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BRANDSTOF-NAVORSINGS-INSTITUUT

VAN SUID-AFRIKA.

FUEL RESEARCH INSTITUTE

OF SOUTH AFRICA.

ONDERWERP:
SUBJECT: SOME ECONOMIC ASPECTS OF THE PRODUCTION AND TRANSMISSION OF MANUFACTURED GAS.

AFDELING:
DIVISION: ENGINEERING.

NAAM VAN AMPTENAAR:
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FUEL RESEARCH INSTITUTE OF SOUTH AFRICA.

REPORT NO. 4 OF 1949.

SOME ECONOMIC ASPECTS OF THE PRODUCTION AND TRANSMISSION OF MANUFACTURED GAS.

1.1 Utilization of the Union's low-grade coal reserves may be considered to be of great importance for the industrial development of the country, and the generation of electric power at the pithead shows a way in which this can be accomplished. There are, however, other methods of utilization which might be economically feasable, and in this report the possibilities of gas production from low grade coal, in the coal field, and subsequent transmission of the product to the consuming area, have been investigated.

Technical considerations have only been introduced where they bear directly on the economic aspects, which form the main substance of this report.

1.2 TYPE OF PLANT.

It was felt that a type of generator as developed by the Lurgi Gesellschaft für Wärmetechnik would be suitable for operation under South African conditions. In this process, coal is gasified continuously by a steam and oxygen blast at a pressure of about 20 atmospheres (250 - 300 lbs/sq.in). Advantages in the case considered here are:-

1. The oxygen requirements are moderate (A.1))*

2. The gas is/............

)* Reference numbers preceded by A refer to the appendix to this report, those preceded by R to the Literature References.

2. The gas is generated at a fairly high pressure which facilitates transmission.
3. The generator is not very critical as regards size and grade of fuel.

This last consideration rules out the conventional type of gas plant (watergas and coke oven gas plants, for instance, which cannot be operated with low-grade fuels).

The Winkler system does not appear to be very attractive as it produces gas of low calorific value. The type of plant, outlined by Jenny (R.1), using gas turbine cycles in a continuous gas making process, might be suitable for the type of installation considered here. Exact data are, however, still lacking.

1.3 SIZE AND LOCATION OF PLANT

Although the case considered here is entirely hypothetical, it should be made to conform to practical and existing conditions.

For this reason, a short review of the power requirements of the Union is given hereunder; the figures mentioned are quoted or deducted from the Report of the Coal Commission, 1946/47, and are for the year 1946.

The total inland coal trade amounted to approximately 21 million tons, and was made up as follows:-

TABLE NO. 1.

PURPOSE	MILLION TONS
Electric Power Generation	7.2
S.A. Railways	5.1
Gas Production	0.072)*
Coking Coal	.3

Domestic Uses/..........

)* Included as a matter of interest only.

PURPOSE	MILLION TONS
Domestic Uses	2.1)xx
Industrial Uses (by balance)	7.2
TOTAL (Approx.)	21.0

A further study of the data provided by the Coal Commission 1946/47, reveals that of the total amount of coal used for power generation, approximately 5 million tons, or 70% was consumed in the Transvaal. Most of this could be allocated to the Southern Transvaal area, and a conservative estimate for this region would be about half this quantity, or 35% of the total.

Assuming this quota to hold for the industrial consumption of coal in this area, one arrives at a figure of about 2.5 million tons in the Southern Transvaal.

The Southern Transvaal area appears the most favourable one for a bulk gas supply. Having a high energy demand and being situated in reasonably close proximity to important coal fields, it would meet the desirable condition that a large scale gas generation plant should be situated in the coal field while the area of consumption should be as near as possible.)'

In order/............

)xx Separate figures for the domestic demand are available for Natal only, where this item amounts to 10% of the total inland trade. This percentage has been applied arbitrarily to the inland trade for the Union to determine the figure for total domestic consumption.

)' As will be shown later, gas could be transported over considerable distances (up to a few hundred miles) provided that production can be on a sufficiently large scale. The principle the Southern Transvaal area could be supplied from the Breyten-Ermelo coal field, or even from the Waterberg field, or the Natal field (in combination with the Durban area)., if the demand were sufficiently large and enough cooling water could be made available in these fields.

In order to arrive at some basis for estimating the possible demand for gas in the Southern Transvaal, the position in the Johannesburg area may be reviewed.

It is stated in the report of the Coal Commission 1946/47, that the Johannesburg gasworks produced 1367 million cub. ft. of coal gas during 1946 (out of a total of 1877 million cub. ft for the Union).

Assuming the gas to have a calorific value of 460 B.T.U/cub. ft the gas works supplied

$$1367 \times 10^{6} \times 460 = 0.6 \times 10^{12} \text{ B.T.U. p.a.}$$

The total coal consumption (Industrial and domestic) in the Johannesburg area in that year was 863,000 tons, which, at an average calorific value of 10,000 B.T.U/lb. is equivalent to

$$2000 \times 863{,}000 \times 10^{4} = 1.73 \times 10^{13} \text{ B.T.U p.a.}$$

The Gasworks was therefore supplying

$$\frac{6}{173} \times 100 = 3.4\ \%$$

of the total B.T.U. requirements of the Johannesburg area in 1946.

If one considers that the gasworks is only supplying a small section of this area and the price of gas is comparatively high (Ca. 100d. per 10^{6} B.T.U. as against 6 - 12 d. per 10^{6} B.T.U. for coal), the gasworks contribution is quite appreciable. It might have been greater if gas had been available over a wider area.

It may be noted that the demand shows a steady increase, doubling itself in approximately 10 years according to evidence submitted to the Commission.

Reverting now to the Southern Transvaal area, the industrial demand for coal has been assumed to be about 2.5 million tons, or again assuming an average calorific value of 10,000 B.T.U/lb., 5×10^{13} B.T.U p.a.

If one assumed/.........

If one assumes, as a first approximation, that this area could absorb relatively the same amount of gas as Johannesburg, the demand would amount to

$$\frac{3.4}{100} \times 5 \times 10^{13} = 1.7 \times 10^{12} \text{ B.T.U. p.a.}$$

Bearing in mind the increase in demand for gas in the Johannesburg area, and that, as will be shown later, it should be possible to make the gas available at relatively lower rates, it does not seem unreasonable to consider a demand of 5×10^{12} B.T.U. in this area.

A plant of this size has been investigated in some detail, bracketed by calenlations for smaller and larger installations.

1.4 HEATING VALUE OF GAS PRODUCED:

The Lurgi process is capable of generating a gas of approximately 500 B.T.U. per cub. ft. calorific value. By carburetting, it may be possible to improve on this figure. Modifications of the process might have the same effect. Hydrocarbon Research claim that a gas of 1000 B.T.U. per cub. ft. could be manufactured economically within the next 2 or 3 years, but at the moment, this appears to be somewhat unsubstantiated.

Provisionally, the figure of 500 B.T.U. per cent ft., has been adhered to and used in the following Calculations, except where a higher figure has been introduced to show how conditions would be altered if a richer gas could be generated.

2.1 Capital Cost/........

2.1 CAPITAL COST OF PLANT

As capital charges amount to nearly 50% of the production cost, the cost of the plant has to be determined as accurately as possible, yet due to the scarcity of information, this is a matter of considerable difficulty.

The following data were available:-

a. A South African Company intends erecting a synthesis gas plant and considers erection of a Lurgi synthesis gas producer. This plant, having an output of 30 million cub. ft. per day, would cost £2,000,000, complete with purification and methane cracking unit (1947).

For town gas production, a somewhat less elaborate purification would be acceptable and a methane cracking unit can be omitted, in fact, a high methane content is highly desirable. From inspection of a number of Lurgi's tenders and proposals for German and Japanese installations, it appears that omission of these items would result in a saving of from 25 to 40% on the cost of the complete installation. A town gas producer would consequently cost from £1.200,000 to £1,500,000 (This includes the oxygen plant and pressure washing apparatus).

b. The cost of a water gas plant (in the United States) of equal capacity would be $ 9,000,000, whereas for an output of 10 million cub.ft. per day this would be $ 3,500,000. When applying U.S. prices to South African estimates, there is some uncertainty regarding the effective rate of exchange to be applied, and a figure between $ 3. and $ 4. per S.A. £, has been used

here/...............

here, giving prices of max. £3,000,000 and £1,167,000 and min. £2,250,000 and £875,000 respectively. The costs of a Lurgi plant of the same size would be (see C hereunder) 2/3 of this amount or resp.

£1,500,000 and £580,000 minimum.
£2,000,000 and £780,000 maximum. (R.1).

c. In Australia, the erection of a Lurgi producer of pilot plant size, a million cubic feet daily capacity, has been proposed (R.2). The estimated cost of this plant is £200,000, and that of a Watergas plant of half this capacity, £150,000. Unfortunately, it was not possible to ascertain at short notice whether these prices were in £A, so some margin has to be allowed here, but the cost of the Lurgi producer is shown to be approximately 2/3 of the cost of a watergas generator of equal capacity.

Data Under (a), (b) and (c) give an indication of plant cost for three different sizes, and from these figures, a relation between plant size and cost can be derived.

As fairly complete figures of this nature for Oxygen production plants of various sizes were available (R.3) it could be determined that the following relation exists between capital cost K and output U, namely

$$K_o = f\, U_o^{0.61} \qquad (1).$$

f being a constant dependent only on the units used. This relation is shown graphically in the diagram of fig 1.

