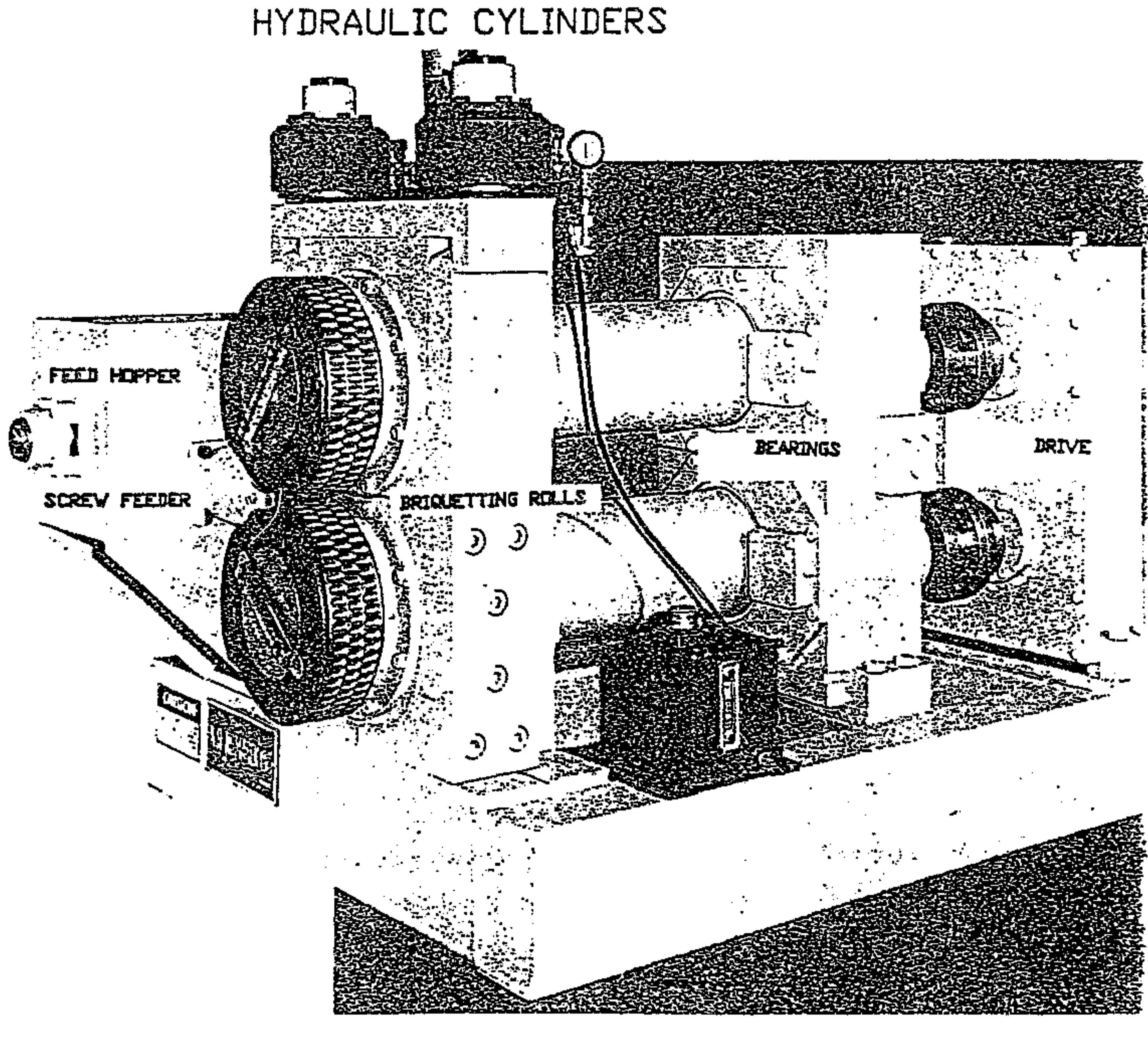


Figure 5.5
KOMAREK BRIQUETTE PRESS



The technical details of the machine are given in Table 5.3.

Table 5.3. Details of Komarek press

Model	Roll Diameter	Roll Separating Force	Capacity
B100	130mm	10 tons	0,5t/h

The roll speed and briquetting pressure are variable and fine material is fed to the rolls by means of a variable speed horizontal screw feeder. Pressure is applied to the rolls by means of two hydraulic cylinders with a piston diameter of 4,87 inches. A maximum pressure of 3000lb/square inch can be applied tc the cylinders resulting in a force of 2 x (3000 x 4,87) = 29220lb.

The rolls are cantilevered on the drive shafts so not all this force is transmitted to the rolls, an actual load of 24162 lb being obtained which is approximately equal to 10 tons.

This machine is ideal for fine material and covers make it dust free in operation. Komarek[22] claim that a shear element is introduced to the briquette due to the shape of the mould which gives added strength as described in the Rhys Jones patent. Air is displaced from the coal powder by the action of the feed screw.

The first trials were carried out with unbeneficiated Kleinkopje underflow dried to 5% moisture. The press was run at its maximum of 10 ton pressure and perfectly formed briquettes were produced, with a very smooth surface. They had sufficient green strength to allow handling but they were not strong enough for commercial use and had absolutely no weatherproof qualities. The crushing strength of the air dried green briquette was 22,4 kg compared with the 80 kg for pitch bound briquettes.

There was some discussion as to whether the unbeneficiated fines contained some clay material which could account for the good briquette formation and which might deteriorate with beneficiated materials. To test this point the pilot scale sub-aeration froth flotation units were used to produce 10kg of feed-stock. Unfortunately only a 16,1% ash was achieved rather than the targeted 10% but never-the-less the briquettes produced were much stronger than the unbeneficiated briquette with a crushing strength in the order of 50 kg.

It must be remembered in comparing the crushing strengths of briquettes that the pitch bound briquettes were of full commercial size while the laboratory press produced small briquettes of 30mm x 15mm.

As wear on the rolls is a function of the briquetting pressure, a further series of tests was carried out to determine the minimum briquetting pressure to produce a briquette of acceptable green strength. It was considered that heat produced by friction between particles could cause tar like material to form a surface skin providing the briquette strength. If the ultrafine coal was heated before briquetting the bond could be even stronger and subsequently briquettes were produced from material heated to 100°C. This was the hottest that the bearings of the laboratory machine could tolerate and so limited the range of the testing.

The results are shown in Table 5.4

Table 5.4 Briquetting pressure, briquetting temperature and crushing strength

Pressure tons	Crushing strength kg	
	Ambient	100°C
2	14,8	-
4	19,0	28,6
6	27,7	37,0
8	37,6	-
10	45,4	49,7

This testwork indicated that binderless briquettes could be produced on a laboratory double roll press but that they would have unacceptable strength and waterproof qualities. When the feed material was heated to 100°C there was a significant increase in green strength which requires further development work to determine the maximum strength that can be developed. The temperature of briquetting will be much lower than the temperatures used for char briquetting.

CHAPTER 6

DEVOLATILISING BRIQUETTES

The binderless briquettes produced in the laboratory tests had insufficient green strength and had no water resistance. They also still had the full volatile matter content of the original bituminous coal so that the next step was to determine whether the volatile matter could be driven off and to see if at the same time some form of carbon bond developed which would give a strong waterproof briquette.

Anglo American Corporation operates a high temperature coke plant at its Vryheid Coronation Colliery in Northern Natal. The coke plant laboratory possesses a 7kg capacity coke oven which is used to determine the quality of coke that a given blend of coal will produce. It was a logical starting point to use this oven to devolatilise the briquettes produced at the C.S.I.R. Pitch and molasses bound briquettes were devolatilised as well as the binderless briquettes. The author carried out the devolatilisation work personally or supervised the technical staff at Vryheid Coronation in the operation of the oven.

