RB 661

26/5/60

CONFIDENTIAL

AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

AMDL 61

Project 1/1/20

Sponsor: South Australian Department of Mines

PROPOSED MANUFACTURE OF SULPHURIC ACID AND CEMENT FROM GYPSUM BY THE BILLINGHAM PROCESS

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Investigation Commenced: January, 1960

Investigation Completed: July, 1960

Report Issued: September, 1960

DIRECTOR: L. Wallace Coffer.

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ABSTRACT

The operation of a plant producing Portland cement and sulphuric acid from anhydrite is described. Profitable operation of the process in South Australia using gypsum as the raw material under present market conditions is shown to be improbable.

1. SUMMARY

A discussion of the chemical reactions and operation of a plant producing sulphuric acid and Portland cement from anhydrite is given. The cost of production of one ton of sulphuric acid plus one ton of Portland cement from gypsum using this process, and at the rate of 50,000 tons per year of each, is shown to be £24.6.0 - £26.6.0. Such a plant would involve a capital investment of £2.85 m. Since the present market price of one ton of sulphuric acid plus one ton of cement is £24.15.0 the process can just be operated profitably under the most favourable circumstances.

2. INTRODUCTION

Studies made by Zawadski(1), Marchal(2), and Hofman and Mostowitsch(3), of the decomposition of calcium sulphate by heat and reduction by carbon, with and without addition of promoting agents (silica, alumina and ferric oxide) showed that it was possible to produce sulphur dioxide together with a material similar to a cement clinker. By suitably proportioning the promoting agents it was found possible to produce simultaneously cement clinker and a gas containing sufficient sulphur dioxide for economic conversion to sulphuric acid. The process was first commercially operated by Müller(4) and later Kühne(5) at Leverkusen, Germany, during World War I (1914-1918) and has since been applied elsewhere in Europe. First operated in England by Imperial Chemical Industries at Billingham, the process will be referred to in this report as the "Billingham Process." Interest in the Billingham process in South Australia arises from large deposits of gypsum and the presence of good sulphuric acid and cement markets. In this report a résumé of the chemical reactions, some details of plant operation, and an estimate of the capital and operating costs of the process are given.

3. DESCRIPTION OF PROCESS

3.1 Chemical Reactions

The overall reactions occurring may be written

$$CaSO_4 + \tfrac{1}{2}C \overset{\text{approx } 1200^\circ C}{=} CaO + SO_2 + \tfrac{1}{2}CO_2 \qquad (1)$$

$$CaO + \tfrac{1}{8}Al_2O_3 + \tfrac{1}{4}SiO_2 \overset{\text{approx } 1400^\circ C}{=} \tfrac{1}{4}(3CaO.SiO_2) + \tfrac{1}{8}\,2CaO.Al_2O_3 \qquad (2)$$

$$SO_2 + \tfrac{1}{2}O_2 \overset{\text{catalyst}}{=} SO_3 \qquad (3)$$

$$SO_3 + H_2O = H_2SO_4 \qquad (4)$$

Reaction (1) is thought to occur in stages[6] with the production and subsequent decomposition of calcium sulphide according to the following reactions.

$$CaSO_4 + 2C = CaS + 2\,CO_2 \quad (5)$$

$$CaS + 3\,CaSO_4 = 4\,CaO + 4SO_2 \quad (6)$$

$$3\,CaS + CaSO_4 = 4\,CaO + 2\,S_2 \quad (7)$$

Addition of clay, alumina or ferric oxide greatly increases the rate of reaction (6) so that at 1100°C quantitative decomposition takes about one hour if the reactants are in stoichiometric proportions.

3.2 Operation of the Process

A full description of a plant operated at Wolfen is given in a British Intelligence Objectives Sub-committee report[12]. Since this report gives the most detailed description available, it will be used here as a basis for cost estimation.

The flowsheet and layout of the plant is given in Appendix A. Anhydrite, coke breeze and fluxes which constitute the "raw meal", separately weighed and proportioned, are fed to a dry grinding mill where they are ground and then passed to storage bunkers. After checking the chemical composition and making any necessary adjustments the ground materials are fed to pulverized-coal fired clinkering kilns where a gas containing sulphur dioxide is produced and cement clinker formed.

The cement clinker is passed through tubular clinker coolers and then conveyed to clinker storage. When the clinker is required for grinding it is mixed with 2-3 per cent. gypsum and ground in tube mills. The ground cement is stored in silos to be bagged and trucked as required.

The kiln gases which contain about 9 per cent. sulphur dioxide are subjected to the normal processes of cooling, dust removal and drying before conversion of the sulphur dioxide to sulphuric acid by the contact process.

In general, the process is operated on typical cement plant plus sulphuric acid plant praotioe with particular attention to the following.

1. Control of raw meal analysis
2. Operation of the clinkering kiln
3. Removal of dust and mist from the kiln gases.

Faotors (1) and (2) are intimately connected and will be considered together.