As there are similarities between a Lurgi generator and an oxygen plant (actually the latter forms an integral and important part of a Lurgi installation), it was felt that a similar relation could be applied to the three rather

isolated sets/.........

isolated sets of data (a), (b) and (c).

The cost of the unit (a) of 30×10^6 cub. ft. daily capacity was assessed at a mean value of £1,500,000 and a line parallel to (1) above drawn through this point (fig. 1). This line is seen to pass between the extreme values of sets (b) and (c) and consequently, for a Lurgi installation the relation

$$K = g\ U^{0.61}$$

may be assumed to exist, wherein

K = plant cost, £ (S.A.)
U = output, cubic feet per day.
g. = a constant = 42.2

2.2 COST OF PRODUCTION

In this paragraoh, the cost of production for a plant of 30 million cub. ft. daily capacity has been calculated. The production cost for other sizes of plant can be derived from these data by making suitable assumptions.

Danulat (R.4) formerly of the Lurgi Company, gives the following heat balance for a Lurgi Generator.

Input.		Output.	
In coal	90%	In Gas	62 %
In Steam	10%	In tar, benzene	14.5 %
		Losses	23.5 %
			100 %

Referred to the coal, the gas making efficiency is $\frac{.62}{.9} \times 100 = 69\%$, and the heating value of tar and benzene is $\frac{.145}{.9} \times 100 = 16\%$ of the heat supplied in the coal.

80% of this amount/.........

80% of this amount (16%) is in the tar produced, 20% in benzene.

These figures are for an installation operating at 20 at (295 lbs/sq.in) and producing a gas of 500 B.T.U. per cubic foot calorific value.

The B.T.U. output of the plant is consequently

$30 \times 500 \times 10^6 = 15 \times 10^9$ B.T.U/ day, requiring

$\frac{15 \times 10^9}{.69} = 2.17 \times 10^9$ B.T.U/day in the coal supplied.

Using coal of 9,000 B.T.U/lb, this requires

$\underline{2.17 \times 10^9} : (9,000 \times 2,000) = 1200$ tons per day, or 50 tons/hour.

Assuming a cost of 5/- per ton, fuel costs amount to

(a) £12.10. 0. per hour (A2).

According to the tenders, mentioned above, (2.1(a)) the following are required per M^3 gas:

Steam 1.15 kg.
Electric Power .2 K.Wh.
Cooling Water 2 kg.

A daily production of 30×10^6 cub. ft. equals

$\frac{30 \times 10^6}{24 \times 35.3} = 35,000$ m^3/h.

Therefore steam required $35,000 \times 1.15 = 40,000$ kg/h.
= 44 tons/h.

Assuming steam to cost 1/6 per ton, cost of steam is

(b) £3. 6. 0. per hour. (A3).

Electric Power/..........

Electric Power requirements are 35,000 x .2 = 7,000 units/h. The cost per unit would depend on the location of the plant, the figure taken here is .25d. per unit (A.4) giving an hourly expenditure of

(c) £7. 7. 0

Cooling Water : 35,000 x 2 = 70,000 kg/h, or 7,000 x 2.2 = 15,400 gal/h, which at 6d per 1000 gal

(d) would cost £7. 8. 4. per hour.

Assuming 8400 operating hours per year, annual costs are:-

Coal	£100,800	
Steam	£27.720	
El.Power	£61,320	
Water	£3,220	
Total	£193,060	for Materials and Power

2.3 SALARIES & WAGES, CAPITAL CHARGES, REPAIRS.

Again, according to Lurgi's tenders, adjusted for South African conditions, the following staff is required, with estimated salaries as tabulated hereunder.

TABLE No. 2.

SCHEDULE OF STAFF.	NO.	SALARY EACH	SALARY TOTAL
Manager	1	£2000	£2000
Chief Engineer or Chemist	1	1500	1500
Shift Engineer	3	1000	3000
Chemical Engineer	1	1000	1000
Laboratory Assistant	4	700	2800
Foreman Operation	4	700	2800
Foreman, repairs	1	700	700
Skilled Workmen	40	550	22000
Labourers	20	400	8000
Natives	40	150	6000
Clerical Staff			3000
			52800
Cost of Living Quarters			13000
			£65800

Capital Charges/.........

Capital Charges.

Amortization	10 %	
Interest	4 %	
	14 %	on £1,500,000 or £210,000 p.a.

Repairs These were estimated by Lurgi at $3\frac{1}{2}\%$ on Capital cost or £52,500 p.a.

2.4. The total operating costs, resulting from the items mentioned above are:-

Coal	£	100,800
Steam	£	27,720
Water	£	3,220
Electric Power	£	61,320
Salaries & Wages	£	65,800
Capital Charges	£	210,000
Repairs	£	52,500
Total	£	521,360 p.a.

2.5 COST OF PRODUCT.

Daily production is 30 million cub. ft. or 1.25×10^6 cub. ft/h, which, at 8400 operating hours per year, gives $8400 \times 1.25 \times 10^6 = 1.05 \times 10^{10}$ cub. ft./year.

At 500 B.T.U./cub.ft., this gives

5.25×10^{12} B.T.U/ year in gas.

In addition, the yield of B.T.U's in tar and benzene is $\frac{14.5}{62} \times 5.25 \times 10^{12} = 1.25 \times 10^{12}$ B.T.U., of which 10^{12} B.T.U. appears as tar, say 25,000 tons, and 2.5×10^{11} B.T.U. as benzene say 6,000 tons.

At a conservative/..........

At a conservative estimate, £1.10. 0. per ton could be realised for tar, £3.10. 0. for benzene, resulting in a credit of £57,000, leaving an operating cost of

£464,360 per year.

Consequently, the cost per million B.T.U. at the works will be $\frac{464,360 \times 240}{5.25 \times 10^6} = 21.3$d.

2.6 EFFECT OF SIZE OF PLANT ON COST OF PRODUCTION

As indicated in paragraph 2.1 (c), capital cost of plant K in £ and output V in cubic feet per day are related by

$K = 42.2\ V^{0.61}$ and capital charges and repairs can be taken as 17.5% of this amount.

Charges for coal, water, steam and electric power and credits for tar and benzene, can be assumed to be in proportion to V. Charges for management (except for very small sizes) will be constant and amount to £10,000 p.a. Labour can be charged in proportion to output.

Consequently:

Material charges $M = £190,060 \times \frac{V}{30 \times 10^6}$

Credits $r = £57,500 \times \frac{V}{30 \times 10^6}$

Management $h = £10,000$

Labour $l = £55,800 \times \frac{V}{30 \times 10^6}$

Capital Charges $k = £.175 \times 42.2\ V\ 0.61 = 7.4\ V^{.61}$

Output, B.T.U./Year $= 500\ V \times \frac{8400}{24} = 1.75 \times 10^5\ V$

The cost per/.........

The cost per million B.T.U. is

$$\frac{(m-r + 1) + h + k}{1.75 \times 10^5 \ (V \times 10^{-6})} \times 240 \text{ pence.}$$

$$= \frac{188{,}360 \times \frac{V}{30 \times 10^6} + 10{,}000 + 7.4\, V^{.61}}{1.75 \times 10^5 \quad (V \times 10^{-6})} \times 240$$

$$= 8.35 + \frac{13.7}{(V \times 10^6)} + \frac{45.5}{(V \times 10^{-6})^{.39}} \text{ pence per million B.T.U.}$$

This gives the costs tabulated hereunder and illustrated in fig. 2.

TABLE 3

Production Cost of Gas.

Plant Size. Cub.ft. per day. $\times 10^6$	Cost of Gas. d. per million B.T.U.
1	67.6
3	42.5
5	35.3
10	28.3
30	20.8
100	16.1

2.7 ADJUSTMENTS FOR OTHER CAPITAL COSTS AND CALORIFIC VALUES

If the capital cost of the plant should have been £2,000,000, the capital charges (including repairs) will be increased by 17.5 % over £500,000 or £87,500.

Other things being equal, the cost per million B.T.U. will now be $\frac{464{,}360 + 87{,}500}{464{,}360} \times 21.3 = 1.19 \times 21.3 = 25.3$d.

So an increase in Capital cost of plant by 331/3% increases the product cost by 18%.

On the other hand, an increase in capital cost would be quite acceptable if a gas of a higher calorific value could

be manufactured/.....

be manufactured, even if this required a more complicated and consequently more expansive plant.

The effect of variation of this nature may be evaluated as follows:-

Assume constant number of heat units produced. Coal, steam, water and electric power requirements, also credits for tar and benzene, can be taken to vary in proportion to the calorific value of the gas, H, but as the volume decreases as $\frac{1}{H}$, the total remains as before.

Labour will increase also with H (a plant producing a richer gas will be more elaborate and require more attention) but not as fast as H, so an increase proportionate to $\sqrt{H}$ has been assumed; as the volume decreases in proportion to $\frac{1}{\sqrt{H}}$, labour will be reduced by $\frac{1}{\sqrt{H}}$ for the same B.T.U. output.

How the capital cost will be affected is impossible even to guess at this stage, but it is possible to calculate to what extent an increase in capital cost, resulting in a higher calorific value, is justified. It will be shown that, using the assumptions set out above, the allowable increase is quite small.

Consider the plant of 30 million cub. ft daily capacity, and suppose it possible to manufacture gas of 1000 B.T.U./cub. ft. To keep the same B?T.U. output, the volume should now be halved.

Charges for power & materials	193,060	as before.
Credits	52,500	" "
	140,560	
Management	10,000	
Labour, reduced by $\frac{1}{\sqrt{2}}$	39,500	
Production costs	190,060	
Total Charges should not exceed	464,360	
Amount available for total capital charges	274,300	

which, capitalised/.....

which, capitalised at 17½%, allows an investment of a capital of approx. £1,560,000 which is only £60,000 more than for a plant producing 500 B.T.U. gas.