6.1 Description of the 7kg oven

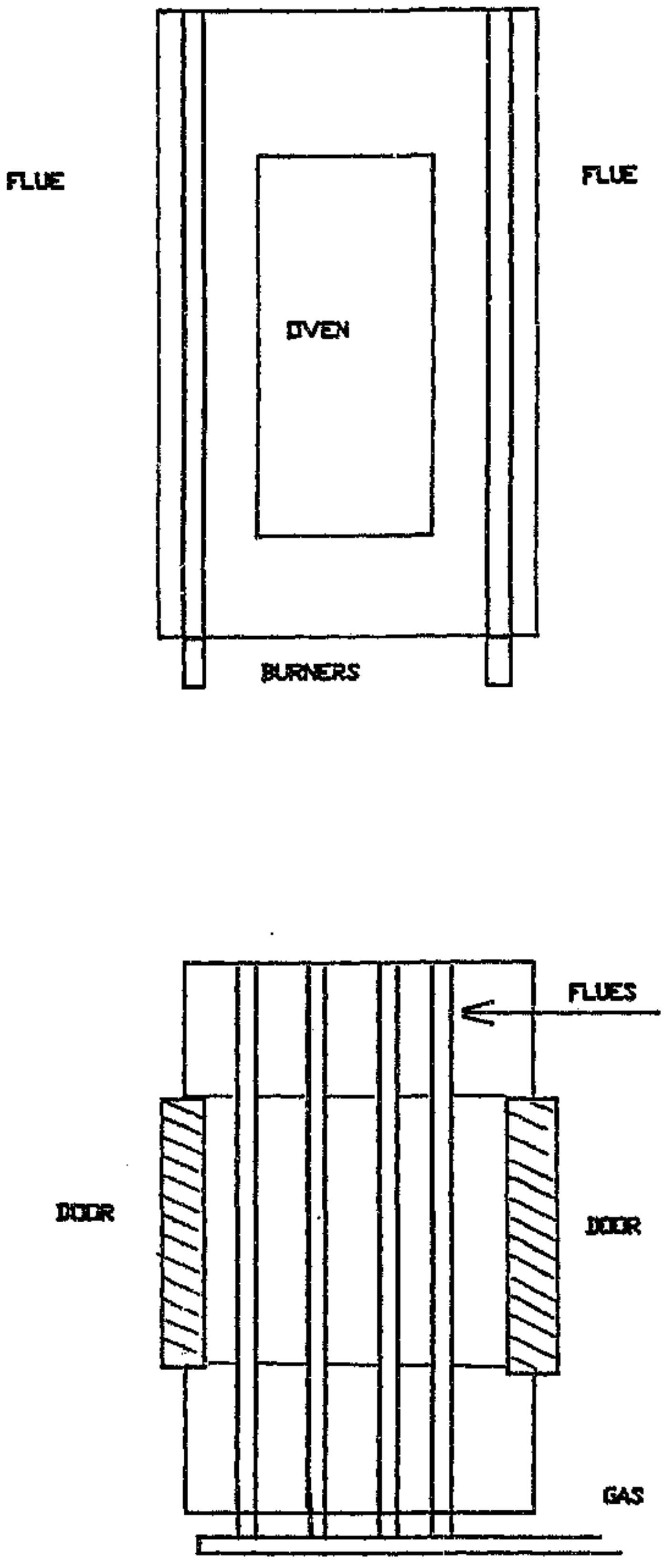
The oven consists of a silica brick chamber with removable doors at each end. The chamber is heated by liquid petroleum gas burners located in flues on each side of the chamber. Normal coking temperature is 900°C for 2 hours. The oven is brought up to operating temperature and the charge introduced through the pusher side door. The door is replaced and sealed to prevent entry of air. After regaining the required temperature the charge is carbonised for 2 hours before both doors are removed and the coked charge pushed into a container and then quenched with water.

In order to maintain reactivity in the briquettes it was decided to carbonise at 750°C and 500°C thus retaining some volatile matter to assist with easy lighting of the briquettes but having removed sufficient volatile matter to render them smokeless.

The oven is shown in Figure 6.1.

The briquettes produced were analysed for ash content and volatile matter and tested for strength and water resistance. The appearance of the briquettes was virtually unchanged after carbonising perhaps being a slightly dull grey colour compared to the shiny black appearance of an uncarbonised briquette. Volatile matter reduction was good with a corresponding increase in ash content.

Figure 6.1
7kg TEST OVEN



Results

Table 6.1 Briquette quality after carbonising

	Molasses	8% Pitch	12% Pitch	Binderless Unbeneficiated	Binderless Beneficiated
Carbonising Temp°C	500	500	700	700	700
Carbonising Time hrs.	1,5	1,5	2,25	2,25	2,25
Volatile matter start %	26,4	26,2	26,9	22,7	22,4
Volatile matter end %	13,0	14,9	9,6	5,6	9,8
Ash start %	23,0	23,0	23,0	23,0	16,1
Ash end %	27,2	26,5	28,4	29,6	19,4
Strength start kg	87,5	51,5	80,7	22,4	60,0
Strength end kg	33,8	48,2	57,6	69,0	150,0

After carbonising the molasses briquettes exhibited low strength. The pitch bound briquettes lost strength from the uncarbonised state but were still strong enough to be commercially viable. The binderless briquettes exhibited good strength which was retained after immersing in water for up to two weeks and probably indefinitely. It must be borne in mind that the binderless briquettes were much smaller than the pitch bound briquettes and therefore a direct comparison of strength should be avoided.

The beneficiated binderless briquettes showed the highest increase in strength.

6.2 Defining optimum carbonising conditions

From these initial tests it was obvious that some knowledge of briquette strength and volatile matter was required at different carbonising temperatures. A series of tests was carried out to determine these parameters as well as the effect of the briquetting pressure.

Binderless briquettes were produced at 4, 6, 8 and 10 tons pressure. The green strength was determined on a sample of each of these briquettes. A sample from each of the pressure ranges was then carbonised at 400, 500, 600 and 700°C and the carbonised briquettes tested for strength and analysed for volatile matter and ash content.

The results obtained are shown in Table 6.2.

Table 6.2 Qualities after carbonising at different temperatures.

Briquetting pressure tons	4	6	8	10	Ave
Inherent Moisture	3,9	3,8	3,8	3,8	3,8
Green strength kg	19,0	27,7	37,6	45,4	-
Ash %	20,2	20,5	20,8	20,8	20,6
V/M. %	23,2	24,0	23,5	23,9	23,6
Carbonised at 400°C					
Inherent Moisture	2,2	2,5	2,4	2,3	2,3
Ash %	22,0	22,2	21,9	22,3	22,1
V.M. %	18,3	18,4	18,5	18,4	18,4
Strength kg	11,8	17,7	23,5	32,3	-
Carbonised at 500°C					
Inherent Moisture	2,5	2,9	2,3	3,2	2,7
Ash %	22,9	23,5	23,3	23,5	23,3
V.M. %	14,7	13,8	14,2	13,0	13,9
Strength	13,9	13,8	45,9	46,1	-
Carbonised at 600°C					
Inherent Moisture	4,1	3,9	4,5	4,4	4,2
Ash %	25,1	25,3	25,3	25,5	25,3
V.M. %	8,6	6,8	8,1	6,6	7,5
Strength kg	20,5	36,3	56,7	101,3	-
Carbonised at 700°C					
Inherent Moisture	5,7	6,4	6,2	6,1	6,1
Ash %	26,1	26,3	26,5	26,3	26,3
V.M. %	4,9	4,9	3,7	3,5	4,3
Strength kg	26,7	34,7	90,5	105	-

These resultr show that the briquetting pressure has no effect on the loss of volatile matter for a given carbonising temperature. However for a given temperature there is an increase in crushing strength with increasing briquetting pressure.

For a given briquetting pressure there is an increase in crushing strength with an increase in carbonising temperature, the strongest briquettes being made using the highest briquetting pressure and the highest carbonising temperature.

There is an increase in the inherent moisture of the briquettes with increase in the carbonising temperature. As this occurs with a decrease in volatile matter it is possible that the briquettes have developed increased porosity which could hold the inherent moisture.

The average weight of briquettes produced at different briquetting pressures are recorded in Table 6.3.

Table 6.3 Effect of briquetting pressure on weight

Briquetting pressure (t)	Briquette weight (g)
4	8,6
6	9,2
8	10,1
10	10,1

These results are shown graphically in Figures 6,2, 6,3 and 6,4.

