Unaccounted for gas losses with changing manufacturing processes

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UNACCOUNTED FOR GAS LOSSES WITH CHANGING MANUFACTURING PROCESSES

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by

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Submitted,
Sydney, June 1969

DECLARATION

The Candidate, Theo Gough Phillips, hereby declares that none of the work submitted in this thesis has been submitted to any other University or Institute for a higher degree.

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SUMMARY

Unaccounted for gas is the difference between the gas made and that sold and used on the Works. Meters registering the make and usage of gas on Works are in general accurate and not affected by a change from coal gas.

The accuracy of registration of individual consumers' meters varies considerably. In any one town with the substitution of tempered liquefied petroleum gas for coal gas meters in the average tend to run faster but not enough to appreciably affect the unaccounted for gas. Similar results would be anticipated with the substitution of other gases.

Above ground leakage from wet holders and at consumers' meter installations can be readily detected and remedied and does not present any problem.

Below ground leakage makes the major contribution to unaccounted for gas. Dehydrated coal gas, reformed, tempered liquefied petroleum and natural gases all have a very low "oil" dewpoint. Roll in rubber ring joints in cast iron mains have adsorbed condensable hydrocarbons from coal gas and as a result have expanded. The distribution of an "oil dry" gas has evaporated these condensable hydrocarbons and the rings have shrunk allowing the joints to leak. Gas conditioning by spraying a suitable oil into the gas re-expands the rubber and seals the joints. The effectiveness of the treatment is determined by measuring the leakage before and after spraying.

In the case of hemp and lead joints, it is the moist hemp which provides the gas tight joint. The substitution of a "water dry" gas will dry out the hemp and the joint will leak.

The quantity of gas sent out from the Works at various pressures can be represented by an equation of the form $S = A + Bh + Ch^2$ where S is the gas sent out, h is the pressure of gas in the main, A is the rate at which gas is being used during the period of the test and B and C are constants for the particular system.

Subtracting the usage gives the equation for the leakage of gas $Q = Bh + Ch^2$.

The leakage of gas appears to follow Darcy's Law. After the rubber ring joints have been sealed the rat e of leakage per unit of pressure is a constant. The overall values of "permeability" of the gas through leaks in the joints and mains and services and the soil was calculated.

While there was no correlation between permeability and types of joint and pipe, there was some correlation with the general soil type in the area in which pipes were laid.

The substitution of T.L.P. gas of higher specific gravity than coal gas increases the pressure drops in the district and necessitates higher pressures being maintained at the Works with consequent higher average pressures and greater leakage. Natural gas with its higher calorific value and the same gravity would enable lower pressures to be carried at the Works. But in order to obtain correct combustion at appliances greater pressures are required at their inlet and unaccounted for gas is increased.

With the substitution of higher calorific value gases the thermal loss would increase in the ratio of the calorific values.

INTRODUCTION

The quantity of gas made in a Gas Works is in excess of that sold. This can be expressed by the equation

Quantity of gas made = quantity of gas sold + quantity used on works + gas lost or transposing

Gas lost = gas made - gas sold - gas used on works.

In general gas is distributed through a heterogenous collection of mains and services varying in size and in the composition of the material employed. In addition different types of joints are used with the different materials.

It is with the gas lost or "unaccounted for", that gas which is made and does not reach consumers' appliances, that every Gas Undertaking is vitally concerned. The magnitude of the problem will be appreciated from the figures in Table 1 which shows the sales of gas and gas losses for Undertakings and Companies in New South Wales for the year ended 31/12/67.

The losses expressed as a percentage of the gas sold vary from 7% to 99%. Experimental work was carried out at the latter undertaking, Molong, and the losses have been very considerably reduced.

Table 1

Sales of Gas and Gas Losses for Undertakings and Companies in New South Wales, year ended 31/12/67

Undertaking or Company	Sales of Gas 1000 cuft.	Gas Losses 1000 cuft.	% of Sales
Aberdare	94,295	22,068	23.1
Armidale	81,491	9,315	11.5
Bathurst	174,585	25,037	14.3
Bega	22,038	3,793	17.2
Bowral	32,349	2,588	8.0
Camden	8,938	1,881	21.0
Cootamundra	23,456	3,443	14.7
Cowra	19,917	8,474	42.6
Dubbo	53,641	10,231	19.1
Glen Innes	14,360	3,201	22.3
Grenfell	5,729	1,148	20.0
Kiama	13,225	3,424	25.9
Lismore	75,208	11,582	15.4
Lithgow	72,898	9,195	12.6
Molong	6,400	6,352	99.2
Muswellbrook	44,462	8,432	19.0
Nowra	27,913	5,136	18.4
Orange	71,849	24,547	34.1
Parkes	16,828	8,980	53.3
Tamworth	50,275	13,370	26.6
Wagga Wagga	395,988	28,292	7.2
Wellington	26,054	3,682	14.1
Yass	11,980	2,064	17.3

Undertaking or Company	Sales of Gas 1000 cuft.	Gas Losses 1000 cuft.	% of Sales
Albury	74,833	13,690	18.3
Casino	8,175	4,240	51.6
Goulburn	82,867	9,417	11.3
Katoomba	53,222	14,807	27.8
Singleton	12,825	5,117	39.9
Wollongong	225,980	22,432	10.0

FACTORS CONTRIBUTING TO UNACCOUNTED FOR GAS

The gas made, sold and used on Works are all measured by meters of one type or another and their accuracy of registration is one factor governing the apparent quantity of gas lost. In addition, however, there are other factors inherent in the distribution system which also contribute to the loss.

The various factors may be summarised as follows:-

Meters

Accuracy of registration of station meter, consumers' meters and meter registering gas used on works.

Above Ground Leakage

(a) Gas holders. Leakage in low pressure wet holders due to corrosion, usually internal, of crown and side sheets above water line.

(b) Consumers' meters and connections.

(c) Service cocks of the tapered plug type at inlet to meters.