For satisfactory operation of the process it is essential that the raw meal composition be closely controlled as the cement clinker must conform to the appropriate standard [6], [8], [11]. If possible materials should be of uniform, or variations regulated so that adjustments of the proportions in the raw meal is simplified. The kiln firing rate must be adjusted so that the reduction of the calcium sulphate to calcium sulphide (reaction (5) section 3.1) proceeds at the correct rate. If too much calcium sulphide is formed some will remain in the final clinker rendering it unsuitable for cement manufacture. If too little calcium sulphide is formed a high proportion of calcium sulphate will be present in the clinkering zone. As mixtures of calcium sulphide and calcium sulphate have a low melting point and are corrosive to some refractories the fused mixture may attack the kiln lining[20].

It has been stated[6] that more difficulty is experienced with dust and mist in the manufacture of acid from the process than when using pyrites. This is thought to be due to some of the volatile matter from the coke being carried forward into the catalytic section where water is produced and a fine acid mist formed. Mist formation can be reduced by maintaining a slightly oxidising atmosphere in the kiln.

3.3 Commercial Applications

Available data on plants constructed to produce sulphuric acid from calcium sulphate are summarised in Table 1.

4. RAW MATERIALS

Overall material and energy balances for the Wolfen plant[12a] were as follows:

Basis: Cement clinker and sulphur trioxide are produced in the ratio 125 tons of cement clinker: 100 tons of sulphur trioxide, i.e. 1 ton of cement clinker: 1 monoton of H_2SO_4.

Anhydrite	1.956 tons
Equivalent to $CaSO_4$	1.948 "
Gypsum	0.021 "
Coke breeze	0.154 "
Sand	0.134 "
Pyrites cinders	0.010 "
Clay	0.321 "
Coal @ 12500 BTU/lb	0.312 "
(Coal using gypsum	(0.364) ")(see Appendix B
Power	197 kwh
Water	7260 gal.

Each of the above raw materials will be considered in turn on the basis of a 50,000 mono tons per year acid plant to be located at Port Adelaide.

4.1 Calcium Sulphate

A greater weight of calcium sulphate is required for this process than any of the other raw materials. Alternative sources of this material are anhydrite and gypsum. With one exception, anydrite is used in all plants operating in England and the Continent. There are no technical reasons why gypsum cannot be used, the removal of the combined water being an additional cost in equipment and fuel. In fact, dehydrated gypsum seems to be more easily decomposed than natural anhydrite [1],[2] and the additional fuel required may not be as great as allowed below. At Miramas, France, a plant is operated using gypsum but the method of dehydrating the gypsum is not known to the author.[13] It is assumed here that the decomposition of the gypsum takes place in the clinkering kiln, the extra heat being supplied by burning additional coal and allowance is made for reduced kiln capacity.

The anhydrite used at Wolfen[12] and Billingham[8] contains 96.5 - 99.5 per cent. calcium sulphate. A gypsum containing 76.4 - 79.0 per cent. calcium sulphate as $CaSO_4 \cdot 2H_2O$ would be required if the above grade of calcium sulphate were to be produced by calcination. Although gypsum is widely spread and large reserves proved in South Australia the unbeneficiated mineral does not reach the high grade specified above. Typical analyses of weighted average samples of gypsum obtained from Lake MacDonnell(14), Stenhouse Bay(14) and Streaky Bay(28) are set out in Table 2.

TABLE 1. PLANTS FOR THE MANUFACTURE OF SULPHURIC ACID AND CEMENT FROM CALCIUM SULPHATE.

Location	Raw Material	Date of Erection	Capacity and Remarks
		Germany	
Leverkusen	Gypsum	1916	Original experimental plant. Projected capacity was 55,000 short tons of H_2SO_4 annually, but it was never completed. Now dismantled.
Wolfen	Anhydrite	1938	Capacity 165,000 short tons of H_2SO_4 annually, was standing undamaged but shut down in 1945. Alleged to have later been removed by the Russians, and to be in progress of reconstruction for 100,000 tons capacity by 1952 and 195,000 tons by 1955.
		France	
Miramas	Gypsum	1937	27,000 short tons of H_2SO_4 annually. Operated until 1940, and sporadically from 1940-1945 during German occupation. As at 1957 closed.
		England	
Billingham	Anhydrite	1929	180,000 tons H_2SO_4 annually
Whitehaven (Cumberland)	"	1955	100,000 tons H_2SO_4 annually (Solway Chem).
Widnes	"	1955	148,000 tons H_2SO_4 and 132,000 tons cement clinker annually.
		Poland	
Breslav	Anhydrite	1950	
Busko	"		
Zdroi	"		
		Austria	
Linz	Anhydrite	1953	45,000-55,000 tons H_2SO_4 annually.

Note: (1) Production of acid is recorded in tons of 100% H_2SO_4 equivalent to the actual total production of H_2SO_4 of all concentrations.

1 ton of 100% H_2SO_4 = 1 monoton

(2) All tonnages are in long tons unless otherwise specified.

References: (6), (7), (8), (9).