Figure 6.2

STRENGTH V. TEMPERATURE

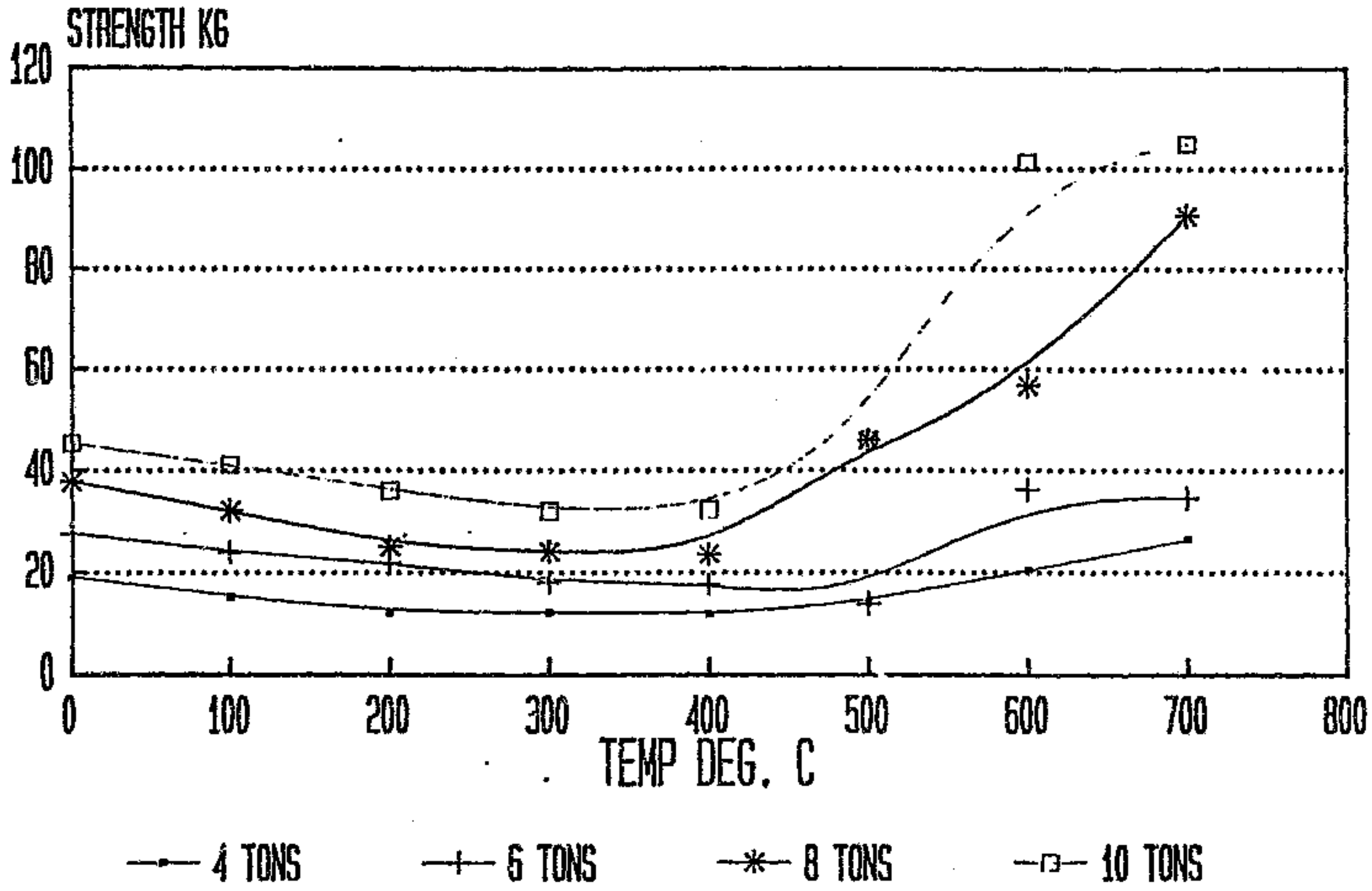


Figure 6.3
V.M. & I.M. V. TEMPERATURE

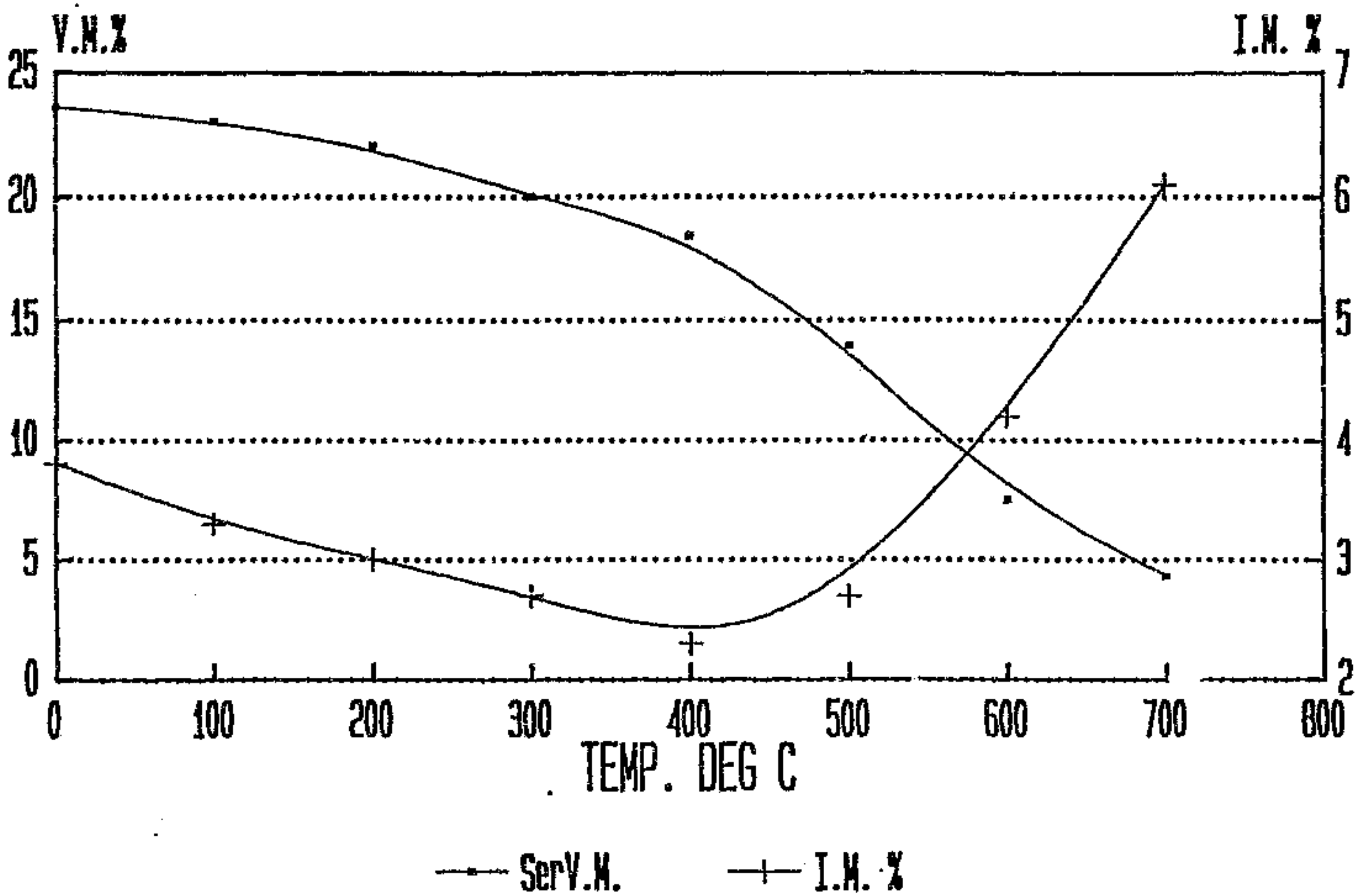
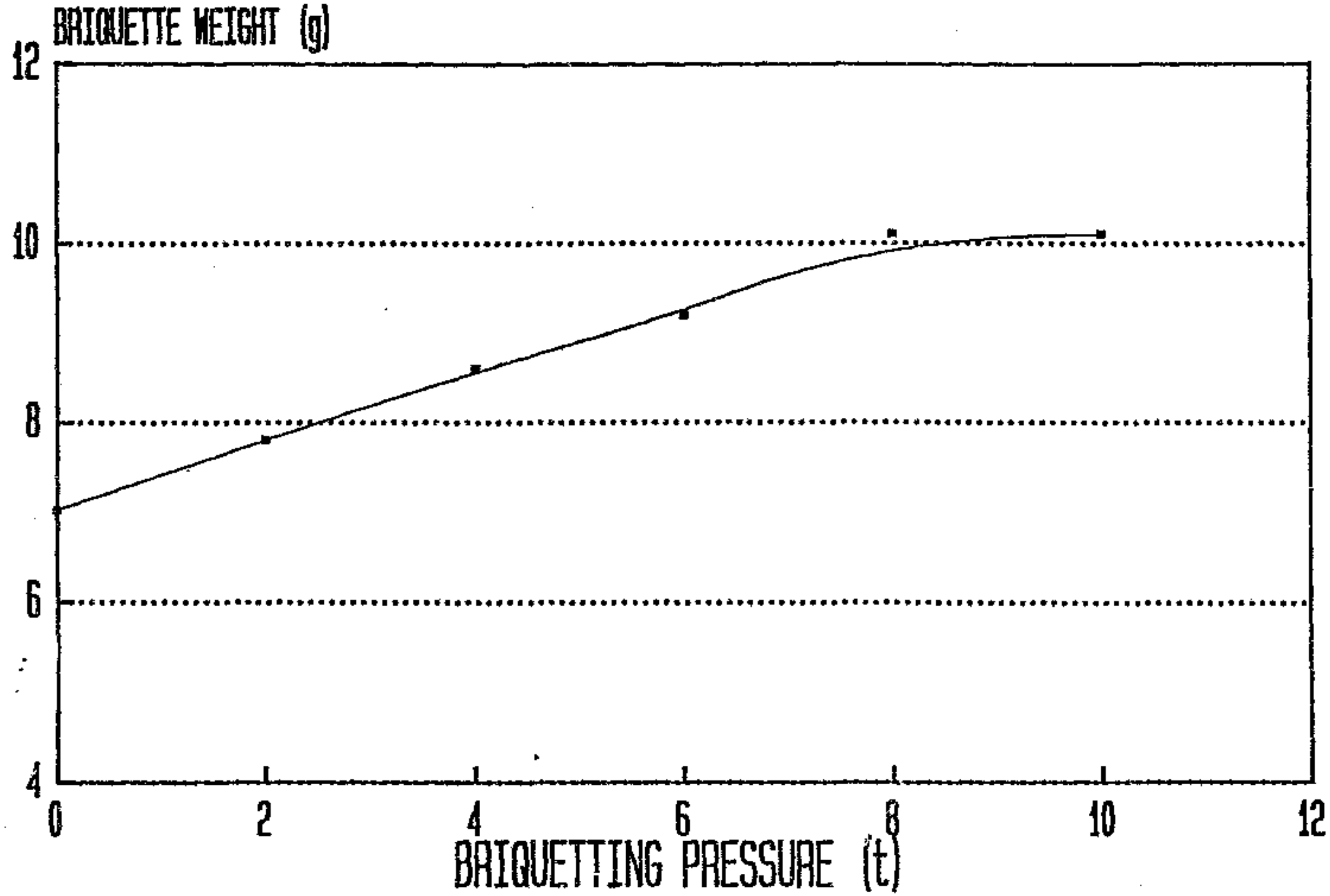