(d) Service governors at inlet to meters in high pressure distribution systems.

Below Ground Leakage

Mains (a) Cast Iron (α) Joints (i) Hemp and lead

Services (ii) Rubber rings

(β) Corrosion or breakage of pipe wall

(b) Steel   (α) Joints   (i) Screwed

(ii) Welded

(β) Corrosion of pipe wall

Gas pressure at outlet of Works

Thermal content of gas due to distributing gas of a higher calorific value.

DIFFERENT GASES AND THEIR SALIENT PROPERTIES

In the majority of cases in the past, gas manufactured from the carbonisation of coal has been distributed in these systems. In the case of the large undertakings to provide flexibility carburetted water gas produced from coke, steam and oil has been added.

With the advent of oil refineries in Australia liquefied petroleum gases have become available as by-products. These gases comprise mainly propane, propene, butane and butene, generally grouped as commercial propane and commercial butane, these two materials predominating in each case.

Liquefied petroleum gases can be utilised in two ways, either as L.P. gas/air mixtures or as feedstock for a catalytic reforming plant. Because of its lower boiling point, about $-50^{o}F$, propane is generally used for L.P. gas/air mixtures whereas the higher boiling point butane $0^{o}F$ is used as reforming plant feedstock.

The other gas new to Australia, natural gas, will soon be flowing through distribution systems in various parts of the country.

Coal gas and coal gas - carburetted water gas mixtures are scrubbed with water to remove impurities and then stored in water sealed holders before being released into a low pressure system of supply. Even if the holders are oil filmed, the gas as distributed is still fairly wet. Some of this water is condensed out in various mains, services and meters and even house pipes.

Along with the water, some of the condensable hydrocarbon content of the gas is also deposited, giving a mixture of oil and water commonly known as "drip oil" or "gas oil".

These condensable hydrocarbons consist essentially of 70% aromatic compounds such as benzene, toluene and xylene together with 15% of paraffins and 15% of unsaturated compounds. Small quantities of sulphur compounds mainly carbon disulphide and thiophene are also present. Not only is this condensate a nuisance, its removal entails cost and it has a deleterious effect on meters.

To overcome this disability some Undertakings partially dehydrate the gas at outlet of Works to water dew points varying from say 45^{o}F in summer to 38^{o}F in winter. At the same time condensable hydrocarbons are removed, the extent depending on the final water dew point.

Water and hydrocarbons are also removed when coal gas is compressed for storage in high pressure cylinders or for transmission through high pressure mains.

Natural gas is dried to a very low dew point to avoid the formation of hydrates when the gas is compressed to very high pressures for long distance transmission. It is usually re-hydrated when it reaches its destination to assist in avoiding dust storms inside the mains. The extent of the re-hydration and the final dew point will depend on local conditions.

A propane/air mixture known as simulated natural gas or S.N.G. is being distributed in two outlying and isolated areas of the Australian Gas Light Co.'s System. This gas has a Wobbe Index which is similar to that of natural gas making it interchangeable as far as combustion characteristics are concerned.

Appliances in the S.N.G. area can be changed to natural gas with no alteration and the gas making plant can be retained as peak shaving or standby in the event of failure of the natural gas supply.

The different types of gas together with their salient properties are enumerated in Table 2.

While variations occur, the analyses of individual gases are reasonably typical of those obtaining in practice.

The kinematic viscosity has been calculated from the gas analysis according to the equation of Zipperer and Müller using the kinematic viscosities of each of the constituent gases. From a knowledge of the specific gravity the true viscosity was calculated.

TABLE 2

TYPICAL CHARACTERISTICS OF COAL GASES AND OF GASES THAT MAY BE SUBSTITUTED FOR THEM

TABLE 2

TYPICAL CHARACTERISTICS OF COAL GASES AND
OF GASES THAT MAY BE SUBSTITUTED FOR THEM

		Vertical Gas Steaming	Horizontal Gas plus Producer Gas	Horizontal Gas Dehydrated by Compression	Reformed Gas	Liquefied Petroleum Gas Air		Natural Gas [illegible]
						T.L.P.	S.N.G.	
Analysis	CO_2 %	3.3	6.0	4.2	2.1	15.2	-	0.6
	O_2	2.0	1.1	0.9	1.5	57.4	9.7	0.1
	N_2	6.4	21.6	22.0	6.5	-	36.0	1.2
	CO	21.4	7.4	6.5	14.3	-	-	-
	H_2	47.6	32.0	35.1	53.6	-	-	-
	CH_4	13.5	24.3	24.8	15.5	-	-	95.0
	C_2H_6	1.2	2.1	1.7	0.6	-	-	1.3
	C_3H_8	0.8	0.4	-	-	14.9	29.6	0.3
	C_4H_{10}	-	-	-	-	- 0.8	1.7	0.6
	C_2H_4	1.7	2.6	3.7	5.2	-	-	-
	C_3H_6	1.6	1.3	0.7	0.7	11.4	22.6	-
	Unsats.	0.6	1.2	0.4	-	-	-	0.9
Calorific value B.T.U./cu.ft.		521	550	540	500	682.4	1351-1393	1040-1075
Kinematic viscosity stokes at 60°F (1)		0.2137	0.1728	0.1883	0.2463	0.0897	0.0645	0.1472
Density grams/ml. 60°F $\times 10^{-3}$ (2)		0.6487	0.784	0.7344	0.5263	1.3942	[illegible]	[illegible]
Viscosity poises $\times 10^{-6}$ (3)		138.7	135.1	138.3	129.6	124.1	102.4	[illegible]
Specific gravity (air=1)		0.53	0.64	0.60	0.43	1.14	1.30	0.64-0.[illegible]
Wobbe Index (4)		716	688	697	762	639	1185-1218	[illegible]
Water Dew Point °F (5)		55.5	68.4	20.3	- (7)	45.2-60.9	- (7)	-40
Condensable Hydrocarbons ml./cu.ft. (6)		1.587	1.46	0.25	Nil	Nil	Nil	Nil

(1) Calculated from the analysis by Zipperer and Müller formula

(2) Density of air x specific gravity

(3) Kinematic viscosity x density

(4) Wobbe Index = $\frac{\text{Calorific value}}{\text{specific gravity}}$

(5) Determined by Gas Light & Coke Co. Hygrometer. B.S.S. 3156 - 1968 Part 2 ,P 62

(6) St. Claire Deville apparatus. B.S.S. 3156 - 1968 Part 2,P 32

(7) Water Dew Point will depend on conditions under which gas will be distributed

The water dew points were determined by the G.L.C.C. Hygrometer in the case of gases where leakage determinations were carried out and represent the condition of the gas entering the distribution system.