TABLE 2. GYPSUM ANALYSES

Constituent	Lake MacDonnell	Stenhouse Bay (Rock)	Streaky Bay (Sand)
	(per cent.)	(per cent.)	(per cent.)
Gypsum ($CaSO_4.2H_2O$)	94.49	94.20	88.6
Calcium Carbonate ($CaCO_3$)	3.46	4.38	7.4
Sodium Chloride (NaCl)	0.93	0.50	3.0
Insoluble matter	0.18	-	0.3
Silica (SiO_2)	-	0.20	
Oxides of iron and alumina (Fe_2O_3 and Al_2O_3)	0.30	0.28	
	99.36	99.48	99.3
Hence gypsum calculated as $CaSO_4$	74.7	74.5	70.1

Impurities in the material would affect the process as follows:

1. Calcium carbonate present would lower the output of the kiln with respect to SO_3 produced per ton of clinker produced.

2. The magnesia content of the raw material should be such that the finished cement product should contain not more than 4 per cent. MgO.[25]

3. The sodium chloride content of the gypsum would have to be reduced to give less than 1 per cent. Na_2O in the product. If all of the soda in the product came from sodium chloride in the gypsum, a grade containing not more than about 1 per cent. NaCl would be required.

As most of the gypsum produced in Australia does not reach the open market it is not possible to quote a normal market price. An ex mine price of 24/10 per ton is quoted for South Australian gypsum in 1957[16] but this would be for a plaster grade material.

The cost of production of gypsum was estimated from a consideration of the mining cost, loading and unloading charges and transport charges. The deposits of gypsum at Lake MacDonnell, Streaky Bay and Marion Lake (Stenhouse Bay) have been chosen as being the most probable sources of supply from the available deposits in South Australia (Appendix C).

4.1.1 Mining Cost

A mining cost of gypsum has been estimated by comparison with the large scale open cut coal mining at Leigh Creek. During 1958 three million cubic yards of overburden were removed at Leigh Creek for the production of some 700,000 tons of coal at a cost of 24/2 per ton of coal.[29] The cost of mining was at that time approximately 4.6 shillings per ton of over-burden and coal. Assuming that gypsum may be mined from a dry lake deposit by similar means and with a relatively small amount of overburden disposal and blasting a cost of say five shillings per ton of gypsum ex mine at Lake MacDonnell is allowed. An additional charge of one shilling per ton for drilling and blasting is allowed at Marion Lake.

The cost of gypsum mined from a lake deposit near Streaky Bay has been estimated by Mansfield as being between 10/2 and 21/9 per ton stockpiled at the mine.

4.1.2 Washing Cost

The gypsum obtained at Lake MacDonnell and Marion Lake contain less than the permissible sodium chloride content but washing of the product from Streaky Bay would be necessary. Moffitt & Ashton[28] have shown that the sodium chloride content of a sample of this ore can be reduced to less than 0.1 per cent. by a relatively simple washing process and that gypsum losses can be kept low. A cost of two shillings per ton of product is estimated for washing gypsum to reduce the sodium chloride content to less than one per cent.

4.1.3 Transport Costs

The transport cost is made up of:

1. Transport from the mine to sea transport. (The alternatives of competitive road and/or rail transport from the mine to Port Adelaide are dismissed as trivial).

2. Wharfage at the point of shipping and arrival.
3. Transport in bulk ore carrying ships.
4. Loading and unloading charges.

TABLE 3. TRANSPORT CHARGES FOR BULK GYPSUM

Charge	Unit	Rate	Basis
Road transport	shill./ton mile	1.0	Estimated (Streaky Bay)
Private Railway	"	0.5	Estimated (Thevernard (Stenhouse Bay)
Wharfage:			
Thevernard	shillings/ton	0.6	Harbours Board
Stenhouse Bay	"	0.6	" "
Sceale Bay	"	0.6	Estimated
Pt. Adelaide	"	2.5	Harbours Board
Loading	"	0.25	Limestone, Klein Pt.
Unloading	"	7.0	Gypsum, Osborne (small vessel)
		2.5	Coal, Osborne
Shipping	shillings/ton laden mile	0.20	Gypsum-Edithburg to Newcastle x 2*
		0.07	Coal-Wollongong to Osborne x 2*
		0.10	Gypsum-this report

*Coal ships have back loading, gypsum ships some back loading.

The average distance from mine to wharf at Lake MacDonnell, Marion Lake and Streaky Bay are approximately 64 miles, 2 miles and 10 miles respectively.

The distance from Port Adelaide to Thevernard, Sceale Bay and Stenhouse Bay are respectively 370 miles, 300 miles and 80 miles. The cost of gypsum f.o.w. Port Adelaide is calculated in Table 4.