It might be argued that it would be better to base the calculation on the assumption that the volume handled remains the same, and the output (in heat units) doubled. Although, apart from the fact that it might be impossible to dispose of this increased output, this would embody financial advantages, these again are comparatively light.

Charges for Materials, power and credits will now be doubled and are	£281,120
Management	10,000
Labour, now $\sqrt{2}$ times that of original plant	79,000
	£370,120.

A plant of similar capacity ($10,5 \times 10^{12}$ B.T.U. per year) but producing 500 B.T.U. gas, would cost (see Fig. 1) £2,250,000 and would produce gas at a cost of 18d. per million cub. ft. Consequently, in the case considered here, the total operating costs should not exceed

$10.5 \times 18 \times \frac{1}{240} \times 10^6$ = £790,000, therefore the amount for Capital Charges becomes £419,880 which is equivalent to a capital of £2,400,000.

It has to be observed that the assumption as to labour requirements are not very well substantiated and might be less severe than those used here.

Also, for transmission purposes, a high calorific value is of great advantage, but here again, the savings are smaller than they appear at first sight.

Generally/................

Generally speaking, this points to the conclusion that a high heating value is desirable, but can only be justified if plant and operating costs are not unduly increased.

The same will be found to apply to the effect of the calorific value on the cost of transmission, storage and final distribution. In each of these instances, a saving will be obtained if the heating values is increased, but relative to the manufacturing cost, the amount is small, and the same applies to the total savings, which although not negligable, are by no means large.

2.0 TRANSMISSION OF GAS

Under South African conditions, gas would not be produced near the centres of consumption and a pipeline will be necessary to convey the gas.

The following data illustrate American practice and give an idea of the pressures and quantities involved.

Small quantities are transmitted at high pressure, 900 - 1200 lbs/sq.in.

Medium quantities are transmitted at medium pressure, 300 - 500 lbs/sq.in.

Extremely large quantities are transmitted at low pressure, 100 - 150 lbs/sq.in.

A daily transmission of 500 million cub. ft. per day is a common occurrence, some companies send out twice this amount.

The Lurgi/............

The Lurgi process makes the gas available at approx. 20 atom., and the Rend could be easily free from the Witbank or Vereeniging area without further compression.

Modern practice favours fairly high distribution pressures, especially for industrial distribution (in the region of 50 lbs/sq.in). For domestic purposes, which are hardly considered here, low pressures are more favourable.

In the following paragraphs, cost of transmission for an 80 mile and a 200 mile pipe line will be calculated.

2.1 80 MILE PIPELINE

Various formulae are in use for the calculation of the required pipe diameter. Theoretically, all have to be of the form

$$\frac{P1^2 - P2^2}{P2^2} = \left[Af \frac{V2\ W}{D^5} \pm \frac{h}{L} \right] \frac{2\ L}{P2V2}$$

wherein P1 = send out pressure.
P2 = terminal pressure.
A = a constant, depending on units used.
f = coefficient of friction
V2 = specific volume at pressure P2
W = weight conveyed per hour.
h = difference in altitude at ends of line.
L = length of pipe line.
D = diameter of line.

f is not a constant, but depends on the operating conditions and the diameter, and is included in the somewhat simpler formulae, proposed by Weymouth:

$$Q = 18.062 \frac{To}{po} \left[\frac{(P1^2 - P2^2)\ D^{16/3}}{G.T.L.} \right]^{\frac{1}{2}}$$

which has been extensively tested and found sufficiently accurate for estimating purposes

wherein/..........

wherein

Q = cubic feet transported hourly (Temperature To and pressure po)[x])
G = specific gravity (air = 1)
T = absolute temperature °F
$P1, P2$ = as above, in lbs/sq.in.
L = Length, miles.
D = diameter, inches.

In the case under consideration, L = 80 miles, send out pressure 300 lbs/sq.in., terminal pressure 70 lbs/sq.in. The specific grqvity will depend on the gas composition. As the gas contains mainly hydrogen, methane and carbon monoxyde, it will be considerably lighter than air, a value of 0.45 has been assumed here. Inserting these values, the formula reduces to

$$D^{8/3} = 790\ (Q \times 10^{-6}) \text{ inches, for } L = 80 \text{ miles and}$$

to

$$D^{8/3} = 88.5\sqrt{L}\ (Q \times 10^{-6}) \text{ for } L \text{ arbitrary.}$$

This gives the results tabulated hereunder

TABLE NO. 4.

Pipe Sizes Required for 500 B.T.U. Gas.

x 10^6 B.T.U./Amm.	x 10^6 Cub. ft/hour.	x 10^6 Cub. ft/hour.	Diameter Ins.
1.75×10^5	1	0.0415	3.7"
5.25×10^5	3	0.125	5.6"
8.75×10^5	5	0.208	6.75"
1.75×10^6	10	0.415	8.7"
5.25×10^6	30	1.25	13.3"
1.75×10^6	100	4.15	20.8"

(Calorific Value : 500 B.T.U./cub.ft).

For a 1000/............

---

[x]) As $\frac{Q\,po}{To}$ is constant, any consistent set of conditions may be used here.

For a 1000 B.T.U. Gas)* volumes would be halved with the following results:-

TABLE No. 5.
Pipe Sizes required for 1000 B.T.U. Gas.

B.T.U./Min $\times 10^6$	Cub. ft./hour. $\times 10^6$	Diameter inches.
1.75×10^5	.021	2.86
5.25×10^5	.063	4.3
8.75×10^5	.104	5.25
1.75×10^6	.208	6.75
5.25×10^6	.625	10.0
1.75×10^6	2.075	16.1

2.2 COST OF TRANSPORTATION

Quass (R5) gives the following figures for pipe line costs in the United States:-

Pipes up to 10", laid including wrapping, ditching welding and all other operations required : \$ 1600 per inch diameter, per mile.

12"	\$ 21.000 per mile.
16"	\$ 28.800 " "
20"	\$ 37.000 " "

The only figure available for South African conditions gave £2.10. per foot for an 18" pipe, completely installed. (about £14,000 per mile), which is considerably higher. As long piperuns of this description are practically unknown in the Union, it may be possible to reduce the cost somewhat by using American methods, so the figures quoted above have been used with an upward adjustment of $33\frac{1}{3}\%$

Figure 3 illustrates pipe line costs for various diameter per hundred miles.

Operating costs/.........

)* This would presumably be mainly methane, the difference in specific gravity as compared with 500 B.T.U. gas is neglected.

Operating costs are given as follows (R5).

Diameter	Operating costs per 100 miles.
8"	$ 12.000 per year.
12"	20.000 "
16"	26,000 "
20"	35,000 "

and can be proportionally increased or decreased for other lengths. They include maintenance (45%), repairing of leaks and patrolling.

It might be assumed that for quite small pipe diameter, operating costs will depend on the length of the pipeline only (i.e. the cost of handling and repairing a 4" pipe should not differ materially from that for a 3½" pipe) and for all sizes under 8" a cost of £2500 per 100 miles p.a. has been assumed. (See Fig. 3.)

Capital Charges have been taken as 8% of capital cost. For the installation discussed in paragraph 2.1, table 4, this gives the following results (fractional pipe sizes are adjusted to the nearest whole number).

TABLE No. 6

Transmission Costs for 500 B.T.U. Gas.

B.T.U/Year x 10^6	Pipe Size Inches.	Capital Cost £	Operating Charges £/Year.	Transp. cost per million B.T.U.
1.75 x 10^5	4"	170.400	15.632	21.4d.
5.25 x 10^5	6"	256.000	22.480	10.2
8.75 x 10^5	7"	300.000	26.000	7.1
1.75 x 10^6	9	384.000	33.000	4.5
5.25 x 10^6	13"	620.000	53.300	2.45
17.5 x 10^6	21"	1.030.000	90.000	1.23

The cost of the gas, delivered at the terminal is therefore as follows:- (500 B.T.U/c.ft. gas).

TABLE No. 7.

Terminal Costs for 500 B.T.U Gas.

Plant Capacity. Cu. Ft. per day x 10^6	B.T.U. per year x 10^6	Cost of Gas. pence per million B.T.U.
1	1.75×10^5	89.0
3	5.25×10^5	52.7
5	8.75×10^5	42.4
10	1.75×10^6	32.8
30	5.25×10^6	23.25
100	17.5×10^6	17.33

For comparison, the pipe line and transportation costs for 1000 B.T.U. gas are tabulated hereunder:-

TABLE No. 8

Transmission Costs for 1000 B.T.U. Gas.

B.T.U. per year x 10^6	Pipe Size Inches.	Capital Cost £	Operating Charges £/ Year.	Transp. Cost per million B.T.U.
1.75×10^5	3	128.000	12.240	16.8
5.25×10^5	4	170.400	15.632	7.1
8.75×10^5	5	213.000	19.088	5.25
1.75×10^6	7	300.000	26.000	3.6
5.25×10^6	10	424.000	37.120	1.7
1.75×10^6	16	768.000	66.640	.9

Comparing these figures with the corresponding transmission costs for 500 B.T.U. gas (Table 7 of this paragraph) it is seen that a saving of approx. 25% on transmission cost is obtained, but the reduction in total cost is not very significant. For instance, assuming that the production cost for 1000 B.T.U. gas would be the same as for 500 B.T.U. gas, the reduction of the terminal cost price for the smallest plant would be 4.6d (on 89.7d, or 5%), and for the largest plant considered .33d. (on

18.03d./.............