The condensable hydrocarbon content of the coal gases was determined by the St. Claire Deville Method in which the hydrocarbons are condensed out by a dry ice-acetone mixture and the condensate weighed. It is to be noted that these hydrocarbons are present only in coal gas from horizontal and vertical retorts under normal conditions. No condensable hydrocarbons are present in L.P. gas/air mixtures, natural gas or reformed gas. They will be present in varying quantities in dehydrated coal gas according to the degree of dehydration.

METERS

The early station meters were of the wet type with rotating drums. While they were very large for their capacity, they were extremely accurate and retained their accuracy over long periods. The drums which were constructed of tinned steel finally corroded and leaked thus giving a slow registration. As they were too costly to repair meters of the Roots type were substituted. While these meters are accurate only down to 10% of their rated capacity, they are usually operated well above this rate, and hence the registered quantity of gas made is a reasonably true one.

Similarly the original customer's meter was a wet one with an accuracy within 0.5%. While these meters were bulky, they proved satisfactory so long as the load per consumer consisted mainly of a cooker and gas lights. With the advent of bath heaters and gas fires, the wet meter required became very bulky and architects and builders refused to make space available for their installation in blocks of flats. To overcome this disadvantage the dry meter was born. Although it was much smaller architects to-day are demanding a further reduction in size.

The internal construction of a dry meter is shown in Plate 1.

It consists essentially of a case divided horizontally by a valve plate into two compartments, the upper and smaller one is termed the attic while the lower and larger one is known as the body. The body is divided into two compartments by the diaphragm plate on either side of which are attached the diaphragms of sheep skin. The diaphragms are supported by attachment to diaphragm discs which are in turn supported by hinges knows as flags. Lateral movement of the diaphragms is caused by their inflation and deflation by the gas in its passage through the meter. This lateral motion is communicated by the flags which are attached to flag rods mounted vertically and which by tangential gearing in the attic, convert it into rotary motion to actuate the recording index. In addition they operate the valves which open and close the inlet and outlet ports to the measuring chambers. Figure 1 shows four diagrams of a dry meter, each depicting a phase in the cycle of operation.

Plate 1 The internal construction of a dry meter.