TABLE 4. COST OF GYPSUM

Source Cost analysis	Lake MacDonnell (Shillings*)	Marion Lake (Stenhouse Bay) (Shillings*)	Streaky Bay (Shillings*)
1. Mining	5.0	6.0	10.1
2. Washing	-	-	2.0
3. Transport to Wharf	32.0	1.0	10.0
4. Loading	0.25	0.25	0.25
5. Shipping	37.0	8.0	30.0
6. Unloading	2.5	2.5	2.5
7. Wharfage (total)	3.1	3.1	3.1
Grade (%$CaSO_4$	74.7	74.5	70.1
Total cost per ton of $CaSO_4$			
(a) at mine		8.0	
(b) f.o.w. Pt. Adelaide	107	28	96

*All figures are in shillings per ton of product

4.2 Coke Breeze

The Wolfen plant used a bituminous coke breeze made during the gasification of a Ruhr coal. Alternatives to this other gas works' coke and Upper Silesian coke breeze were used.

A typical analysis of the coke used was as follows:

Constituent	Per cent.
Fixed carbon	78-80) Dry basis
Ash	10-15) Dry basis
Moisture (as received)	8-16
Calorific value	12,200-13,000 BTU/lb

Analysis of coke breeze ash:

Constituent	Per cent.
SiO_2	35 - 45
Al_2O_3	20 - 30
Fe_2O_3	15 - 20
CaO	6 - 10
SO_3	4 - 8

Metallurgical coke breeze which is at present being stockpiled at Port Pirie is considered to be a satisfactory substitute. Coke breeze might also be available from the B.H.P. Whyalla, where some undersize coke is used as a fuel in the powerhouse and the balance stockpiled.

A price is estimated based on the ex works price of coke at Port Kembla, and the shipping cost of Newcastle coal to the Electricity Trust, Osborne as follows:

Basis - 1 ton coke

Metallurgical coke f.o.w. Pt. Kembla	£9.3	
Metallurgical coke breeze, say 80% of	£9.3	= £7.50
Freight cost (c.f. coal from Newcastle to Pt. Adelaide)		= £1.77
Wharfage, unloading, binnage		= £0.33
Total		£9.60

Allow £10 per ton at plant, Port Adelaide.

4.3 Sand and Clay

The relative amounts of sand and clay used in the process obviously depends on the clay analysis. At Wolfen typical materials used have the following analysis.

Constituent	Dry Clay (per cent)	Dry Sand (per cent)
H_2O (bound)	ca 10	
SiO_2	49.53	89.94
Al_2O_3	30-35 (including about 4% TiO_2)	4.6
Fe_2O_3	ca 3	
CaO	ca 1	0.5-2

A normal cement shale could be substituted for these components provided experimental work confirmed its suitability. For simplicity the sand and clay will be costed as "shale". Adjusting the price of cement shale quoted in 1949(13) by the basic materials price index(18) a cost of 15/- per ton in 1960 is obtained.

4.4 Fuel

The clinkering kiln fuel is usually pulverised coal, the ash content of the coal being included in the calculation of the raw meal composition. This is normal practice in cement burning operations. The quality of the coal which can be used for the process considered here is peculiar in that the sulphur content carries no penalty. The presence of iron sulphides (and gypsum) in the coal could be desirable, provided that the calorific value was not significantly affected and there was an iron deficiency in the shale. Alternative fuels are discussed below.

4.4.1 Leigh Creek Coal

Current cement plant and electrical power station demand is for coal having a calorific value of 12,000 - 13,000 BTU/lb dry weight. Adelaide Cement Company burned some Leigh Creek coal mixed with Newcastle coal in their pulverised coal fired kilns but were not satisfied with the combination and returned to the black coal as soon as possible. The Leigh Creek coal had a high ash and sulphur content and a calorific value of only 5300-6900 BTU/lb at a standard moisture content of 31 per cent. This coal in the pulverised form has been used successfully since 1954 and the main operating problems associated with its use have been overcome. Wigan and Thomas(19) described the method of pulverising and burning Leigh Creek coal at Pt. Augusta where the annual consumption is now approximately 700,000 tons.

With the present planned expansion of the powerhouse and with an economic life of 30 years for the known reserves of Leigh Creek coal amenable to economic open cut mining, little of this material would be marketed. Some coal considered not suitable for powerhouse use would probably be available.

4.4.2 Newcastle Coal

The fuel at present used at South Australian Cement works is pulverised Newcastle coal. The present contract price to the Electricity Trust of South Australia for this coal having a gross calorific value of 12,500-13,000 BTU/lb (dry weight basis) is 100/- per ton at stockpile, Osborne. This price is for very large quantities, but coal should be available at say 105/- per ton on a contract of approximately 20,000 tons per year.

4.4.3 Fuel Oil

Fuel oil is used overseas and in Australia for firing cement kilns. In a comparison of fuel oil and pulverised coal fired units the factors to be considered are

1. Fuel costs
2. Labor charges
3. Operating cost
4. Repairs and maintenance
5. Investment charges

Since neither South Australian cement manufacturers use fuel oil firing and both installations were made quite recently, it must be assumed that pulverised coal firing is cheaper. This position may change when the oil refinery is commissioned at Hallet Cove.

4.5 Pyrites Cinders

Iron oxide is used in the process to aid the decomposition of the calcium sulphate. To provide the required iron content in the kiln feed it may be necessary to add some iron rich material, commonly pyrite cinders. At Wolfen a typical pyrite cinder analysis on a moisture free basis was as follows.