Figure 6.4
WEIGHT V. PRESSURE



6.3 Devolatilising in practice

Although the test briquettes were devolatilised in a 7kg coke oven, the design of a coke oven is not suitable for charging the green briquettes. Conventional coke oven practice is to charge coal into each battery from a larry car, the four cone shaped bins of the larry car feeding four openings in the top of the coke oven. The larry car is filled with coal from a service bunker situated in the centre of the coke oven batteries. The green briquettes would not be strong enough to withstand the handling from the briquette press to the service bunker, service bunker to the larry car and larry car to the ovens.

A mixture of briquettes and coal is charged at the ISCOR works through this type of system but the briquettes are pitch bound and there is no intention of recovering the briquettes in briquette shape after coking. The reason for briquetting part of the charge is to increase the bulk density of the coal and because of the closer proximity of the coal particles a better quality coke can be produced from a given coal.

If the coke oven design is not suitable then an alternative method of devolatilising must be found. From various options that have been tested on an international basis, the two designs that appear to be capable of handling the green briquettes are the Disticoke oven and the Shawinigan travelling grate carbonising coker.

6.3.1 Disticoke Oven

The Disticoke oven has been used in South Wales since the 1930's. Maslin[23] describes the ovens as being of a "peculiar" shape in that the force of gravity causes the briquettes to discharge from the oven when the door is removed. Phurnacite briquettes are made from low volatile steam coal (10-14% VM) using pitch as a binder. The green briquettes are then carbonised in the Disticoke oven at 800°C for 4 hours. The oven is 8 inches wide and has a capacity of 2,25 tons. Gas driven off from the briquettes is cooled to remove tar and is then used to fire the ovens.

The Phurnacite pitch b and briquettes are stronger than the Kleinkopje green briquettes but it is considered that the Disticoke oven would cause very little breakage to the Kleinkopje briquettes. The oven is shown in Figures 6.5 and 6.6

The capacity of each oven is 2,25 tons and a battery consists of 40 ovens. With a carbonising time of 4 hours each oven has a capacity of 2,25 x 24/4 = 13,5 tons per day.

Kleinkopje briquette production is 77 tons/hour or 1848 tons/day which would require 128 ovens or 3 batteries of