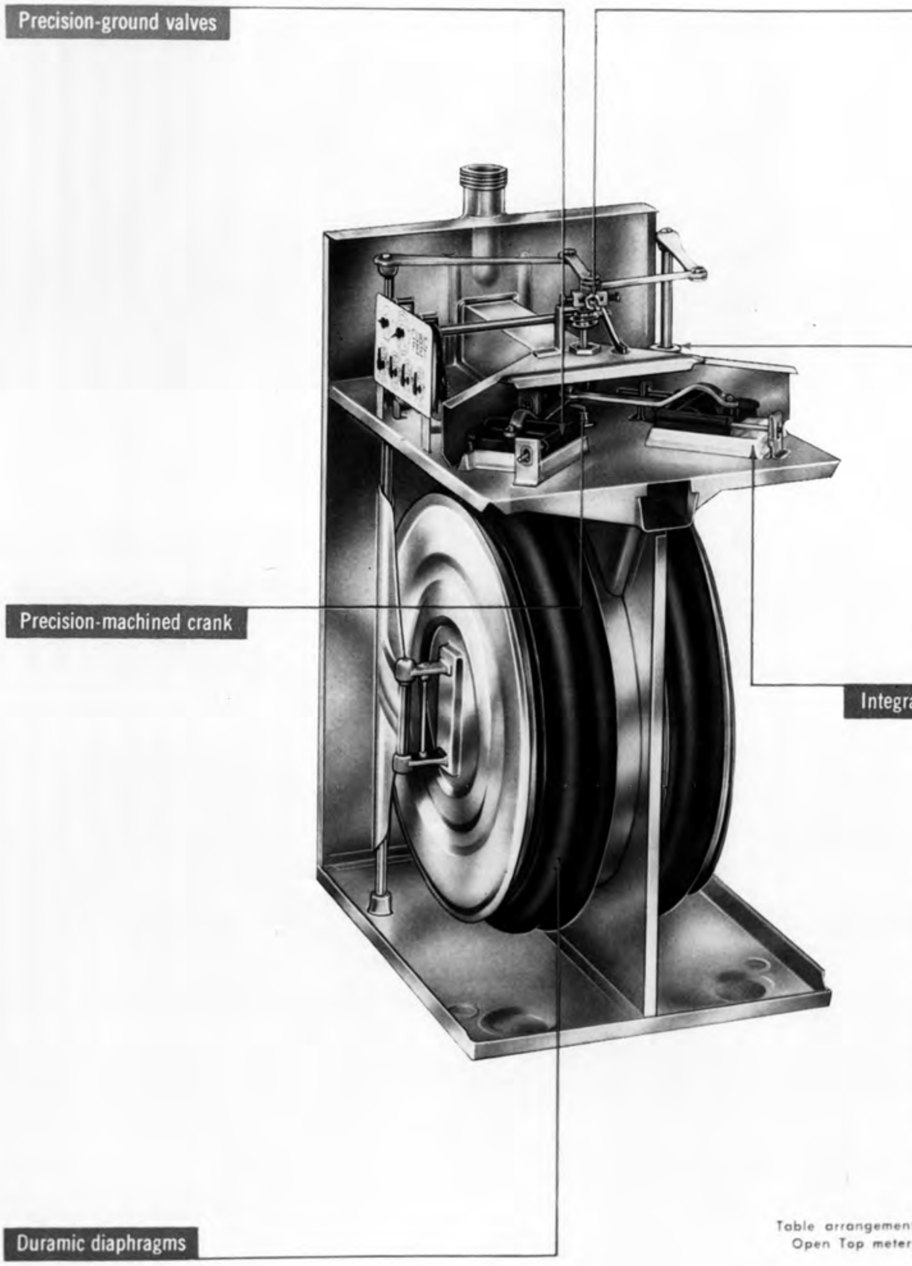
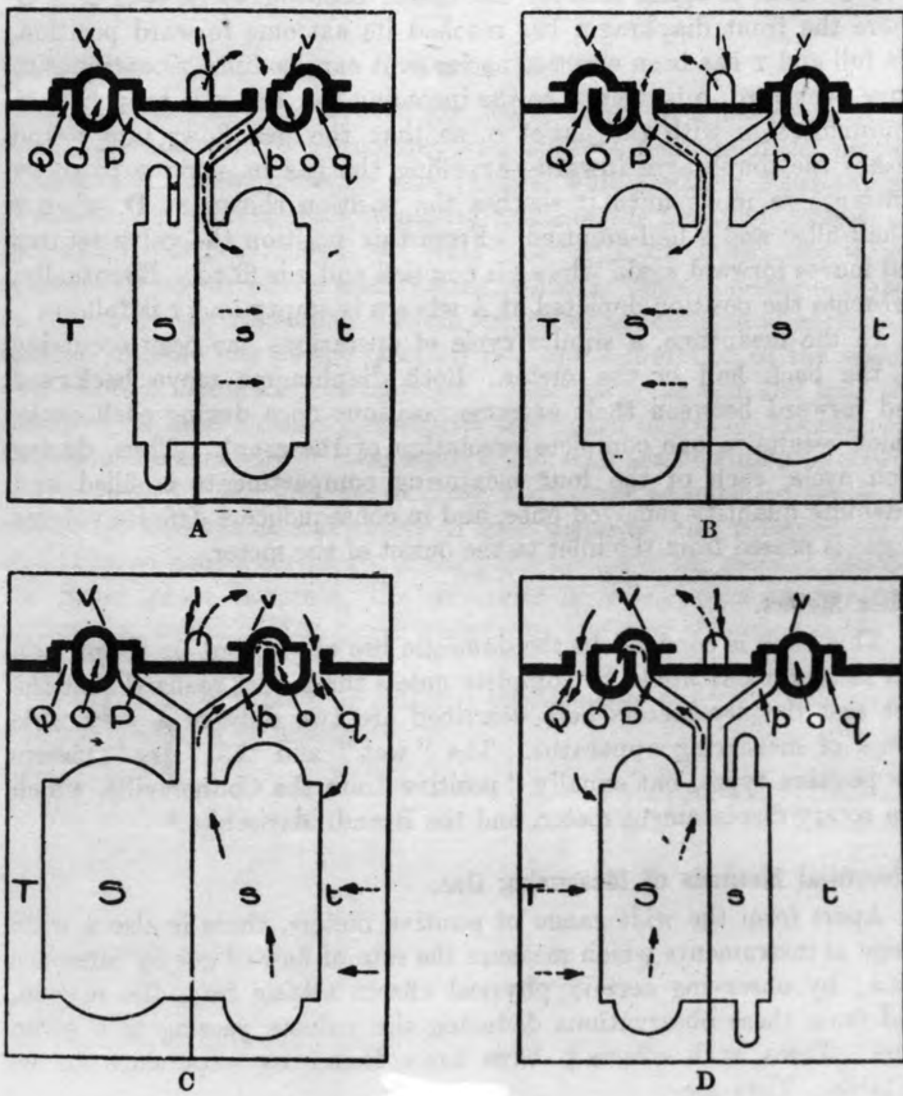


Table arrangement of Open Top meters.

Fig. 1 Four diagrams of a dry meter each depicting a phase in the cycle of operation.



V, *v*—Slide valves.
I—Inlet port.
O, *o*—Outlet port.
P, *p*—Ports to inside of diaphragms.
Q, *q*—Ports to outside of diaphragms.
S, *s*—Measuring chambers inside diaphragms.
T, *t*—Measuring chambers outside diaphragms.

The quantity of gas measured each stroke of a diaphragm depends on the configuration of the leather at the end of the stroke. The leather is impregnated with oils and greases, sometimes containing colloidal graphite, with the purpose of keeping it soft and pliable.

If the meter is to retain its accuracy of registration it is essential to maintain the diaphragm in a stable form so that there is no contraction or expansion in the cell structure of the leather. Meter leather dressings have an affinity for "drip oil". This results in a lowering of the viscosity of the dressing and an increase in its volume. Some of the mixture runs to the bottom of the diaphragm and finally drips onto the bottom of the case.

While the leather is impregnated with the condensates, it remains soft and pliable. However if the condensate is allowed to evaporate the leather becomes dry and stiff. It is obvious that although the condensates have a leaching effect on the diaphragm dressing so long as there is sufficient moisture and oil vapour present in the gas to saturate the leather, no variation in meter accuracy will be noted.

More drip oil per 1000 cubic feet of gas distributed is removed from the mains in winter than in summer and hence the gas entering the meter is more deficient in vapours in the winter than the summer. If the temperature of the meter is higher than that of the ground, the gas will have a tendency to pick up light oil and moisture present in the meter, thereby drying out the leather.

The reverse of this condition will obtain in the summer when a period of condensation in the meter will occur. The degree of condensation will determine the extent to which leaching of the diaphragm dressing will proceed.

The continual cycling of these condensing and evaporating periods has an adverse effect on accuracy of registration.