Component	per cent.
SiO_2	1.0 - 3.0
Fe_2O_3	92.0 - 96.0
SO_3	1.0 - 3.0

Sulphuric Acid Limited manufacture sulphuric acid at Birkenhead by roasting pyrites and have indicated that a cinder similar to the above is produced. Apart from recent token shipments to the B.H.P. smelters at Port Kembla this cinder has been dumped locally. Ample supplies for this process would be available for sale at a nominal price which for costing purposes will be set at 5/- per ton.

TABLE 5. CAPITAL COST OF SULPHURIC ACID PLANT IN AUSTRALIA

Type of Plant	Capital cost per ton/year of H_2SO_4 Capacity	
	In U.K. (£A)	In Australia (£A)
Chamber - brimstone	11.25	11.5
Contact - "	11.25	11.25
Chamber - pyrite	22.5	20.9
Contact - "	22.5	22.5

Adjusting the capital cost of a contact pyrite plant using the ratio of the wholesale basic material price index(18) for 1953-54 (332) to that for 1957-58 (370), a cost of £A25 per ton/year is obtained.

5.2.2 Cost of Portland Cement Plant

No capital costs of plants manufacturing Portland cement in Australia could be obtained from the literature. A figure of £A25 per ton per year was agreed to be a good average figure at a recent conference of the Cement and Concrete Association of Australia(27). Of this £25 approximately £10 is spent in the burning section of the plant. As the coal required by the gypsum plant is greater by about 17 per cent. than when using anhydrite, a 20 per cent. increase in cost of the burning section is allowed. The cement section of the plant is therefore costed at £A27 per ton per year capacity.

5.2.3 Total Capital Cost of Plant

Sulphuric Acid Section	£A25	per ton per year
Cement Section	£A27	" " " "
Sub total	£A52	
+ 10% " "	5	
Total cost	£A57	per ton per year

∴ Cost of 50,000 tons/year plant = £A2.85 m.

5.3 Cost of Production

The cost of production of one monoton of sulphuric acid plus one ton of Portland cement at Port Adelaide, (A) and at the mine, (B), is outlined in Table 6.

5.4 Present Market Prices of Sulphuric Acid and Cement

5.4.1 Portland Cement

The ex-works price of cement in bags is £9.15.0 per ton f.o.r. Port Adelaide.

5.4.2 Sulphuric Acid

The ex-works price of sulphuric acid in tank-car lots of approximately 35 tons is £15 per ton f.o.r. Birkenhead.

TABLE 6. COST OF PRODUCTION

Item	Unit	Units required	Cost per unit (shillings) A	Cost per unit (shillings) B	Cost per 1 ton H_2SO_4 + 1 ton Cement (shillings) A	Cost per 1 ton H_2SO_4 + 1 ton Cement (shillings) B
$CaSO_4$	ton	1.948	28	8	56.5	17.6
Gypsum	"	0.021	21	6	0.4	0.1
Coke breeze	"	0.154	200	200	30.8	30.8
Sand	"	0.134	15	15	2.0	2.0
Pyrites cinders	"	0.010	5	5	0.1	0.1
Clay	"	0.321	15	15	4.8	4.8
Coal	"	0.364	105	105	38.2	38.2
Power	kwh	197	0.158	0.158	31.1	31.1
Water	1000 gal	7.260 gal	2	2	14.5	14.5
Wages	man-hour	2.3	15	15	34.5	34.5
					212.1	172.9
General Charges						
Maintenance		7.5% on capital = .075 x £57			85.5	85.5
General expenses (including administration and plant supervision)		5% on capital = 0.05 x £57			57	57
Interest and depreciation		15% on capital = 0.15 x £57			171	171
					525.6	486.4
or to the nearest shilling					526/-	486/-

5.5 Comparison of Production Cost and Current Market Price

The cost of production from gypsum of 1 ton of cement plus one ton of sulphuric acid at Port Adelaide has been shown to be £26.6.0. The current market price of a similar quantity of acid and cement is £24.15.0 which is less than the cost of production in the proposed plant by £1.11.0.

5.6 Effect of Plant Location

If the plant could be located at a gypsum deposit and

(1) the cost of other raw materials was unaltered,
(2) an adjacent market existed for the plant products.

the cost of production of one ton of cement and one ton of sulphuric acid would be reduced to £24.6.0. The margin of profit would then be insufficient to be competitive on the present markets.

6. DISCUSSION

6.1 Effect of Plant Location

In all references to this process, emphasis has been placed on the necessity of a market for the products and the source of calcium sulphate being adjacent for successful operation. Due to the freight charges on the unwanted water of crystallisation present, the above requirement becomes a necessary condition when the calcium sulphate is obtained from gypsum rather than anhydrite.

In section 5.6 it was shown that if the plant was located at a gypsum mine which was at a market for the products, the process could just be operated profitably.

6.2 Future Operation of the Process

Possible operation of the process would depend on an increase in the price of cement and sulphuric acid and the availability of a market.