Figure 6.5
DISTICOKE OVEN

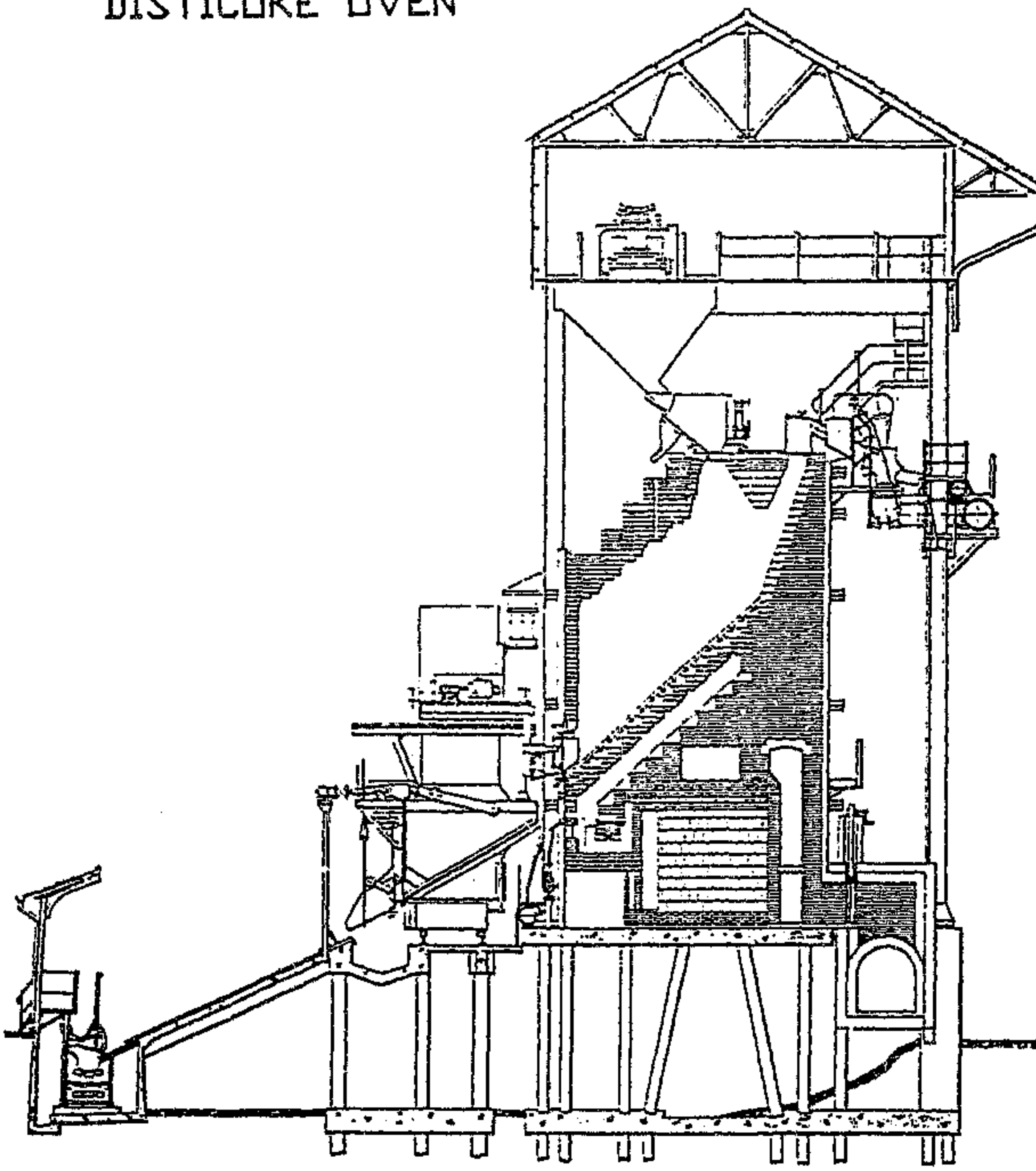
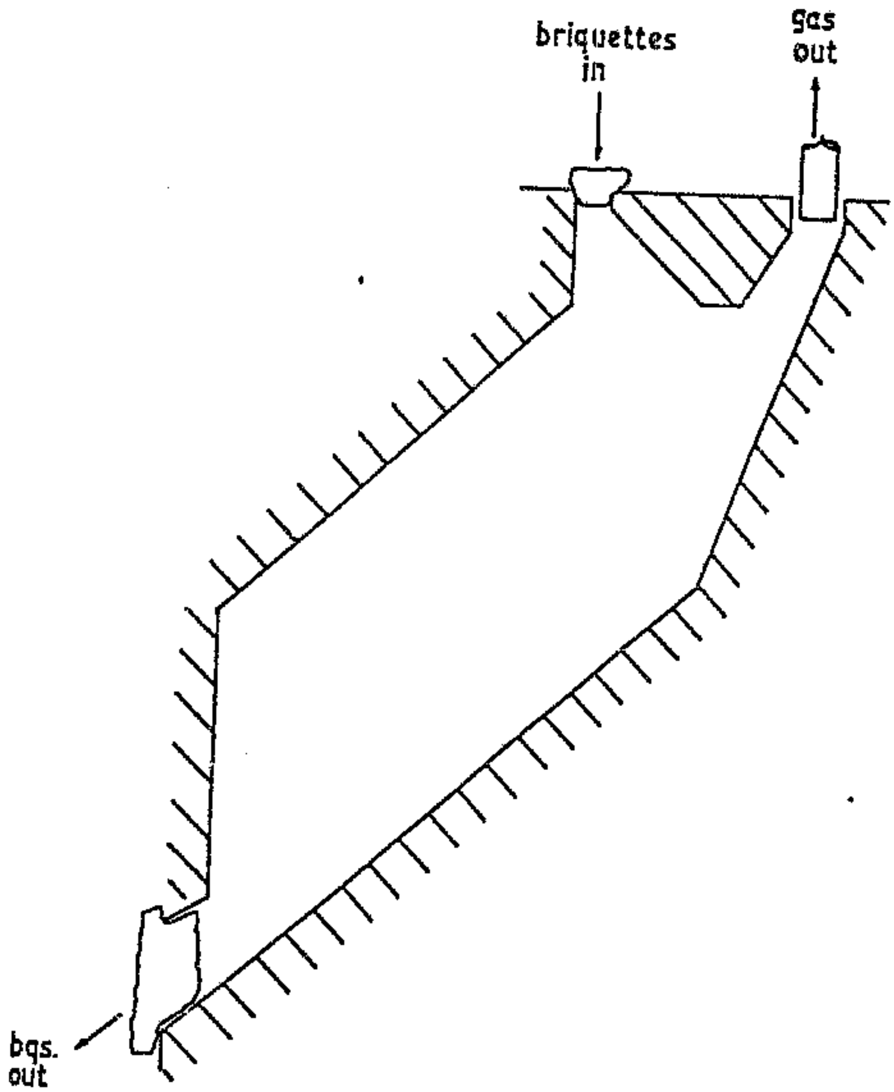


Figure 6.6
DISTICOKE OVEN CHAMBER



Disticoke ovens. With the required charging and quenching equipment, ovens of this capacity would cost in the order of R 80 million, far too expensive for this project.

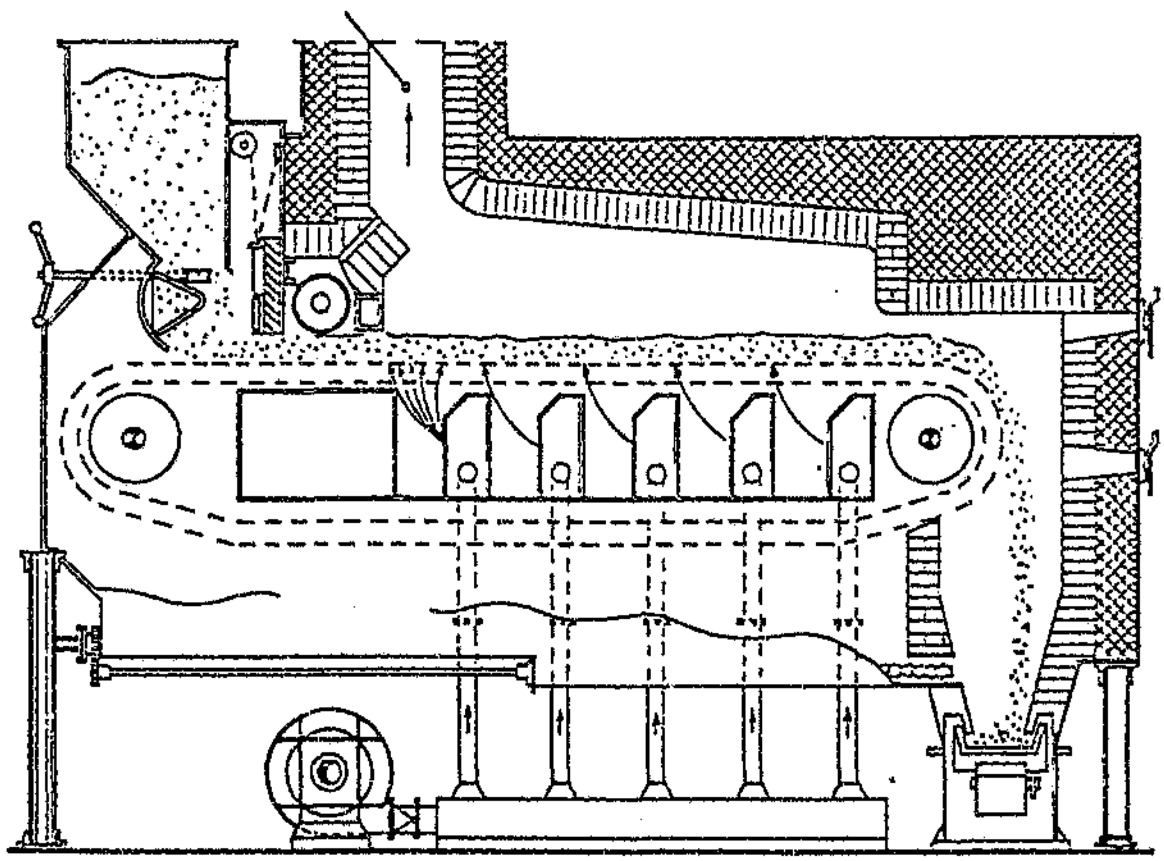
6.3.2 Shawinigan travelling grate coker

The travelling grate stoker as used extensively for firing boilers was modified by the Shawinigan Chemical company of the U.S. to allow the production of a char. The grate is shown in Figure 6.7. This was achieved by reducing the primary air and controlling the secondary and tertiary air to burn off volatile matter. The speed of the grate can be varied as can the bed depth. A chain grate stoker at the ex Vaal power station has been modified in a similar manner for char production.