18.03d. or under 2%).

According to these calculations, transmission costs by pipe line are quite small for medium to large quantities. In par. 3.7 a comparison with other means of transport is made.

2.3 200 MILE PIPELINE

The calculations will now be repeated for a 200 mile pipeline, where additional compression of the gas has to be considered.

In the United States, long pipelines are usually operated by compressor stztions, spaced 80 to 100 miles apart the most usual compression ratio being 1.5 : 1 or 2 : 1.

As the compression ratio is increased, work of compression and consequently compressor size and operating charges increase, but the pipe line can be made to a smaller diameter, with a resultant reduction in Capital and operating charges. Usually, there will be an optimum compression ratio, for which the total of compressor and pipeline charges is a minimum.

The conditions are investigated hereunder for plant sizes of 1, 10, 30 and 100 million cub,ft. daily capacity, producing 500 B.T.U/Cub. ft. gas, denoted as plants A, B, C and D.

2.4 COMPRESSOR SIZES

For isothermal compression, the work of compression is given by $A = 144 (poVo) \ln r$, ft.lbs wherein

po = /....................

p_o = pressure in lbs/ sq. in r = compression ratio

V_o = volume compressed in cub. ft.

10^6 cub. ft. per day equals $\frac{10^6}{60\times24}$ cub. ft/min.

1 HP = 33,000 ft. lb/min.

For the lower compression ratio, a single stage compressor would be used, the higher ratio requiring a two stage compressor. In neither case would compression be isothermal, so an allowance of 30% is made for the calculations of compressor horsepower, which is found from

$$HP = \frac{144\ (p_oV_o)\ \ln r \times 1.3}{33.000 \times 1440}$$ or for $V_o = 10^6$ cub. ft./day.

HP = 5.8 ln r per million cub. ft. daily capacity.

r =	1.5	2	2.5	3	4	5
HP =	23.5	40.5	53	64	80	93.5

As quantities range from 1 to 100 million cub. ft/day, compressor sizes will be from 23.5 to 9350 H.P.

CAPITAL COST OF COMPRESSORS.

For 30 million cub. ft. daily capacity, a price of $ 210 per installed H.P. has been quoted (R5). This figure includes land, buildings, machinery, cooling and auxilary plant and housing for operators. Under South African conditions £80 per H.P. has been estimated for the smallest size, £50 - for the largest and intermediate sizes as indicated in the diagram shown in Fig. 5.

The figures indicated in this diagram can be taken to be valid for moderate working pressures up to 900 lbs/sq.in. In the following calculations, they have been increased by 10% for compressors, supplying gas at 1200 lbs/sq.in, and by 20% for pressures of 1500 lbs/sq.in.

OPERATING COSTS/..........

2.6 OPERATING COSTS OF COMPRESSORS.

Compressors can be either electrically or internal combustion engine driven, the deciding factor being the cost of the gas as compared to electric power.

1 H.P. = 42.5 B.T.U/Min. or 22×10^6 B.T.U/Year.
At 30% efficiency of the I.C. engine, this requires an input of 73.5×10^6 B.T.U./Year.

At 95% efficiency of the electric motor, 1 compressor H.P. would require 23×10^6 B.T.U./Year in electric power.
At a price of .25d/kwh or .25d per 3420 B.T.U., the cost per year for electric operation is

$$\frac{23 \times 10^6}{3420} \times .25 = 1680\text{d.} \quad (\text{£}7).$$

Consequently, as a gas cost of p pence per million B.T.U., electric operation is cheaper where $p > \frac{1680}{73.5} = 23$d., which is the case for the two smaller plants considered here.

Power costs per H.P. year are therefore

Plant	A	£7. 0. 0.
	B	£7. 0. 0.
	C	£6.11. 0.
	D	£5.12. 0.

Wages (for supervision and repairs) repairs and metering expenses are estimated at £4. 0. 0. per H.P. year (R5).

Capital Charges are taken as 8% of Capital Cost.

In the first/...........

In the first case considered, it has been assumed that compressors are installed at the gasworks, and the whole length of the pipeline is served by these compressors, the gas being available at 300 lbs/sq. in., at the generator, the terminal pressure being 70 lbs/sq.in.

Table No. 9 shows the figures obtained.

See Page 26.

2.7 PIPE SIZES REQUIRED

For each plant size, and each compression ratio considered, pipe sizes are calculated, using Weymouths formula, and capital and operating costs determined as in paragraphs 2.1 and 2.2.

These cost figures are however, for normal pipes, having a wall thickness of ¼" to ⅜", depending on the size. In some of the cases considered here, the send out pressure exceeds the safe working pressure of these pipes, so a heavier pipe should be allowed for.

The terminal pressure, p2 has been assumed to be 70 lbs/sq.in, and as L = 200 miles, diameters are found from

$$D^{8/3} = \frac{36500}{\sqrt{p_1^2 - 70^2}} \times \frac{Q_2}{24}, \text{ wherein}$$

Q = million cub. ft. conveyed per day.

Table 10 and figure. 6.. show the results obtained. Where diameters are marked X, the working pressure for standard pipes has been exceeded and an allowance in Capital cost and operating charges has been made to cover additional costs of a heavier pipe.

From the table/...........

From the table and the diagram, the following conclusions can be drawn.

1. Small quantities should be transmitted at very high pressures, but the transmission process is expensive.
2. Medium and large quantities should be conveyed at medium to low pressures.
3. Near the optimum point, the curves are fairly straight so operating conditions can be made to fit the nearest standard pipe diameter without adverse effect on the economic operation.

It will be noted that the optimum conditions for plants A and B falls outside the pressure range considered here. For the reason given under (3), it is not worth while to increase the send out pressure. Moreover, compressor costs and for plant B pipe line costs as well, will increase sharply if a pressure of 1500 lbs/sq.in. are exceeded.

Using pipes of standard diameter, the most economical operating conditions would be:-

TABLE No. 11.

Plant.	Daily Capacity. $\times 10^6$ cub. ft.	Pipe Dia. Inches	Operating costs. £/ annum	Costs per 10^6 B.T.U. pence.
A	1	2½"	29,000	39.8
B	10	6"	71,000	9.7
C	30	10"	126,000	5.75
D	100	18"	260,000	3.6

As the production/......

As the production cost at the plant per million B.T.U. was resp. for A,B,C and D

68.3 29.0 21.5 16.8d.

the cost at the terminal will be

108.1 38.7 27.25 and 20.4d.

2.8 GAS OF HIGHER CALORIFIC VALUE

Conveying a similar amount of heat units in a gas of higher calorific value (say 1000 B.T.U./Cub.ft.), would give the following savings:-

1. The work of compression is reduced by 50%, as the volume to be transported is reduced by this amount.
2. The pipe diameter will be reduced to 77% of the value required before (as according to Weymouth's formula $\frac{D1}{D2} = \left(\frac{Q1}{Q2}\right)^{3/8}$

It is assumed that the same send-out pressure is used. For plant C a pipe diameter of .77 x 10.2" = 7.85" (see **Fig. 3.**) would now be adequate i.e. an 8" pipe could be used, and this reduces the pipe cost to £74,800 p.a. The compressor charges can be taken as £15,000 p.a. the total charges say £90.000, as compared with £123,500 for 500 B.T.U. gas, or 72% of the former amount. The transport cost per million B.T.U. thus becomes 4.0d.

For plant C, the pipe diameter would be .77 x 20.9" = 16", requiring £163,000 p.a. With £17,000 for compressor charges, the total transport charges are £180,000, or

68% of the original amount, reducing the transportation cost per million B?T.U. to 2.45d.

If the 1000 B.T.U. gas could be manufactured at the same cost (per heat unit) as the 500 B.T.U. gas, the prices at the terminal would be:-

500 B.T.U. gas	Plant C	27.1d.
	D	20.4d.
1000 B.T.U. Gas	Plant C	25.5d.
	D	19.25d.

or a saving of approx. 6% in both cases.

Although appreciable, this amount is not very large and demonstrates again that the production of a gas of high calorific value is only justified if this can be achieved at about the same cost as that for gas of medium heating value.

2.9 Under actual conditions, compressor stations would not be more than approximately 100 miles apart. It can be shown that operation would be at slightly lower cost than under the conditions assumed here (paragraph 2.7) but as the savings amount to a few percent only, the calculation is not included in this report.

3.1 EFFECT OF VARIABLE LOAD

In practice, the gas requirements of the consuming area will vary, and for satisfactory operation, the maximum demand must always be met. In consequence, the plant will operate at fractional load for most of the time.

If the load/.............

If the load factor F is defined as

$$\frac{\text{Units sent out per year}}{\text{Maximum possible production in one year}},$$

it is evident that all fixed charges (per heat unit) will be increased in the ratio $^1/_F$, and as these fixed charges form the major part of the cost, the price per unit will increase considerably when the plant operates at fractional load for any length of time.

The load factor depends on two others viz, the daily and the seasonal variation in the load curve. If the industrial load is far in excess of the domestic load, which has been assumed to be the case in the Union, so that little gas is used for space heating, the daily variation is the most important one.

Apart from special tariffs, penalising a fluctuating demand, the following technical measures can be taken to smooth the peak in the demand on the producing side:-

1. Temporary enrichment of the gas in the areas of high momentary demand.
2. Local peak load stations.
3. Storage in the consuming area.

The first alternative could not very well be used in the Union, as it requires large supplies of propane or butane. It is used, however, in the United states to meet the winter heating demand.

The second/............