6.2.1 Sulphuric Acid Market

The principal producers and the annual output of sulphuric acid in Australia are detailed in Appendix C An average rate of increase of production of approximately 8 per cent. per year is shown together with a vigorous policy of expansion in the Eastern States.

In South Australia present requirements of sulphuric acid are met from lead sinter gases at Port Pirie and roasting of pyrites at Birkenhead, the latter works being at present operated on reduced output. The immediate sulphuric acid position in Australia is one of plentiful supply with projected expansion sufficient for the immediate future.

6.2.2 Portland Cement Market

The principal producers of cement in Australia, the estimated annual capacity, and production statistics are detailed in Appendix . The average rate of increase of production was 9.2 per cent. per year over the past ten years. The increase in apparent consumption over the corresponding period was 9.6 per cent. The cement companies are engaged in an expansion programme in order to overcome the deficit and competion is at present very keen. Cement is produced which betters the Australian standard specification in many characteristics. For example, in some cases minimum tensile and compressive strength is double that called for in the standard. The difficulty of operating a process to produce, simultaneously, two products of highest quality should be realised, a compromise being frequently necessary. In England, United Sulphuric Acid Corporation sell their clinker to the adjacent works of Associated Portland Cement Company for admixture with the latter company's product. It is suggested that under present Australian market conditions a similar arrangement would be necessary.

7. CONCLUSIONS

1. It is not profitable at present to produce sulphuric and cement from gypsum in South Australia.

2. Projected expansion of cement plant and sulphuric acid plant capacity is sufficient to satisfy Australia's immediate needs.

3. It would be difficult to market cement produced by this process in competition with cement produced by conventional means without price reduction.

4. Freight charges have a considerable bearing on the economic application of the process.

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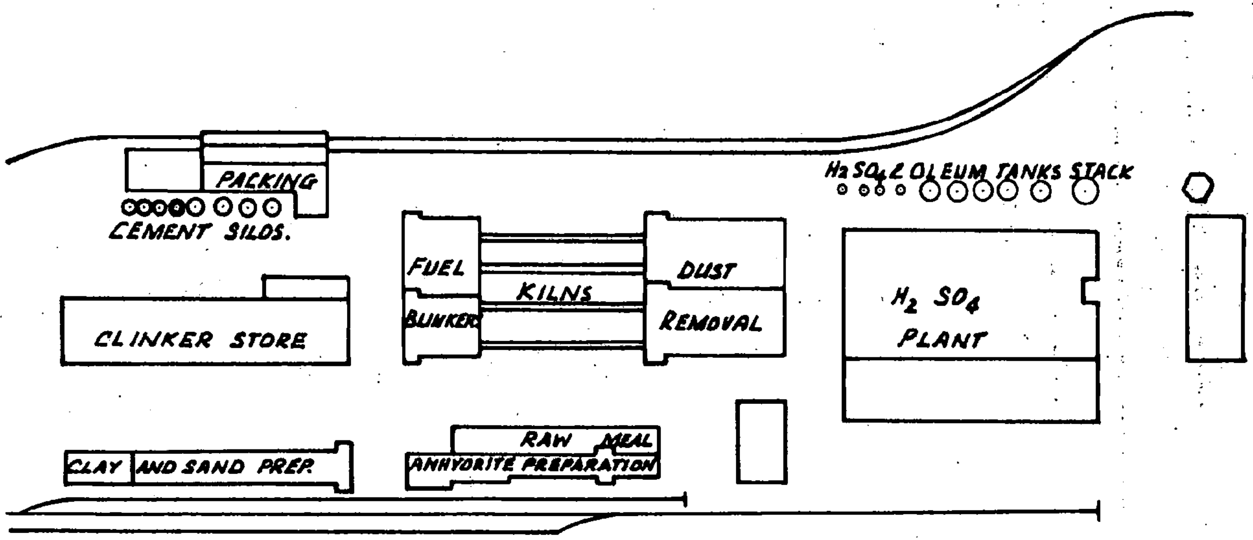
APPENDIX. A. CEMENT SULPHURIC ACID PLANT - WOLFEN