John Thompson (South Africa) produce a chain grate stoker which is suitable for modification and which has a capacity of 8 tons/hour with a residence time of 1 hour. 9 of these units would be required to devolalitise 72 tons/hour of briquettes.

The volatile matter being released heats up the brickwork which radiates heat back to the incoming briquettes. The exhaust gases from the grates have a high temperature and can be used in the thermal dryer thus avoiding the expense of a separate heat source for thermal drying. As they are products of combustion the oxygen content is very low and

Figure 6.7
SHAWINIGAN TRAVELLING GRATE COKER



therefore the chances of ignition of the briquettes in the dryer are reduced.

The cost of the travelling grate cokers is very much less than the Disticoke oven, R 15 million would cover purchase and installation and therefore this method would be used for devolatilisation of the briquettes.

CHAPTER 7

ECONOMIC ASSESSMENT

The information presented in the previous sections provides data for the selection of equipment. The flowsheet is shown in Figure 7.1.

The equipment is capable of treating all the ultrafines produced at Kleinkopje, the tonnages per hour being shown in Table 7.1.

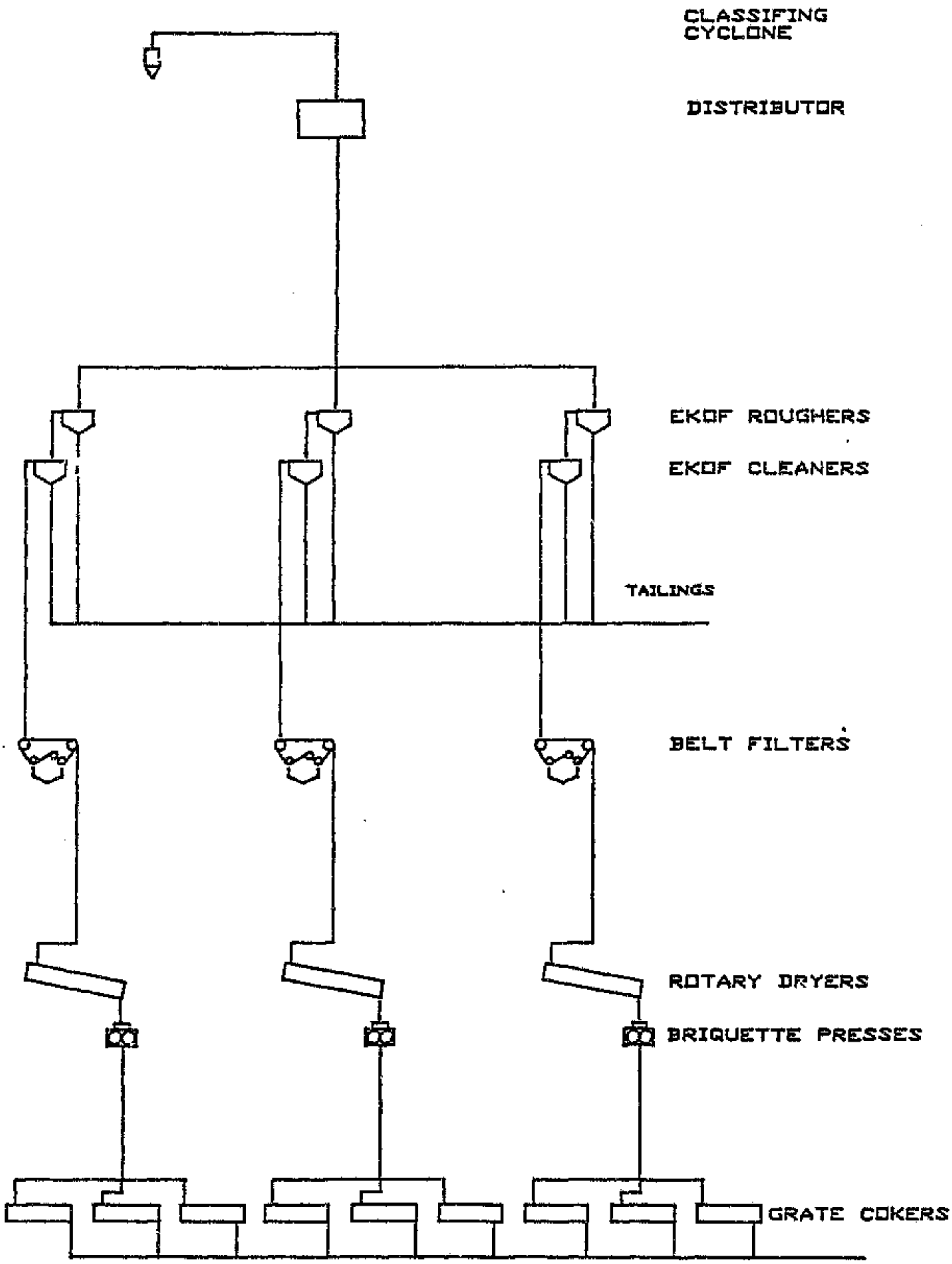
Table 7.1 Mass balance

Raw coal to plant	Raw Superfines	Beneficiated superfines	Green Briquettes	Devolatilised Briquettes
1500	120	77,0	77,0	66

66 tons per hour of devolatilised briquettes is equivalent to 336 600 tons per annum.

This assumes superfines are 8% of feed to plant, beneficiation yield is 64% and that the volatile matter reduces from 24% to 10%.

Figure 7.1
PROCESS
FLOWSHEET



7.1 Capital costs

The cost of equipment has been obtained from suppliers as follows, prices in January 1993 values.

Table 7.2 Cost of equipment.

	Rand x millions
Double stage froth flotation	10,0
Belt Filter	7,5
Thermal Drying	25,0
Briquetting	25,0
Devolatilising	30,0
Sub-Total	97,5
Electrics and Instrumentation	12,0
Engineering Fees	14,0
Total	123,5

7.2 Marketing and pay-back period

The intended market for the briquettes is in England. The product is a premium smokeless fuel, the equivalent product is currently selling for R 500 per ton. To penetrate the market it is proposed that the selling price should be extremely competitive and R 400 would be in the right order.

Operating costs to produce the briquettes are estimated per annum as being:-

Table 7.3 Operating costs.

	Rand x million
Labour	1,8
Maintenance and stores	10,8
Power and water	0,3
Total	12,9

Briquettes produced per annum = 336 600 tons

Table 7.4 Calculation of operating profit

	RAND
Revenue = 336 600 x 400 =	134 640 000
Less Operating cost	12 900 000
	121 740 000
Less Shipping	10 098 000
	111 642 000
Less Railage to RBCT	12 790 800
	98 851 200
Less selling costs England	1 683 000
Profit before tax	97 168 200

Payback period $\frac{123\ 500\ 000}{97\ 168\ 200}$ = 1,3 years.

CHAPTER 8

CONCLUSIONS

Kleinkopje superfines can be converted to a binderless, smokeless briquette by the application of coal processing technology. The concept is a departure from established processing routes although each separate stage has been used somewhere in the international coal processing scene.

The process flowsheet is complex by normal coal beneficiation standards.

The product is a premium domestic fuel which from its analysis will burn completely smokelessly and be sufficiently reactive for all domestic close stove use. The next step in development would be to produce sufficient briquettes to carry out tests to ensure compliance with British Standards for domestic fuels. Even more briquettes would be required to carry out consumer acceptance tests before a full scale plant could be considered.