In America, where a change was made from coal gas or carburetted water gas to natural gas as early as 1930 it was realised that some gas conditioning would be necessary. As conditioning possibly has a greater effect on mains and services than meters, the methods of carrying it out will be discussed under those headings.

K.C. Tomlinson [(1)] states "The flexibility of the leather in the diaphragm is affected by any major change in the humidity of the gas".

H.U. Crawford[(2)] shows that with relatively small volumes passed, meters correct at 80% relative humidity registered 1% fast at 40% and 1% slow at 95% humidity.

It was stated in "Fuel & Flue Gases"[(3)] that meters set correctly at 40% relative humidity ran 1.2% fast at 5% after 45 days and 0.5% slow at 90% humidity after 15 days.

Oil fog was found to have travelled a distance of six miles in ten days in one section of the system of the New York & Richmond Gas Co. on Staten Island. It had passed through district governors and was noticed at appliance pilot filters. Under these circumstances it had also passed through the meters.

On inspecting these meters in the repair shop, it was found that leaching of the diaphragms had not occurred and while there was no oily saturation of the leather, it had an oily look and feel. All incoming meters are tested for accuracy and they show practically no change since conversion to natural gas.

In 1949, Wakefield Diaphragm "C" dressing was used to treat new leathers being fitted to repaired meters at the North Shore Gas Co., Sydney. The leather is soaked in the dressing, which contains colloidal graphite, for 5 - 6 days and then Diaphragm Grease is rubbed over both surfaces. This method of treatment is still being used and has been found very satisfactory.

The Gas & Fuel Corporation of Victoria has developed a lanoline based dressing which it is claimed withstands the action of light oil and moisture.

About 1937-8 experiments were carried out at the Australian Gas Light Co., Sydney using moulded synthetic rubber diaphragms. The results were very unsatisfactory. Where the diaphragms were banded to the pans, they had a core of natural rubber. This was attacked by the light oils and the swelling force was sufficient to burst the steel banding wire.

F. Hibberd of Hibberd Meters Ltd. commenced experiments at

Roma, Queensland in 1965 on two of their standard meters fitted with synthetic rubber diaphragms. The meters were connected at the outlet of the separators in the open and subject to atmospheric temperature variations. In 3 years the meters which have a badged capacity of 200 cuft/hour passed 13,000,000 cuft. of natural gas at the rate of 500 cuft/hour continuously. At the commencement of the test one meter registered 1.0% slow, at the end it was 0.5% slow. The other was 1.0% slow at the beginning and 2.25% slow at the end.

The meters were examined and the diaphragms found to be in perfect condition. The oily deposit on the valves and grids which probably accounted for the increased slowness, was cleared off and they have been put into service with the Brisbane Gas Company.

These meters should be very suitable for use with T.L.P. and natural gases.

It will be seen from Table 2 that a coal gas dehydrated by compression contains very little condensable hydrocarbons and has a dew point of 20°F. If this gas is substituted for a normal wet gas, it would be anticipated that leathers would dry out, shrink and the meter would register fast.

Liquefied petroleum gases do not affect leather dressings so that a leaching action would not occur. However there would be a drying out of the condensable hydrocarbon content of the leather. The water content would depend on the method of storing the L.P. gas/air mixture.

A certain amount of moisture is entrained with the air, and if the gas is stored in a wet holder, which is not oil filmed, the dew point would be approximately the same as the original coal gas.

Reformed gas does not contain any condensable hydrocarbons and the same remarks apply to it as T.L.P. gas.

Natural gas as delivered to the city gate is very dry and is usually rehydrated both for the sake of the meters as well as to maintain hemp-lead joints in mains gas tight and reduce dust storms. It also does not contain any condensable hydrocarbons and would tend to evaporate the oil content of the leathers.

Tempered liquefied petroleum gas is the only one which has been substituted in its entirety for coal gas in a town. Where reformed gas is manufactured, it is being mixed with coal gas and the effect of its properties is masked.

An investigation was made in a number of towns to determine the accuracy of registration of meters when measuring coal gas and the variation when T.L.P. gas was distributed. In some cases tests were not made prior to conversion.

This work was carried out by connecting a standard test meter in series with the meter under test. It has been found that if a meter is removed from the location in which it is used, its accuracy of registration alters. Hence it is necessary to carry out the test in-situ taking care to disturb the meter as little as possible.

The results of tests for accuracy of registration of some 2700 meters are summarised in Table 3.

The Gas & Electricity Act states that a gas meter is deemed to be within registration if it is not more than 2% fast or not more than 3% slow. This accounts for the manner in which the results have been dissected.

It will be seen that individually there is a wide variation in the accuracy of registration, some meters being more than 8% fast and others more than 5% slow. In the average, however, meters are in general registering on the fast side and it is this average which determines the effect of meter registration on gas losses.

In the case of meters measuring coal gas with one exception, the average registration is slightly on the fast side. This has always been found in Country Gas Undertakings in past surveys.

In general, the average accuracy of registration of meters operating on T.L.P. gas has not varied to any extent from that obtaining with coal gas.

TABLE 3a

RESULTS OF IN-SITU TESTS TO DETERMINE THE ACCURACY OF REGISTRATION OF METERS AFTER CHANGING FROM COAL GAS TO T.L.P. GAS

	Town G.I.		
	Coal Gas	T.L.P. Gas	
		after 6 months	after 18 months
Meters Installed	450	450	522
Meters Tested	293	343	330
% of Total	65.1	76.2	63.2
Average Accuracy %	+1.57	+1.81	+1.41
> 8% fast	5.9	9.6	6.4
6% - 8% fast	4.8	4.8	4.5
4% - 6% fast	15.1	12.6	13.7
2% - 4% fast	12.7	8.1	9.9
nett - 2% fast	21.6	21.6	21.1
nett	7.2	8.7	8.6
nett - 3% slow	20.3	23.6	25.6
3% - 5% slow	7.6	7.5	6.4
> - 5% slow	4.5	3.5	3.5
Non Registering	0.3	-	0.3