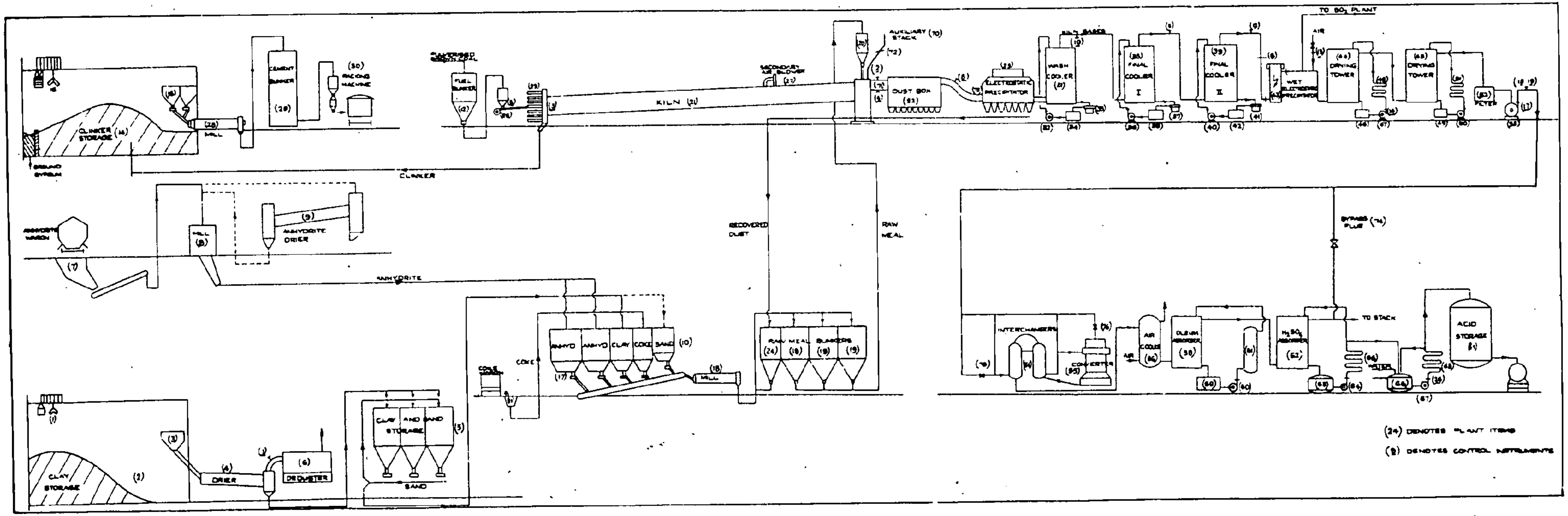
SCALE 1:2500

LAYOUT OF CEMENT H_2SO_4 PLANT

(BASED ON FACTORY LAYOUT PLAN)

R.S. 418.

APPENDIX. A. CEMENT SULPHURIC ACID PLANT. WOLFEN FLOWSHEET.



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APPENDIX B

Additional Coal Required Using Gypsum to Replace Anhydrite in the Process

Gypsum decomposes when heated according to the reaction

$$CaSO_4 \cdot 2H_2O_{(S)} \overset{\text{approx } 200^{\circ}C}{=} CaSO_{4(S)} + 2\,H_2O(g) \quad H_{298} = 45{,}000 \text{ BTU/lb mole}$$

The heat required to produce 1.948 tons of calcium sulphate from gypsum would therefore be

$$1.948 \times 2240 \times \frac{45{,}000}{136} \text{ BTU}$$

Using coal having a calorific value of 12,500 BTU/lb in a kiln with a thermal efficiency of 65 per cent. the weight of fuel required would be

$$\frac{1.948 \times 2240 \times 45{,}000}{136} \times \frac{1}{12{,}500} \times \frac{1}{2240} \text{ tons} = 0.052 \text{ tons}$$

The total weight of coal required per ton of cement clinker plus one monoton of sulphuric acid from gypsum would therefore be (0.312 + 0.052) tons.

APPENDIX C. PRODUCERS OF GYPSUM IN SOUTH AUSTRALIA AND THE KNOWN PROBABLE RESERVES OF GYPSUM* †

Producer	Locality	Hundred	Area held under lease (acres)	Reserves: Rock Gypsum (tons)	Reserves: Seed Gypsum (tons)
Waratah Gypsum Pty. Ltd.	Marion Lake	Warrenben	1,378	4,000,000	2,500,000
Waratah Gypsum Pty. Ltd.	Lake MacDonnell	Kevin & Keith	17,535	765,000,000	50,000,000
S.A. Gypsum Co. Ltd.	Lake Fowler	Melville	90	-	1,430,000
Broken Hill Pty. Ltd.	Mt.Middleback	Moonabie	1,046	-	-
D. Smith	Cooke Plains	Coolinong	85	-)	3,180,000
D. Smith	" "	Roby & Coolinong	87	-)	
Col. Sugar Refining Co. Ltd.	Lake MacDonnell	Kevin & Keith	880	(included above)	
Dry Creek Plaster Co. Ltd.	Craigie Plains	Brownlow & Anna	320)		
" " " " "	" "	Brownlow	10)	100,000	-
F. Ingham & Co.	Tickera	Tickera	18	52,000	-
G.R. Raethel	Section Cw2	Paisley	10	-	-
Pitt Ltd.	Peesey Swamp (Sec. C)	Moorowie	50	-	-
E.P. Schulz	"	"	33	-	-
Wohling & Marschall	Section 51	Waikerie	16	-	-
Castle Bros	Sections Dw and 14	Paisley	6	-	-
-	Streaky Bay †	Scott, Ripon Forrest and Wrenfordsley	-	-	-
F. Ingham & Co.	Kangaroo Is.			35,000,000	520,000
					2,500,000

* Willington C.M. "Gypsum deposits in S.A." Mining Review 92: p 171 (1950).

† Forbes B.G. "Gypsum Deposits near Streaky Bay and some other gypsum localities." S.A.D.M. 2044/58.