The complexity of the process flowsheet is reflected in the high capital cost of the equipment. The fact that the payback period is in the order of one year does not alter the fact that over R 125 million is required to treat the total Kleinkopje superfines. The process lends itself to a modular basis, three streams being suitable to treat the total tonnage. To reduce the commercial risk it would be wise to install one module to begin with and to install other modules as demand builds up and after the trouble spots in the original design are developed out of the system. In this manner production could start with an outlay in the order of R 40 million, still a big commitment but easier to convince management to invest.

With regard to system development, concern has been expressed that scaling up from a laboratory press to a 25 ton/hour press could result in weaker briquettes. Trials with a commercial press could be carried out while the market research briquettes were being produced.

Technically there is no reason why this process will not be viable and a useless and environmentally troublesome discard turned into a profitable and sought after premium fuel.

APPENDIX

APPENDIX 2

Table 2.1 CK10 + FK1

DOSAGE RATE			WEMCO		EKOF	
Litres/tonne			Ash %	Yield %	Ash %	Yield%
CK10	FK1	COMB.				
1,87	0,21	2,08	9,05	21,39	NOT	
1,89	0,21	2,10	11,85	52,17	TESTED	
2,18	0,24	2,42	11,84	13,64		
2,91	0,32	3,23	11,51	38,21		
4,84	0,55	5,39	14,05	37,28		
5,25	0,58	5,83	10,97	20,95		

These reagents formed unstable bubbles and gave variable ash and yields. It was considered an unusable combination and no comparisons were done on the Ekof cell.

Table 2.2 CK10 + FK2

DOSAGE RATE			WEMCO		EKOF	
Litres/tonne			Ash %	Yield %	Ash %	Yield%
CK10	FK2	COMB.				
1,05	0,33	1,38	14,0	67,6	16,5	74,2
1,18	0,21	1,39	14,1	72,8	15,1	65,2
0,98	0,54	1,51	15,9	86,1	13,8	79,8
1,35	0,44	1,79	15,9	75,9	16,2	72,9
1,81	0,69	2,5	17,9	80,8	17,4	81,0

Ashes are too high. Appears to favour the Wemco cell.

Table 2.3 CK10 + FK3

DOSAGE RATE			WEMCO		EKOF	
Litres/tonne			Ash %	Yield %	Ash %	Yield%
CK10	FK3	COMB.				
1,08	0,40	1,48	11,6	71,2	13,3	74,8
1,15	0,35	1,50	13,1	67,1	10,9	48,2
1,28	0,29	1,57	11,2	39,7	11,0	53,1
1,44	0,57	2,01	13,0	77,1	14,5	87,3
2,14	0,55	2,69	12,3	77,9	16,7	88,0
2,63	1,05	3,68	13,6	73,4	16,8	81,7

Table 2.4 CK10 + FK4

DOSAGE RATE			WEMCO		EKOF	
Litres/tonne			Ash %	Yield %	Ash %	Yield%
CK10	FK4	COMB.				
0,87	0,71	1,58	12,3	81,1	13,8	89,9
1,20	0,54	1,74	10,9	65,3	11,2	72,7
1,72	0,55	2,27	16,6	93,4	12,3	81,5
0,86	2,12	2,98	12,2	73,6	11,7	74,9

These tests show that FK4 has a higher floating capability than FK3. Good ash at good yield.

Table 2.5 CK30 + FK1

DOSAGE RATE			WEMCO		EKOF	
Litres/tonne			Ash %	Yield %	Ash %	Yield%
CK30	FK1	COMB.				
0,90	0,10	1,00	10,3	9,6	NOT	
1,28	0,14	1,42	9,6	16,7	TESTED	
2,01	0,22	2,23	10,4	50,6		
4,27	0,40	4,74	9,8	73,5		

The very low yields negated testing with the Ekof cell.

Table 2.6 CK30 + FK2

DOSAGE RATE			WEMCO		EKOF	
Litres/tonne			Ash %	Yield %	Ash %	Yield%
CK30	FK2	COMB.				
0,54	0,28	0,82	15,1	64,6	16,9	75,1
0,65	0,38	1,03	15,0	45,6	15,3	33,3
1,14	0,83	1,97	14,4	60,6	17,5	69,4
1,95	0,97	2,92	18,1	86,0	19,7	97,8
2,66	1,00	3,66	12,6	38,6	17,2	66,0
2,50	1,28	3,78	17,7	64,6	17,6	86,4

Ashes are too high at these dosage rates.

Table 2.7 CK30 + FK3

DOSAGE RATE			WEMCO		EKOF	
Litres/tonne			Ash %	Yield %	Ash %	Yield%
CK30	FK3	COMB.				
0,15	0,83	0,83	14,1	39,9	14,3	63,7
0,91	0[illegible]	1,03	19,7	40,5	12,0	28,8
0,16	1,39	1,39	12,9	52,5	13,4	37,2
1,57	0,90	2,47	13,1	53,8	14,5	86,8
2,38	0,57	3,04	12,9	77,4	12,6	78,9
2,67	1,[illegible]	4,30	13,9	77,0	15,3	82,4

Table 2.8 CK30 + FK4

DOSAGE RATE			WEMCO		EKOF	
Litres/tonne			Ash %	Yield %	Ash %	Yield%
CK30	FK4	COMB.				
0,27	0,76	1,03	10,9	38,9	12,2	41,6
0,88	0,53	1,42	10,9	58,5	11,4	45,9
0,56	0,92	1,48	10,2	47,9	12,0	47,9
0,20	3,60	3,81	13,9	74,5	13,1	70,3

These are very encouraging results. It appears that almost a 10% ash is being produced at 45% yield.

Table 2.9 CYANAMID

DOSAGE RATE	WEMCO		EKOF	
Litres/tonne	Ash %	Yield %	Ash %	Yield%
CYANAMID				
2,24	17,7	86,9	20,7	96,5
2,95	12,7	73,9	13,0	89,9
3,19	11,3	60,2	14,1	92,0
3,26	16,2	79,5	14,9	58,8
3,45	13,0	69,0	15,6	81,4
4,42	16,2	70,3	20,1	86,5

All ashes are too high.

Table 2.10 SASOLCHEM

DOSAGE RATE			WEMCO		EKOF	
Litres/tonne			Ash %	Yield %	Ash %	Yield%
SASA212	S/CHEM	COMB.				
2,20	0,5	2,17	15,8	82,3	13,3	67,6
2,95	1,20	4,15	15,6	91,9	13,3	73,5
3,72	1,29	5,01	17,1	96,3	14,0	89,7
10,51	4,65	15,16	10,8	43,6	11,2	60,7

The ashes are too high. The reagents were unpleasant to use.

Table 2.11 Feed and Product ash content and yield

Test No.	Feed Ash %	Product Ash %	Yield %
1.	20,3	11,8	8,1
2.	21,1	11,5	7,3
3.	21,4	12,1	31,2
4.	21,7	10,3	41,7
5.	-	10,1	45,9
6.	21,4	10,9	65,4
7.	20,7	11,3	68,3
8.	25,2	9,7	15,2
9.	26,6	9,6	23,2
10.	25,2	15,5	74,3
11.	25,4	14,2	56,9
12.	-	13,0	75,0
13.	21,7	13,3	82,3
14.	21,4	12,3	46,0
15.	20,4	12,4	63,9

Test No.	Feed Ash %	Product Ash %	Yield %
16.	20,6	12,5	55,6
17.	21,4	13,6	62,8
18.	21,8	12,2	52,8
19.	19,6	12,9	80,3
20.	20,1	12,2	72,3
21.	20,1	11,3	47,5
22.	21,2	-	21,3
23.	21,4	7,7	15,8
24.	21,3	-	4,7
25.	26,7	-	1,3
26.	27,1	-	1,1
27.	27,2	0	0,0
28.	27,3	0	0,0
29.	25,3	-	2,4
30.	25,3	-	2,4
31.	-	-	27,1