TABLE 3 b

RESULTS OF IN-SITU TESTS TO DETERMINE THE ACCURACY OF REGISTRATION OF METERS AFTER CHANGING FROM COAL GAS TO T.L.P. GAS

	Town M		
	Coal Gas	T.L.P. Gas	
		after 10 months	after 16 months
Meters Installed	249	258	258
Meters Tested	197	208	165
% ofTotal	79.1	80.6	64.0
Average Accuracy %	-0.34	-0.86	+2.86
> 8% fast	2.1	7.7	17.3
6% - 8% fast	0.5	3.4	9.2
4% - 6% fast	14.1	7.2	11.7
2% - 4% fast	9.4	10.6	9.9
nett - 2% fast	18.2	6.2	14.7
nett	3.1	4.3	5.6
nett - 3% slow	27.6	28.4	15.4
3% - 5% slow	10.9	13.9	5.6
> - 5% slow	12.0	18.3	5.6
Non Registering	2.1	-	-

TABLE 3 c

RESULTS OF IN-SITU TESTS TO DETERMINE THE ACCURACY OF REGISTRATION OF METERS AFTER CHANGING FROM COAL GAS TO T.L.P. GAS

	T.L.P. Gas			
	Town B after 7 months	Town C after 13 months	Town G after 29 months	Town Y after 7 months
Meters Installed	610	660	1317	374
Meters Tested	442	376	340	321
% of Total	72.5	57.0	25.8	85.8
Average Accuracy %	+1.35	+2.47	+4.69	+2.50
> 8% fast	7.0	13.8	25.9	9.0
6% - 8% fast	3.8	6.4	9.7	7.8
4% - 6% fast	13.6	15.2	16.2	14.7
2% - 4% fast	19.8	11.4	8.8	15.7
nett - 2% fast	13.1	20.5	11.3	26.0
nett	7.0	2.9	5.6	5.3
nett - 3% slow	24.8	17.8	14.1	12.2
3% - 5% slow	5.0	5.8	3.5	5.3
> - 5% slow	5.9	5.1	5.0	3.1
Non Registering	-	1.1	-	0.9

TABLE 3 d

RESULTS OF IN-SITU TESTS TO DETERMINE THE ACCURACY OF REGISTRATION OF METERS AFTER CHANGING FROM COAL GAS TO T.L.P. GAS

	Coal Gas	
	Town N	Town P
Meters Installed	1146	675
Meters Tested	316	391
% of Total	27.6	57.5
Average Accuracy %	+1.78	+3.08
> 8% fast	3.5	13.6
6% - 8% fast	1.9	8.5
4% - 6% fast	19.6	16.6
2% - 4% fast	13.9	7.4
nett - 2% fast	26.9	13.3
nett	10.8	6.1
nett - 3% slow	16.5	16.6
3% - 5% slow	6.0	5.7
> - 5% slow	0.6	8.7
Non Registering	0.3	3.8

With the changeover in Town G.I. the average accuracy increased from + 1.57% to + 1.81% after 6 months and reduced to + 1.41% after 18 months. The reduction is explained by the fact that immediately after the second test 85 meters, mostly fast, were replaced with meters either new or repaired in 1966 or 1967.

On the third test the average accuracy of the latter meters which had registered only T.L.P. gas was - 0.3% whereas the meters they replaced were averaging + 3.12% With a few exceptions the changed meters remained within the tolerance of + 2% and - 3%. Although their actual accuracy on installation is not known, the results indicate that at this location a meter which has measured T.L.P. gas only is not greatly affected by it.

A further analysis of results showed that 98 meters were tested on all three occasions. Of this number 78 became progressively faster and 19 slower, irrespective of whether they were initially fast or slow. One meter was originally 4.71% fast, became 1.48% slow on the second test and non registering the flow of gas on the third.

While the gas contained moisture it had not been fogged and there is every indication that the condensable hydrocarbons in the leathers had dried out, shrinking them. In the case of the above meter, the leather finally cracked.

In Town M after 10 months the average accuracy was - 0.86%

compared to - 0.34% prior to changeover, with an increase to + 2.86% after a further 6 months.

The survey on coal gas was carried out 2 months before changing to T.L.P. gas. After the test, 47 meters were replaced with 1966 new meters. At the second test it was noticed that 3 of those meters were registering nett, and the remaining 44 were all slow. Of the latter number, 22 meters were of one manufacture, 15 from another and 7 from a third. So it would appear that the fault was not inherent in any one make of meter.

The first dry meters manufactured were fitted with valves and grids of a tin-antimony alloy. With the coal gas - carburetted water gas mixtures, gum forming bodies were deposited on the valve-grid surfaces, tending to make a meter register slow.

To overcome this friction when meters were being repaired they were fitted with plastic valves, working on the metal grid. It would have been impossible to replace the grid with a plastic one. New meters were manufactured with plastic to plastic valves and grids.

One 1966 meter with plastic valves and grids in Town M was registering 9.0% slow. The manufacturer agreed to supply one of his meters with synthetic diaphragms specially made for T.L.P. gas.

Three months later before changing it, the meter was tested again and was now found to be only 5.0% slow. It was replaced by a meter with synthetic rubber diaphragms having an accuracy of 0.20% fast.

The original meter was carefully opened up at the Works and the leather diaphragms appeared in perfect condition. It was noticed however that there were droplets of water on the valve grids. The meter was sealed up and returned to Sydney. After allowing it to stand its accuracy was 0.9% slow.

Arrangements were made to atomise water over the valves and grids. Initially the meter was 7.0% slow decreasing to 3.0% as the water was removed from the surfaces by the operation of the valves. After allowing the valves to dry out overnight, the accuracy was again 0.9% slow. These tests were repeated several times with the same result and it was concluded that the additional friction caused by the water between the plastic valve and grid was responsible for the meter registering slow.

Two old style meters were obtained, one with metal grids and valves, the other with plastic valves working on metal grids. The meters were tested in the same manner as above.