The second alternative would require relatively small generating stations, which on account of their size and the more expensive fuel, could not operate economically.

Storage, however, can be effected at a reasonable cost.

3.2 STORAGE

The gas could be stored either at low pressure (only a few inches water column above that of the atmosphere) or at medium pressure (35 - 70 lbs/sq.in).

For industrial uses, the latter system is to be preferred, for although the cost of the storage cylinders is higher than that of low pressure holders, the distribution costs are lower, and furthermore, it is of some advantage to have the gas available at a fair pressure.

Overseas practice is to supply storage for 30% - 70% of the average demand, say 50% for a mainly domestic load, 40% for industrial load. In addition, the maximum plant output should exceed the average demand by at least 30%.

Communication No. 259 of the Institution of Gas Engineers gives some figures for holder costs (page 35), which, however, are based on price ruling in 1938. If an increase of 33.3% is allowed to bring these prices up to date, they are found to agree with recent American figures (R.6).

As the load will probably be spread over a considerable area, costs have been calculated for units, having an average consumption of 5 million cub. ft per day.

The storage/...........

The storage requirements would then be $.40 \times 5 \times 10^6 = 2 \times 10^6$ cub. ft., which could be erected at a cost of approx. £70,000.

Assuming 7% for all charges, the annual cost would be £4,900. During this period 8.8×10^{11} B.T.U's will have been supplied to the area, consequently cost per million B.T.U's $\frac{4900 \times 240}{8.8 \times 10^5} = 1.3$d.

High pressure storage would require a number of cylinders, say 25 ft diameter by 125 ft. length, at a cost of £12,000 each, and a volume of 61,000 cub. ft.

If a pressure fluctuation from 70 lbs/sq.in to 35 lbs/sq.in is allowed, each cylinder will be able to store $\frac{70 - 35}{14.7} \times 61,000 = 146,000$ cub. ft. of gas at a normal pressure of 14.7 lbs/sq.in.

The total number required would be $\frac{2,000,000}{146,000} = 14$ approx. which would require a capital expenditure of £168,000. As maintenance is less than for a low pressure holder, 6% has been allowed for all charges, or £10,000 p.a. or

$$\frac{10,000 \times 240}{8.8 \times 10^5} = 2.7\text{d per million B.T.U.}$$

In addition to these costs, the cost of production at the works will have to be corrected as the load factor will be less than unity.

Making $F = .70$, to allow for abnormal demand, and slight seasonal variations, all fixed charges will have to be increased by $\frac{1}{.70}$, or 1.4 or 40% increase.

As the final/............

As the fixed charges amount to roughly 60% of the cost of production (see paragraph 2.4 and 2.5) the overall increase in product cost is 60 x .40 = .24 or 24%. Strictly speaking, this figure should be determined for every plant size, but it will be considered as applicable to every plant considered hereunder.

3.3 SUNDRY COSTS

If the gas supply should be undertaken by a public utility corporation, it is likely that from the holder on, the distribution would be undertaken by some local authority.

In order to determine the bulk price, two further charges should be made, viz.

1. Reserve Fund, say 5% of unit cost.
2. Head Office expenses say 2.5% of unit cost.

3.4 BULK SUPPLY COST

The bulk cost of the gas can now be computed as indicated in table No. 12.

TABLE No. 12.

Bulk Cost of 500 B.T.U. Gas.

	PLANT SIZE. Million Cub. Feet per Day.		
	10	30	100
1. Product Cost	28.3	20.8	16.1
2. 24% added	7.0	5.2	4.0
3. Transmission Cost	4.5	2.5	1.2
4. Storage Cost	2.7	2.7	2.7
5. Sub Total	42.5	31.3	24.0
6. Reserve Fund & Head Office, 75%	3.3	1.4	1.1
7. Total	45.8	32.7	25.1

All prices/...........

All prices are pence per million B.T.U's.

1. Product Cost at Works.
2. Extra to account for load factor.
3. Transmission Cost for an 80 mile pipe line.
4. Storage Cost for High pressure Storage.

3.5 FINAL COST

The final cost to the customer will depend on the type and size of load, and will be effected to a very large extent by the cost of the final distribution (from holder to user).

It is almost impossible to determine at this stage what the distribution cost would be.

For domestic uses, requiring gas at low pressure, the distribution cost is quite high, and could easily amount to 12d. per million B.T.U's.

Industrial users could, in all likelihood, be supplied at higher pressures, at a far lower cost.

For the 30 million cubic feet plant, the final cost would therefore probably be between 38d. and 48d. per million B.T.U's.

3.6 COMPARISON WITH OTHER FUELS

The prices of other fuels in the Johannesburg area are approximately as follows:-

Type of Fuel.	Cost per.	£.s.d.	Cost per million B.T.U.
1.Coal	Ton	1. 2. 6.	13.5d.
2.Fuel Oil	Gallon	1. 0.	72
3.Diesel Oil	"	1. 1.	78
4.Coal Gas	1000 cu.ft.	4. 0.	100
5.Electric Power	kWh	.375 -.50d.	112.5 - 150.

1. Retail price for small quantities, cal.val.10.000 B.T.U/lb.

For bulk/............

For bulk supplies, the above prices will be lower.

On a cost per B.T.U basis only, coal is by far the cheapest fuel, and certainly will be the most economical where large quantities of heat are required, but other considerations may offset this advantage to a very large extent, the most glaring example being the open coal fire, which at some 5% efficiency is more expensive than a gasheater, operating at an efficiency of 80%. As a heating load will probably be of very doubtful value to the gas industry (as it would accentuate the seasonal variation in load) it will be better not to stress this point too much.

A second fact emerging from the above schedule of prices is that gas, at say 60d. per million B.T.U. would be a good second in the list, and as it is at least as convenient to handle as the other fuels, it would be able to replace them, except where considerations of portability or special uses (steel making and some furnaces where a very hot flame is required) have to be considered.

Gas at this price could be produced by a plant of 10 million cub. ft. daily capacity and considering that gas of 100d. per million B.T.U. sells up to the capacity of the plant (± 4 million cub. ft. per day) it seems very likely that 2½ times this quantity, if offered at 60% of the present price, could be absorbed in Johannesburg only. For the same reason, the economic possibility of a plant of 30 million cub. ft. daily capacity, serving the Southern Transvaal, and producing gas at a still lower price, can not be entirely dismissed.

The following/............

The following example, which admittedly is a favourable case for gas, will show that the disparity in overall costs for a coal and a gas fired installation is far less than the respective fuel costs seem to indicate.

Consider a small boiler installation supplying 2000 lbs of steam per hour, for 8 hours per day. Fuel: coal of 10,000 B.T.U per lb, price 22/6 per ton (13.5d. per million B.T.U). Some allowance will have to be made for handling charges, so that the price in the bunkers is assumed to be 23/6d. per ton.

Unless attention is given to the boiler over night, the fire will have to be drawn every night and relighted each morning. Under these conditions, a steam production of 5 lbs of steam per lb of coal will hardly be exceeded.

The annual fuel requirements are

$$\frac{2000}{5} \times \underline{360} \times \underline{8} \times \frac{1}{2000} = 575 \text{ tons/year,}$$

resulting in a fuel cost of £675.

Wages, insurance and other allowances for a native stoker would require about £150 p.a.

At 10% ash, 58 tons must be disposed of, cost say £15 p.a.

The total operating costs, for coal firing are consequently £840 per annum.

When gas fired, 2000 x 1000 B.T.U./h are required to produce the steam, which at 80% efficiency, requires an input of 2.5×10^6 B.T.U./h, or $360 \times 8 \times 2.5 \times 10^6 =$

$7,200 \times 10^6$ B.T.U. p.a.

Allowing an additional 5% for heating up in the morning, the total requirements are $7,340 \times 10^6$ B.T.U. p.a.
At 28d. per 10^6 B.T.U., or more than twice the B.T.U. cost of coal, the operating costs of coal and gas would balance.

At 38d./.....

At 38d. per 10^6 B.T.U., the gas cost would be about £306 more than the cost using coal as fuel.

Nevertheless, the smaller space requirements (no bunkers, less floor space in the boiler room) considerations of cleanliness and ease of operation, and absence of smoke would, on many occasions sway the balance in favour of gas.

LITERATURE REFERENCES:

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R3. C.R. Downs and J.H. Rushton, "Tonnage Oxygen." Chemical Engineering Progress, Jan. 1947, Vol. 1 No.1, p.12.

R4. Danulat. "Gazeification Sous Pression." (Photostatic copy only available at the Institute, date and name of periodical from which reprinted are unknown).

R5. F.W.Quass. "The Production and Transmission of Manufactured Gas." Report No.9 of the S.A. Scientific Liason Officer (in Washington).

R6. T.L. Robey (American Gas Association) Private Communication.

APPENDIX:

A1. In S.A.S.L.O. report No.9, Quass quotes a summary, compiled by F.V. Parry, of several gasification processes, from which the following data are extracted:

Process.	Oxygen. Cub. ft. per ton of fuel.
Lurgi	3120
Winkler	10,350 - 18,400
Slagging Producer	18,900

A2. This figure (5/- per ton) depends on a number of circumstances, which can not be analysed at this stage. If the colliery were owned by the gas producing organisation, it might be possible to make coal available at a lower figure.

The following figures (obtained from the 25th annual report of the Electricity Supply Commission) give some indication of the cost:

Power Station.	Cost per ton.	
	1946.	1947.
Witbank	2/9	3/4
Klip	4/4	4/5
Vaal	6/-	5/7

A3. The steam cost of 1/6 per ton is a rough estimate only.