Test No.	Feeu Ash %	Product Ash %	Yield %
32.	-	-	36,7
33.	21,6	10,2	14,0
34.	22,4	12,1	21,5
35.	21,3	13,1	41,4
36.	21,6	11,5	15,9
37.	22,2	10,7	26,9
38.	22,0	10,5	24,5
39.	21,3	10,3	22,5
40.	21,0	12,1	40,6
41.	20,7	11,1	25,4
42.	20,7	11,6	36,3
43.	20,6	10,2	28,2
44.	22,2	15,0	44,2
45.	22,1	14,1	36,9
46.	23,2	13,3	35,8
47.	23,2	14,2	58,8

Test No.	Feed Ash %	Product Ash %	Yield %
48.	22,6	14,7	81,8
49.	22,7	13,4	82,2
50.	24,0	13,8	41,5
51.	24,6	13,1	45,1
52.	25,9	9,9	15,5
53.	25,0	10,2	23,5
54.	24,9	11,2	44,7
55.	24,6	7,9	21,0
56.	24,1	11,5	35,5
57.	23,8	7,6	12,5
58.	24,0	11,3	55,1
59.	24,1	12,5	53,2
60.	24,7	14,9	84,9
61.	24,9	15,0	84,0
62.	25,9	14,0	55,4
63.	25,7	11,3	31,5

Test No.	Feed Ash %	Product Ash %	Yield %
64.	25,2	14,9	81,4
65.	25,6	11,5	49,0
66.	21,7	16,2	89,9
67.	-	14,5	82,7
68.	20,8	10,2	80,1
69.	21,5	7,2	22,4
70.	23,3	11,2	63,6
[illegible]	23,9	9,7	34,3
72.	22,5	8,7	13,0
73.	22,3	8,2	16,7
74.	24,4	13,4	57,4
75.	24,8	8,6	48,51
76.	24,8	11,8	48,5
77.	25,1	9,3	30,7
Average	23,0	11,8	50,1

Appendix 4.1 Readings taken every half hour

1. Hot gas temperature
2. Recycle gas temperature
3. Dryer outlet temp.
4. Stack damper temp.
5. End product temp.
6. Bag filter temp.
7. Bag filter diff. pressure
8. Combustion chamber pressure
9. Combustion air pressure
10. Combustion air fan amps.
11. Main gas pressure
12. Main gas fan amps.
13. Drag link speed
14. Drag link amps.
15. Feed screw speed
16. Feed screw amps.
17. Drum speed
18. Drum amps.
19. Drum tilt
20. Damper opening
21. Inlet feed opening
22. Dilution damper opening
23. Primary air flow
24. Secondary air flow
25. Oil flow
26. Oil level
27. oil consumption

28. Recycle gas oxygen
29. Water rotameter
30. Water injection
31. Dry fines feed rate

Appendix 4.2

ANALYSIS DURING TEST RUN

PARAMETER		UNIT	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30
WET FINES	SAMPLE	WF.....	0	26	27	28	29	0	30	31	32
	MOISTURE	%	0	31.4	22.9	28	29.7	28.7	29.7	29.7	29.7
DRY FINES	SAMPLE	DF.....	0	26	27	28	29	0	30	31	32
	MOISTURE	%	0	2.5	2.5	2	10.6	5	2.8	2.3	1.9
SUSPENDED FINES	SAMPLE	SF.....	0	26	27	28	29	0	30	31	32
	MOISTURE	%	0	0	0.6	0.9	0	0	0.4	0.6	0.3
CYCLONE FINES	SAMPLE	CF.....	0	0	0	0	0	0	0	0	0
	MOISTURE	%	0	0	0	0	0	0	0	0	0
BAG FILTER FINES	SAMPLE	BFF....	0	0	0	0	0	0	0	0	0
	MOISTURE	%	0	0	0	0	0	0	0	0	0

		WET FINES	DRY FINES	SUSPENDED FINES	CYCLONE FINES	BAG FILTER FINES
CV	MJ/KG	26.52	26.82	26.69	0.00	0.00
ASH	%	16.20	16.10	17.10	0.00	0.00
INHERENT MOIST	%	2.10	1.60	1.20		
VOLATILES	%	26.00	25.80	26.00	0.00	0.00
GRADING	1000	1.20	1.10	0.00	0.00	0.00
	500	9.90	10.20	0.40	0.00	0.00
	300	13.60	14.10	2.90	0.00	0.00
	125	22.60	23.00	20.20	0.00	0.00
	106	8.40	9.00	7.90	0.00	0.00
	75	4.10	4.30	7.40	0.00	0.00
	63	2.10	3.00	3.90	0.00	0.00
	53	2.10	2.60	2.80	0.00	0.00
	45	3.60	4.80	3.80	0.00	0.00
	-45	32.40	27.90	50.70	0.00	0.00

Appendix 4.3

TYPICAL LOG SHEET

	PARAMETER	UNIT	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30
1	HOT GAS TEMP.	DEG. C	820	853	876	884	816	710	859	874	884
2	1.RECYCLE GAS TEMP.	DEG. C	144	138	141	160	152	153	133	146	147
3	2.DRYER OUTLET TEMP.	DEG. C	215	189	203	218	257	181	167	163	183
4	3.STACK DAMPER TEMP.	DEG. C	138	137	139	154	147	150	136	146	146
5	4.END PRODUCT TEMP.	DEG. C	111	38	37	76	100	0	52	94	58
6	5.BAG FILTER TEMP.	DEG. C	184	169	178	198	209	171	146	159	169
7	BAG FILTER DIFF. PRESS.	mmWG	74	85	86	75	95	80	115	85	95
8	COMB. CHAMBER PRESS.	kPa	0	0.05	0	0.1	0.15	0.2	0.05	0.1	0.05
9	COMB. AIR FAN PRESS.	kPa	6.8	6.8	7	6.8	6.6	6.8	6.8	7	6.8
10	COMB. AIR FAN AMPS	A	7	8	7	7	6.5	6.5	7	7.5	7
11	MAIN GAS FAN PRESS.	kPa	2.5	2	2	2	2	1.6	1.8	1.8	1.8
12	MAIN GAS FAN AMPS	A	30.5	32	30.5	30	30.5	32.5	32	31	30.5
13	DRAG LINK SPEED	r.p.m	12	12	12	12	12	12	12	12	12
14	DRAG LINK AMPS	A	2.8	2.8	2.8	2.7	2.8	2.7	2.8	2.8	29
15	FEED SCREW SPEED	r.p.m	47	47	47	46	47	47	47.5	47.5	47
16	FEED SCREW AMPS	A	5.3	4.3	5.3	5.2	5.3	5.3	5.3	5.4	5.4
17	MAIN DRUM SPEED	r.p.m	11.5	8	8	8	7	9	8.5	6.5	6
18	MAIN DRUM AMPS	A	11.5	10.9	10.8	10.6	10.5	10.9	11	10.5	10.6
19	MAIN DRUM TILT	DEG.	2	2	2	2	2	2	2	2	2
20	STACK DAMPER OPEN	%	28	30	32	32	30	25	32	35	36
21	IN - FEED DAMPER OPEN	%	10	10	5	8	15	35	10	8	8
22	DILUTION DAMPER OPEN	%	38	45	46	46	45	45	62	50	50
23	BURNER RATE : PRIM. AIR		5	5.2	5.5	5.5	3	3.5	5.8	5.5	5.5
24	SEC. AIR		4	4	4.2	4.5	1	1.5	4.5	4.5	4.5
25	OIL		4	4	4.4	4.2	1.5	3.2	11.5	4.2	4.2
26	OIL READING	L	15	18	14.3	16	1[illegible].6	4.6	11.5	12.2	16.5
27	OIL CONSUMPTION	L/hr	30	36	28.6	32	31.2	9.2	23	24.4	33
28	RECYCLE GAS OXYGEN	%	16	13	12.5	12	14	14.5	12.5	12.5	13
29	WATER ROTAMETER	L/min	4	2	2	2	2	4	2	2	2
30	WATER INJECTED INTO DRYER	L/hr	240	120	120	120	120	240	120	120	120
31	FINES FEED RATE	k.g	12	376	782	1102	1400	1826	396	872	1268
32	FEED RATE	k.g./h	24	728	812	640	596	852	396	952	792

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