The water had no effect on the accuracy of the meter with metal valves, and only a slight tendency to run slow with the plastic valve to metal grid meter.

After one month's service the plastic diaphragm meter at Town M was found to be 3.61% slow. The dewpoint of the gas leaving the Works varied from 60.9°F at noon to 45.2°F at midnight.

It would appear that with varying dewpoints and degrees of condensation of moisture on the present type of valve and grid, it would be desirable to return to the original metal valve and grid.

Between the second and third tests the meters began to register faster. Of the 165 meters tested, 133 registered faster, 21 slower and in the case of 11 there was no change.

The second series of tests were carried out 6 - 10/2/67 in summer, while the date of the third was 10 - 14/7/67 in winter. The dewpoints quoted were determined 2 weeks before the third test. This could be the case of the gas being cooled in the mains and services underground below the dewpoint range of $45^{o}F$ - $61^{o}F$, water condensed out and the gas being saturated at ground temperature. On reaching a warmer meter, it would no longer be saturated and would evaporate moisture from the diaphragms causing them to shrink and the meter to register faster.

The converse could have been the explanation in the case of the meter previously mentioned which was replaced by the meter with synthetic diaphragms. It tested 9.0% slow in February and 5% slow in May when the condensate was being deposited on the valves at a lower rate.

In the case of Towns B, C, G and Y, no surveys were made before the changeover from coal gas to T.L.P. gas. Although 1479 meters were tested, it is somewhat difficult to draw definite conclusions. It would appear that as the time of contact with T.L.P. gas increases, meters on the average tend to register faster. This result is similar to that obtained in the case of Town M.

Oil fogging was not carried out in any of these towns and it would be reasonable to suppose that the gas oils would dry out of the diaphragms causing them to harden.

Dewpoint determinations made at various points in Town B showed a variation in the low pressure system of 50.2^{o}F to 59.3^{o}F. At one point gas is fed from the high pressure system through a governor into the low pressure mains during peak periods. At these times in the vicinity of the governor, the dewpoint was 40.3^{o}F.

High pressure gas of dewpoint 40.3^{o}F is also supplied to the inlet to house service governors in a Housing Commission area. In general water dewpoints were very similar to those obtaining when coal gas was distributed.

It would appear that although the gas oils may have dried out, the moisture content of the gas has prevented the diaphragms from shrinking to any appreciable extent.

Dewpoint determinations were not made in Towns C, G and Y. However, the methods of operating the distribution systems were very similar to those employed with coal gas and it is not anticipated that water dew points would vary to any great extent.

In Town G the 25.9% of the meters tested which were more than 8% fast were responsible for the relatively large average fast registration.

These have been replaced and the average accuracy is now approximately the same as the other towns.

It has been contended that the high oxygen content of T.L.P. gas would have a corrosive effect on the internal parts of a meter. The case of the meter is either tinned steel, cast iron, cast aluminium or pressed steel; the moving parts are tinned steel with stainless steel pins and bushes; stuffing boxes and glands are brass and valves and grids are either tin-antimony alloy or plastic.

In view of the above it would not be anticipated that internal corrosion would occur. This has been the case in the majority of meters examined.

Summarising the findings of the investigation on meters it would appear that:

1. It is not the gas but its moisture and oil content which affect their accuracy of registration.
2. In view of (1) any results obtained with T.L.P. gas would be equally applicable if natural gas or reformed gas were substituted for coal gas.
3. While there is a tendency for meters originally measuring coal gas to register fast on changeover this could be mitigated if not overcome by suitable oil fogging.
4. The substitution of other gases for coal gas would not

substantially affect the unaccounted for gas due to a variation in the accuracy of registration of meters.

ABOVE GROUND LEAKAGE

(a) Gas Holders

These holders are of the water sealed, low pressure type with one or more sections telescoping into a tank of water situated either above or below ground. They are constructed of steel plates varying in thickness from $^{1}/8"$ - $^{3}/16"$ either rivetted or welded with a lap joint. In the case of the rivetted joints a gas tight seal is ensured by means of fabric insertion saturated with red lead. Fillet welds on the outside only are generally used in a welded holder, a construction to be found in holders repaired in recent years.

The external surface of the holder can in general be protected against corrosion by a heavy red lead undercoat, with suitable finishing coats. At wind and water line on the telescoping sections a grease paint is added.

The internal surface of the crown and the side sheets of the top lift down to the gas and water line are the parts which suffer the greatest corrosion.

The gas contained in the holder could contain up to 3.0% of oxygen and in some cases as much as 6.0% of carbon dioxide although 3.0%

would be an average.

An examination of the internal surface of the crown when it is being repaired shows that deterioration takes place on the internal surface of a plate along the line of the next plate attached to it. The metal is clean and there are no corrosion products adhering to it. It appears to be a combination of corrosion with the corrosion products removed by the flexure of the crown. The effect is the same as if the metal had been gouged out by a round nosed tool.

Fortunately when the plate corrodes through to the outside, a thin black telltale line appears, and if the holder is regularly inspected, patching can be carried out. In this way leakage is reduced to a neglibible amount until complete repairs can be effected.

In modern practice, internal corrosion is minimised by oil spraying through permanent fittings welded on the crown plates.

(b) Consumers' meters and connections

(c) Service cocks

(d) Service governors

The loss of gas from all these sources can be readily detected and remedied. In many cases meter readers, on the basis of smell, report leakage in the course of their normal duties.

A gas meter has at least one joint and mostly two in its case, depending on the type, and year of manufacture. The jointing material sometimes suffers minor breakdown allowing small leaks to occur.

Meters are connected into the service by two U shaped pieces of pipe, originally made of lead but more recently of brass or copper. In the case of the lead connections a brass union is attached to each end of a piece of lead pipe by means of a wiped joint. Polythene washers for electrical insulation to minimise electrolytic corrosion of services are fitted to the unions. Leakage may occur through cracks or pin holes in the lead pipe or due to imperfect fitting of the washers.