A4. According to the 25th report of the E.S.C., average prices per unit sold are as follows:

Witbank	.1770.
Klip	.1133.
Vaal	.1654.

LITERATURE REFERENCES:/..

TABLE NO. 9.

Plant.	Cub.Ft. per day x106.	Compr. Ratio.	Send Out Pressure lbs/sq.in.	H.P.	Capital Cost £.	Capital Charges 8% p.a. £.	Operating Charges £.	Fuel or Power £.	Total Charges £.	No.
A	1	1.5	450	23.5	1880	150	94	164	408	A2
		2	600	40.5	3240	259	162	285	706	A3
		2.5	750	53	4240	339	212	371	922	A4
		3	900	64	5120	410	256	448	1,114	A5
		4	1200	80	7040	563	320	560	1,493	A6
		5	1500	93.5	8980	718	374	655	1,747	A7
B	10	1.5	450	235	18,000	1,440	940	1,640	4,020	B2
		2	600	405	29,000	2,320	1620	2,850	6,790	B3
		2.5	750	530	37,000	2,960	2120	3,710	8,790	B4
		3	900	640	44,000	3,520	2560	4,480	10,560	B5
		4	1200	800	58,300	4,664	3200	5,600	13,464	B6
		5	1500	935	72,000	5,760	3740	6,550	16,050	B7
C	30	1.5	450	705	48,000	3,840	2820	4,600	11,260	C2
		2	600	1215	78,000	6,240	4860	8,000	19,100	C3
		2.5	750	1590	97,000	7,760	6360	10,400	24,520	C4
		3	900	1920	115,000	9,200	7680	12,600	29,480	C5
		4	1200	2400	154,000	12,320	9600	15,700	38,620	C6
		5	1500	2805	192,000	15,360	11220	18,400	44,980	C7
D	100	1.5	450	2350	140,000	11,200	9400	13,100	33,700	D2
		2	600	4050	220,000	17,600	16200	22,600	56,400	D3
		2.5	750	5300	280,000	22,400	21200	29,500	73,100	D4
		3	900	6400	335,000	26,800	25600	35,800	88,200	D5
		4	1200	8000	451,000	36,080	32000	44,600	112,680	D6
		5	1500	9350	561,600	44,930	37400	52,200	134,530	D7

TABLE NO. 10.

TRANSMISSION COSTS FOR 200 MILE PIPE LINE.

Plant.	Send Out Pressure lbs/sq.in.	Capacity Millions Cub.ft./day.	Diameter Inches.	Capital Cost £.	Capital Charges £/Annum.	Operating Charges £/Annum.	Total Charges Pipe Line £/Annum.	Compressor Charges £/Annum.	Total Charges £/Annnm.	No.
A	300	1	4.35	480,000	38,400	5,000	43,400	-	43,400	A1
	450		3.76	420,000	33,600	5,000	38,600	408	39,008	A2
	600		3.36	380,000	30,400	5,000	35,400	706	36,106	A3
	750		3.1	340,000	27,200	5,000	32,200	922	33,122	A4
	900		2.9	320,000	25,600	5,000	30,600	1,114	31,714	A5
	1200		2.6	290,000	23,200	5,000	28,200	1,493	29,693	A6
	1500		2.4	270,000	21,600	5,000	26,600	1,747	28,347	A7
B	300	10	10.5	1,080,000	86,400	9,000	95,400	-	95,400	B1
	450		8.9	960,000	76,800	7,000	83,800	4,020	88,000	B2
	600		7.95	860,000	68,800	6,000	74,800	6,790	81,590	B3
	750		7.3	790,000	63,200	5,000	68,200	8,790	76,990	B4
	900		7.06	760,000	60,800	5,000	65,800	10,560	76,360	B5
	1200		6.15	660,000	52,800	5,000	57,800	13,464	71,264	B6
	1500		5.6	560,000	44,800	5,000	49,800	16,050	65,870	B7
C	300	30	15.8	1,890,000	151,200	14,000	165,200	-	165,200	C1
	450		13.5	1,560,000	124,800	12,000	136,800	11,260	148,060	C2
	600		11.8	1,330,000	106,400	10,000	116,400	19,100	135,500	C3
	750		11.0	1,220,000	97,600	9,000	106,600	24,520	131,120	C4
	900		10.2	1,100,000	88,000	8,300	96,300	29,480	125,780	C5
	1200		9.25x	1,100,000	88,000	8,000	96,000	38,620	134,620	C6
	1500		8.5x	1,100,000	88,000	7,500	95,500	44,980	140,480	C7
D	300	100	25.0	3,360,000	268,800	22,500	291,300	-	291,300	D1
	450		20.9	2,620,000	209,600	19,000	228,600	33,700	262,300	D2
	600		19.0	2,340,000	187,200	17,000	204,200	56,400	260,600	D3
	750		17.35	2,120,000	169,600	15,000	185,100	73,100	258,200	D4
	900		16.6x	2,200,000	176,000	15,500	191,500	88,200	279,700	D5
	1200		14.4x	2,100,000	168,000	14,500	182,500	112,680	294,180	D6
	1500		13.15x	1,810,000	144,800	13,500	158,300	134,530	292,830	D7

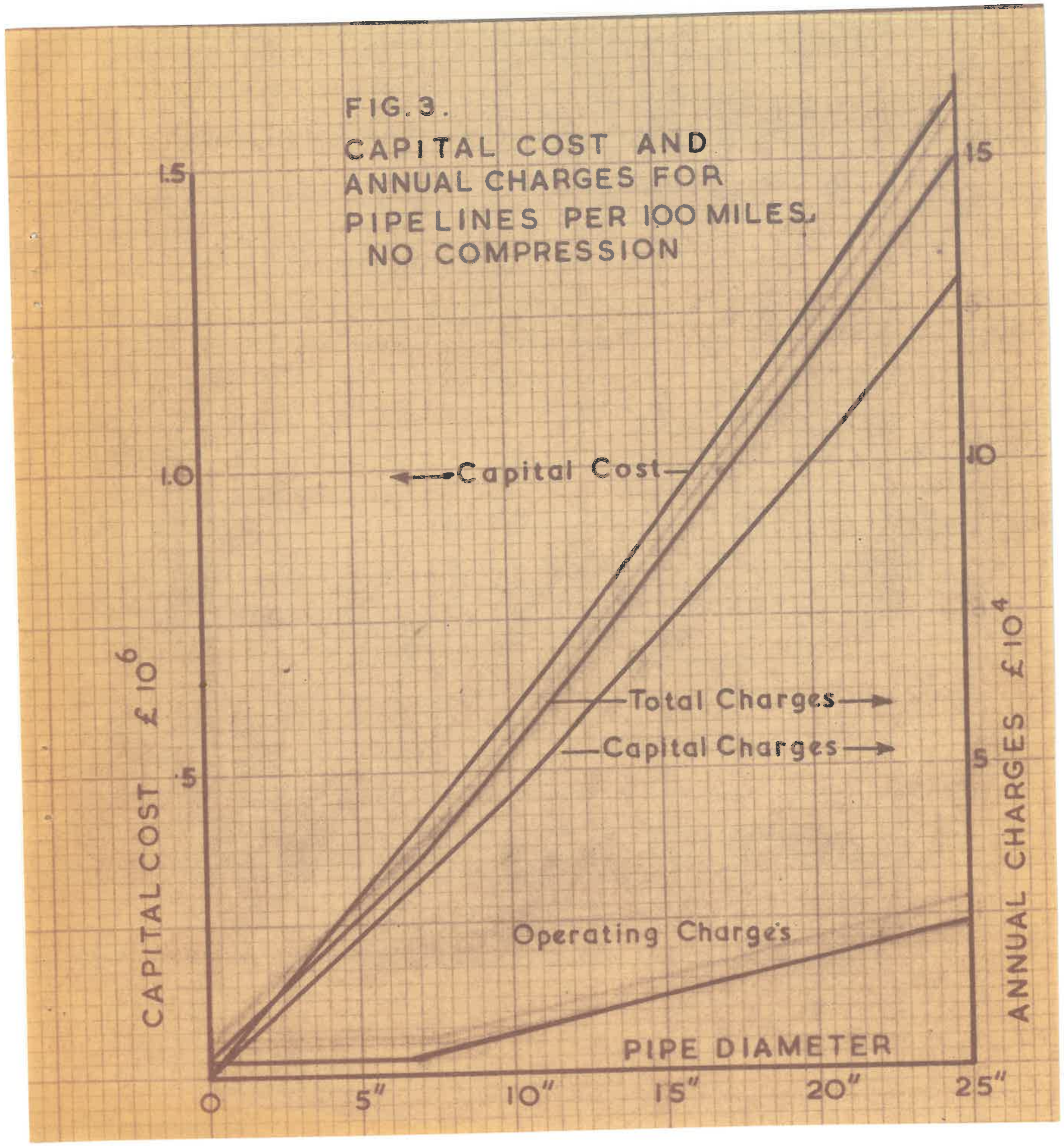
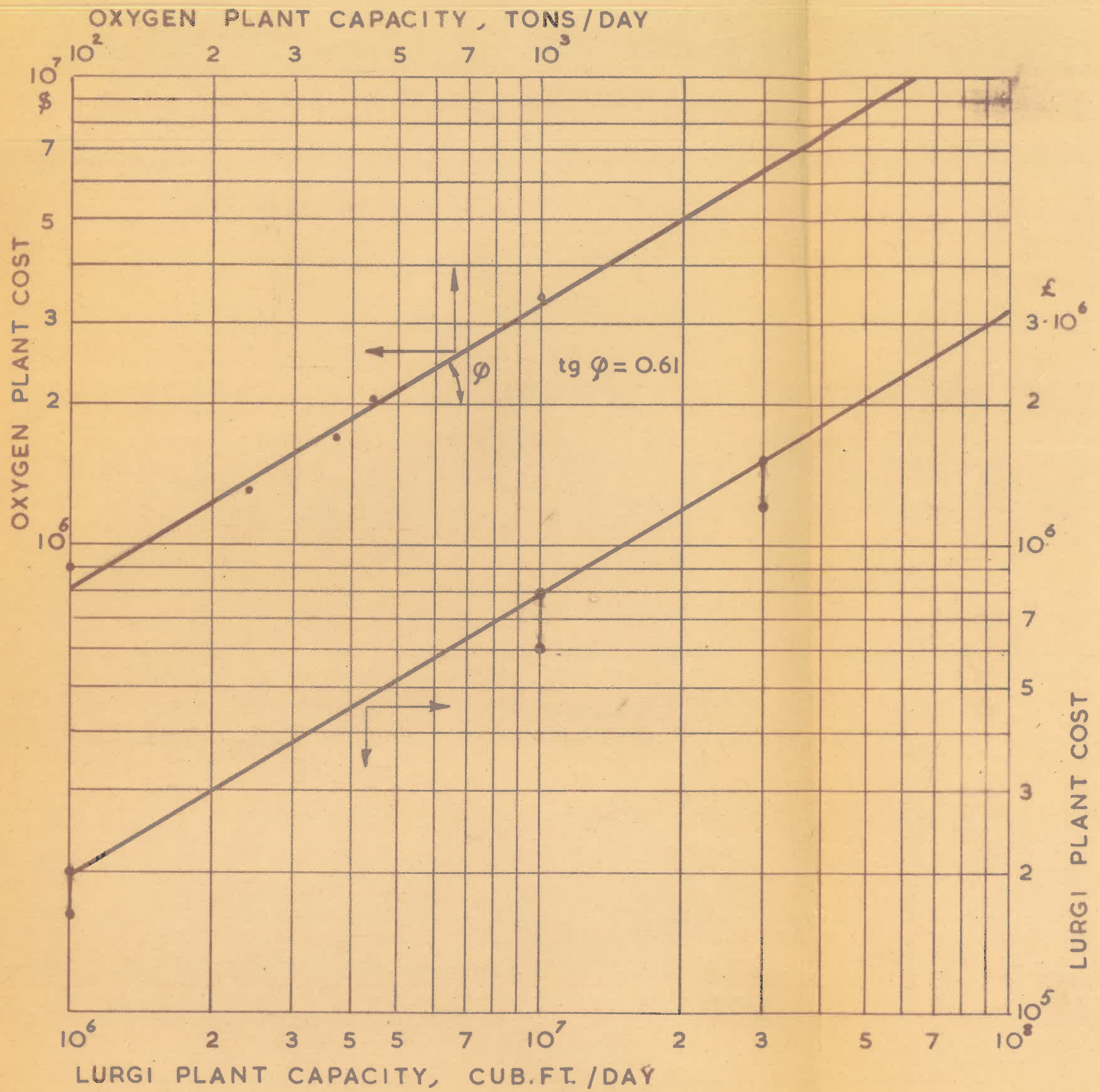