APPENDIX D. TABLE 1. AUSTRALIAN SULPHURIC ACID MANUFACTURES

Producer	Location	Raw Materials	'Capacity' Monotons per An.	Remarks
	NEW SOUTH WALES			
Australian Fertilizers Ltd.	Villawood	Brimstone	100,000	Plant planned to use copper sulphides or S. New 80,000 ton plant scheduled to operate mid 1960
	Pt.Kembla	Pyrites & Brimstone (2 plants		
Sulphide Corp.	Cockle Creek	Pyrites	35,000	
Drug Houses of Aust.	Rozelle	Brimstone	7,000	
Government Explosives Fac.	Mulwala	"	small	Oleum
	VICTORIA			
Commonwealth Fertilizers & Chemicals Ltd.	Yarraville	Brimstone & pyrites + minor spent oxide & oil refinery acid sludge		
Phosphate Coop of Aust. Ltd. } Cresco Fertilizers }	Geelong	Brimstone		
I.C.I. A & N.Z.	Deer Park		Minor	Oleum
Shell Oil Co.	Geelong	Petroleum S content	35,000	Acid purchased by Cresco
Standard - Vacuum				
	QUEENSLAND			
A.C.F. & Shirleys Fertilizers Ltd	Brisbane	Brimstone & pyrites		
	"			
"	Cairns	Brimstone		
Mary Kathleen Uranium Ltd.	Mary Kathleen	"	40,000	For own use only
	SOUTH AUSTRALIA			
Sulphuric Acid Ltd.	Pt. Adelaide	Pyrites	100,000	94% State use from indigenous materials
Broken Hill Assoc. Smelters.	Pt.Pirie	Lead sinter gas	63,000	
Adelaide Chemical Co.	Pt. Adelaide	Brimstone	minor	
	WESTERN AUST.			
Cuming Smith & Mt. Lyell Fertilizers Ltd.	Bassenden	Pyrites & Brimstone	72,000	
	Fremantle	Pyrites	20,000	
	Geraldton	Brimstone	28,000	
	Bunbury	"	25,000	
	Albany			
Cresco Fertilizers	Bayswater	"		
	TASMANIA			
Electrolytic Zinc Co. of Aus.	Risdon	Zinc roaster Gas	172,000	
	NORTH. TERRITORY			
Territory Enterprises	Rum Jungle	Brimstone	14,000	Own use

TABLE D2: PRODUCTION OF SULPHURIC ACID IN AUSTRALIA

Year	Sulphuric Acid Produced (Monotons)	Average rate of Increase (Per cent. per year)
1939	484,500)	2.0
1949	580,000)	
1950	639,600)	
1951	652,100)	
1952	628,300)	
1953	671,500)	8.1
1954	778,000)	
1955	895,800)	
1956	841,225)	
1957	883,800)	
1958	1,001,400	

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APPENDIX E. MAJOR CEMENT PRODUCERS OF AUSTRALIA.

Producer	Location	Approx Plant Capacity (tons/annum)	Remarks.
Commonwealth Portland Cement Co. Ltd.	Portland, N.S.W.	160,000	
Australian Portland Cement Pty. Ltd.	Kandos, N.S.W.	250,000	
Metropolitan Portland Cement Ltd.	Maldon N.S.W.	150,000	Proposed expansion to 275,000 tons per annum.
Southern Portland Cement Ltd.	Berrima, N.S.W.	160,000	
Standard Portland Cement Ltd.	Charleon, N.S.W.	116,000	Proposed expansion to 180,000 tons per annum.
Sulphide Corp. Pty. Ltd.	Cockle Creek, N.S.W.	60,000	Closed April, 1956.
North Australia Cement Ltd.	Townsville, Q'land	90,000	
Queensland Cement & Lime Co. Ltd.	Darna, Q' land	300,000	Major expansion planned 1960/61
Aust. Portland Cement Pty. Ltd.	Fyansford via Geelong Vic.	450,000	
Gippsland Lime & Cement Co. Pty. Ltd.	Traralgon, Vic.	80,000	Planning to double capacity.
Adelaide Cement Co. Ltd.	Birkenhead, S.A.	190,000	
S.A. Portland Cement Ltd.	Angaston, S.A.	165,000	Additional 90,000 t.p.a. on commissioning of new kiln.
Swan Portland Cement Ltd.	Riverdale Ltd. W.A.	100,000	One kiln converted to lime production capable of producing 25,000 t.p.a. hydrated lime.
Rugby Portland Cement Ltd.	Coogie, W.A.	150,000	
Cockburn Cement Pty. Ltd.		100,000	
Mayne Portland Cement Co.	Pt. Fairey, Vic.	30,000	Operated few months in 1952/53 and again by Arcadia Cement & Lime Pty. Ltd. in 1956 but closed due to high freight charges.
Arcadia Cement & Lime Pty. Ltd.		40-50,000	
Goliath Portland Cement Co.	Railton, Tas.	150,000	Provision for expansion to 190,000 t.p.a.