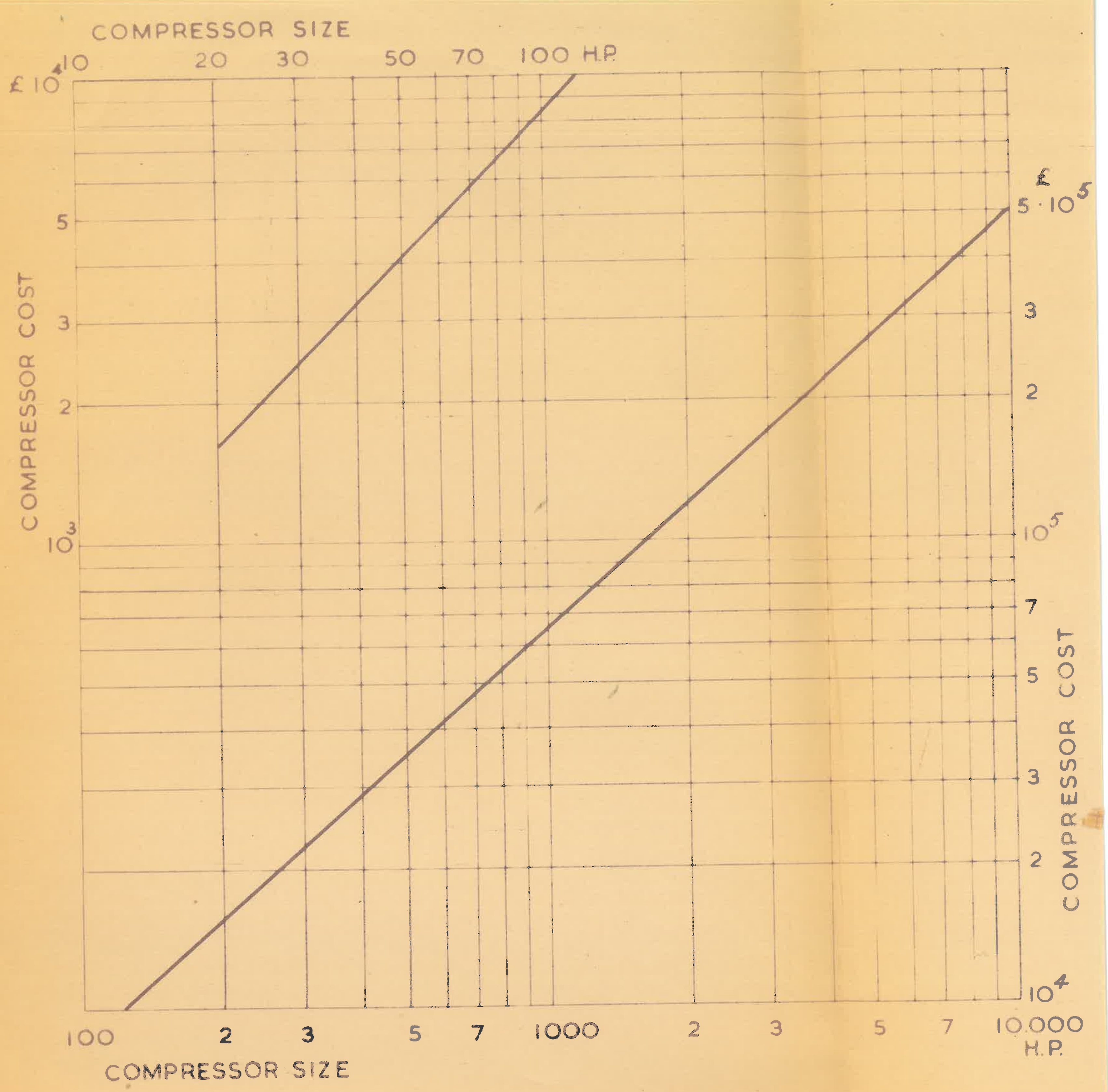
FIG. 3.
CAPITAL COST AND
ANNUAL CHARGES FOR
PIPELINES PER 100 MILES,
NO COMPRESSION

FIG. 1.



CAPITAL COST OF LURGI PLANT.

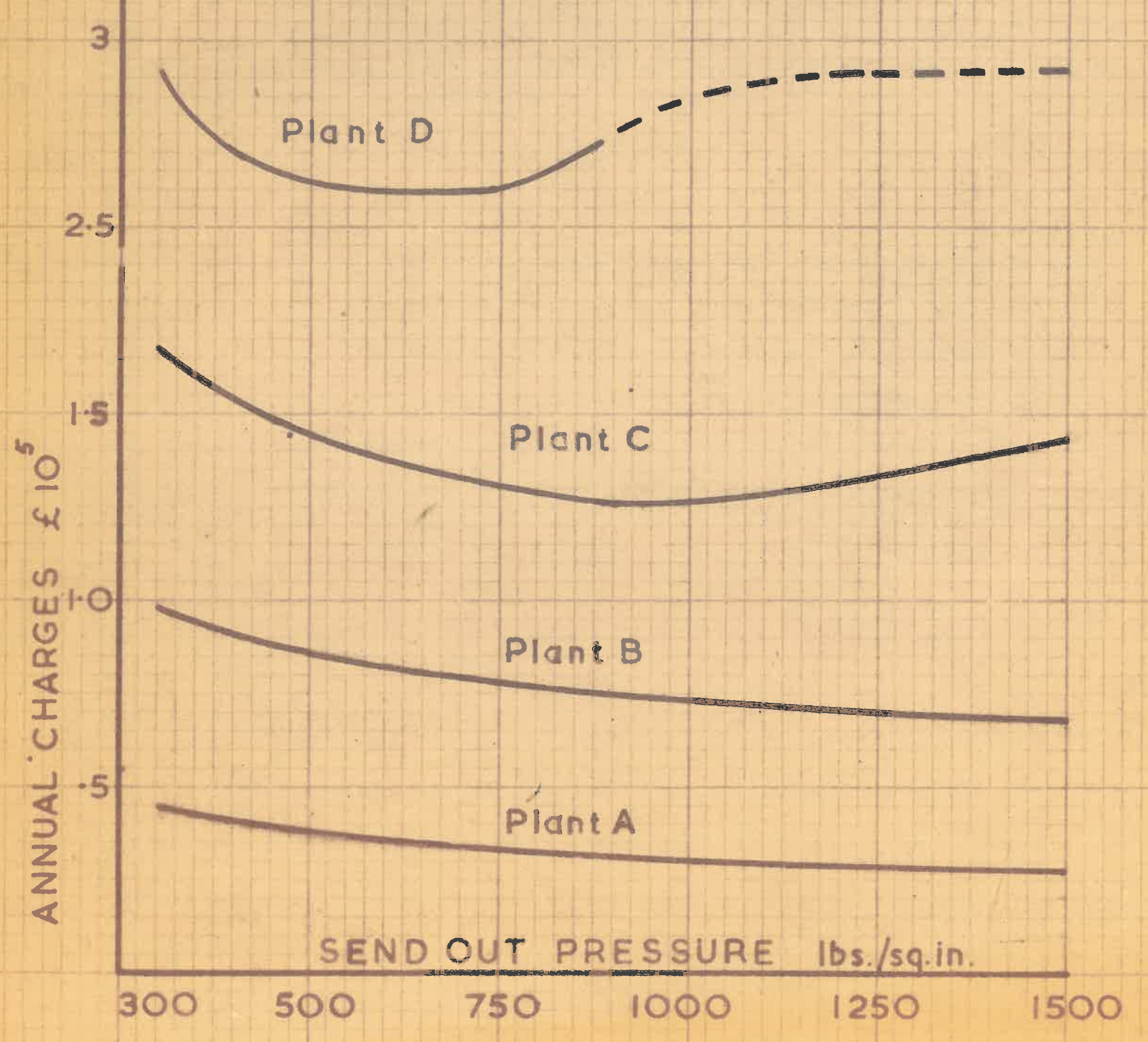
FIG. 5.



CAPITAL COST OF COMPRESSORS.

FIG.6.

ANNUAL OPERATING CHARGES FOR 200 MILE PIPELINES.



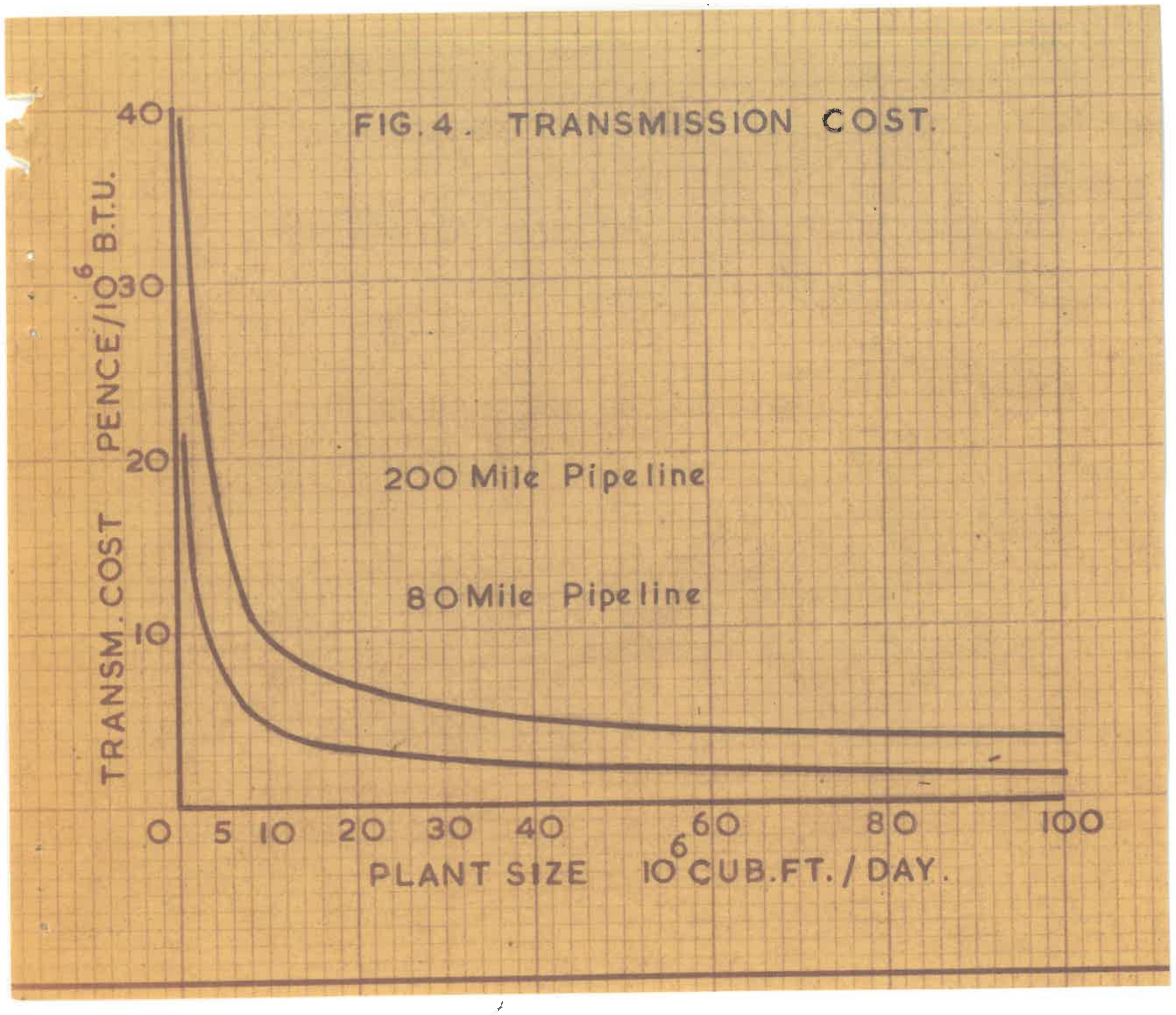


FIG. 4. TRANSMISSION COST.

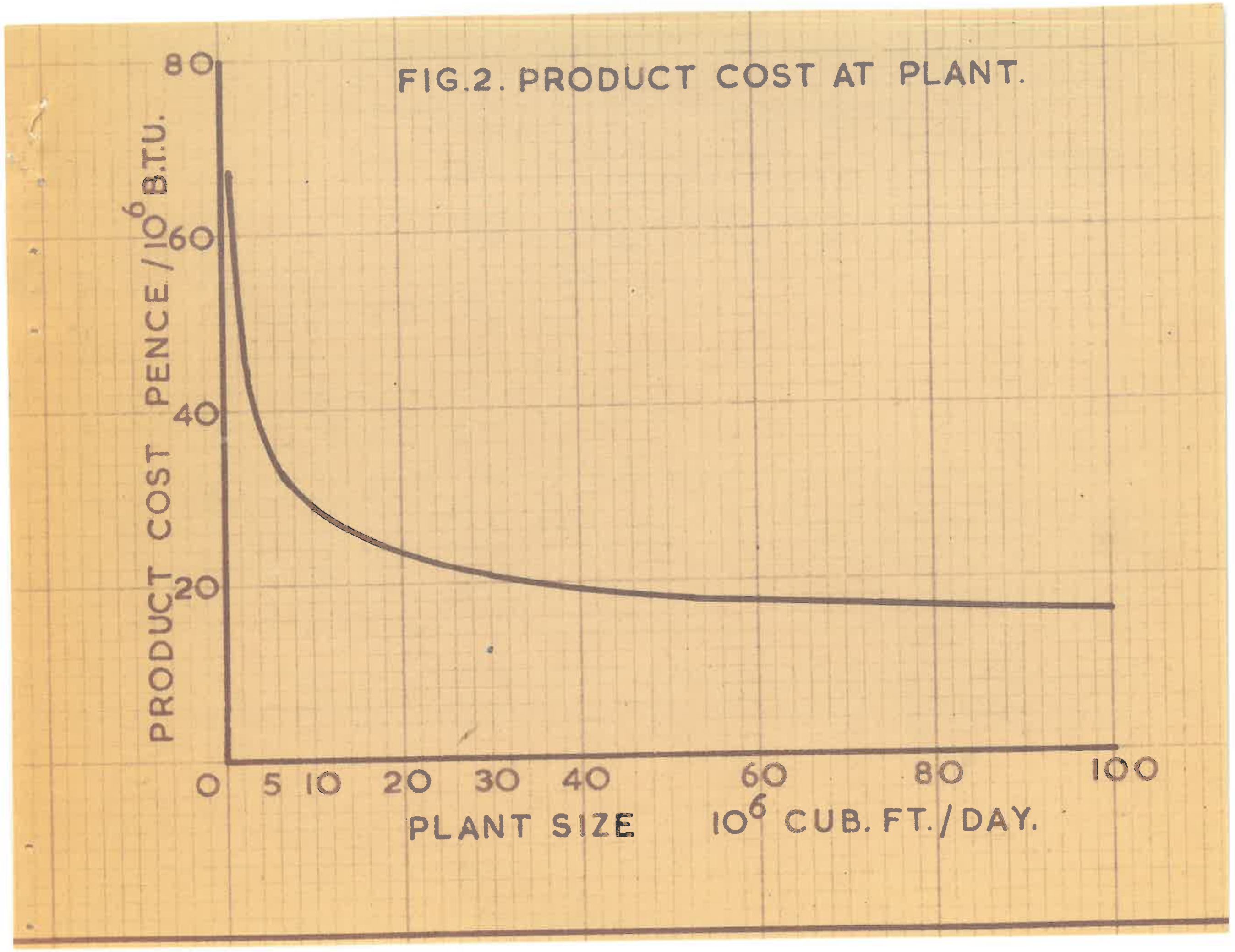


FIG.2. PRODUCT COST AT PLANT.