Service cocks have traditionally been of the tapered plug type. When new, properly ground in and lubricated these cocks are gas tight. With age some types of grease are leached out by the condensable hydrocarbons in the coal gas, or corrosion and wear takes place on the contact surfaces.

With the advent of high pressure distribution, gate valves or plug cocks fitted with glands were employed.

Service governors are fitted only at the inlet to meters in high pressure distribution systems to reduce the pressure to the value required for the satisfactory operation of appliances.

A pressure relief device is fitted on the outlet side of the governor to prevent excessive pressures being supplied to the appliances in the event of the diaphragm leaking or the main valve failing to seat properly. A $\frac{3}{4}$" diameter stainless steel ball ground to its seat and sealed with oil or a flat valve controlled by a spiral spring are commonly used for this purpose. If not regularly serviced slight leakage is liable to occur even under normal outlet pressures.

The results of tests carried out to determine leakage from above ground structures in low pressure distribution systems are shown in Table 4.

Leakage occurred in 24% of the installations examined. The major leaks were found to be equally distributed between the meter connections and the service cocks.

A survey of leakage from service cocks in three Sydney Municipalities yielded the results in Table 5.

Table 5

Results of Tests for Leakage from Service Cocks
Low Pressure Area

Municipality	Total Number of Cocks Examined	Number of Cocks Leaking	Total Leakage Rate cuft./hr.
Artarmon	202	31	8.0
Greenwich	206	30	7.5
Willoughby	533	71	30.5
Total	941	132	46.0

Average rate of leakage = 0.348 cu.ft./hr./cock

Table 4

Results of Tests for Leakage from Above Ground Structures
Low pressure area pressures normally varying from 2.0" - 5.5" w.g.

Municipality	Total Installations Inspected	Leakage at			Leaks Found		Total Leakage cuft./hr.
		Meters	Connections	Service Cocks	Total	% of Inspected	
Crows Nest Wollstonecraft	403	2	48	30	80	19.8	41
Waverton North Sydney	468	9	69	45	123	26.2	72
Chatswood Greenwich Crows Nest Waverton Wollstonecraft	1064	12	128	150	290	27.2	110
Chatswood North Sydney Waverton	988	10	94	107	211	21.3	77
TOTAL	2923	33	339	332	704	24.0	300

Average rate of leakage = 0.426 cu.ft./hr/leak

The average rate of leakage from service cocks is 0.348 cuft./hr. with 14% of those examined leaking.

From Table 4 the rate of leakage from connections and cocks is approximately 0.426 cuft./hr./leak. Hence it would appear that leakage from connections is of the order of 0.078 cuft/hr. or about one quarter of that from service cocks.

In order to appreciate the significance of leakage from this source assume that in a town there are 1000 consumers. At 24%, the number of leaks would be 240. The annual leakage at 0.426 cuft./hr./leak would amount to 0.426 x 240 x 8760 ≑ 896,000 cuft./annum. The total sales of gas would be of the order of 25,000,000 cuft. to 45,000,000cuft. depending on the climate, so that the above leakage would amount to 3.6 - 2.0% of the annual sales. This figure is significant and warrants some work being carried out to locate and remedy the loss.

The results of tests carried out in a high pressure area of supply are given in Table 6. Here leakage occurred in 21% of the installations examined, with an average rate of leakage of 0.476 cuft./hr./leak. This is of the same order as the leakage rate obtained in the case of the low pressure system.

It will be noted that the percentage of meters found leaking in the high pressure area is about $^{1}/5$ of the leaking meters in the low pressure system. When coal gas is compressed, the condensable

Table 6

Results of Tests for Leakage from Above Ground Structures
High Pressure Area
Inlet to governor 30 lbs/sq in. Outlet of governor 4.0" w.g.

Municipality	Total Installations Inspected	Leakage at				Leaks Found		Total Leakage cuft./hr.
		Meters	Connections	Service Cocks	Governors	Total	% of Inspected	
Dee Why	822	4	30	8	156	198	24.0	93
Newport Curl Curl South Curl Curl	760	1	65	36	55	157	20.6	73
Brookvale Manly Seaforth South Curl Curl	996	1	67	32	62	168	16.2	80
TOTAL	2478	6	162	76	133	517	20.8	246

Average rate of leakage = 0.476 cuft./hr./leak hydrocarbons are almost completely removed and this could explain the reduction in the attack on joints in meters in the high pressure system.

All tests in this section were carried out with a gas predominantly coal gas from vertical retorts mixed with some reformed gas, using naphtha as a feedstock.

BELOW GROUND LEAKAGE

The major loss of gas usually falls in this category and by its very nature is the most difficult to locate and remedy.

The underground structure consists of mains transporting the gas from street to street with small diameter services connecting consumers' meters to them.

In the early days, water practice was followed, and sand cast spigot and socket pipes were used, hemp and lead forming the joint. It is the hemp not the lead which renders the joint gas tight provided it is kept moist and that it was thoroughly caulked into the socket before the lead was poured.

With the increased demand the process of sand casting pipes on end became too slow. About 1928 the Super De Lavaud process of casting a pipe in a rotating steel mould was developed by Australian Iron and Steel. It is essential for these pipes to be thoroughly annealed otherwise they are prone to fracture with vibration or even with rough handling before laying.

The hemp-lead type of joint was retained until 1937 when Australian Iron & Steel redesigned the socket to allow a roll in rubber ring of circular cross section to be employed as jointing material. The same rings were used for gas as for water and they were ordered by Australian Iron & Steel to B.S.S. 674/36 which specifically dealt with rubber rings for use in joints for water mains. The material to be used was natural rubber.

Such rubber rings had been used in France for 60 years and for a much shorter period of time at Bathurst, N.S.W. Although there were indications that the rubber had softened due to adsorption of condensable hydrocarbons from the coal gas there was no sign of leakage

Plate 2 shows a cut away section of a rubber ring joint with the ring flattened and backed by cement.

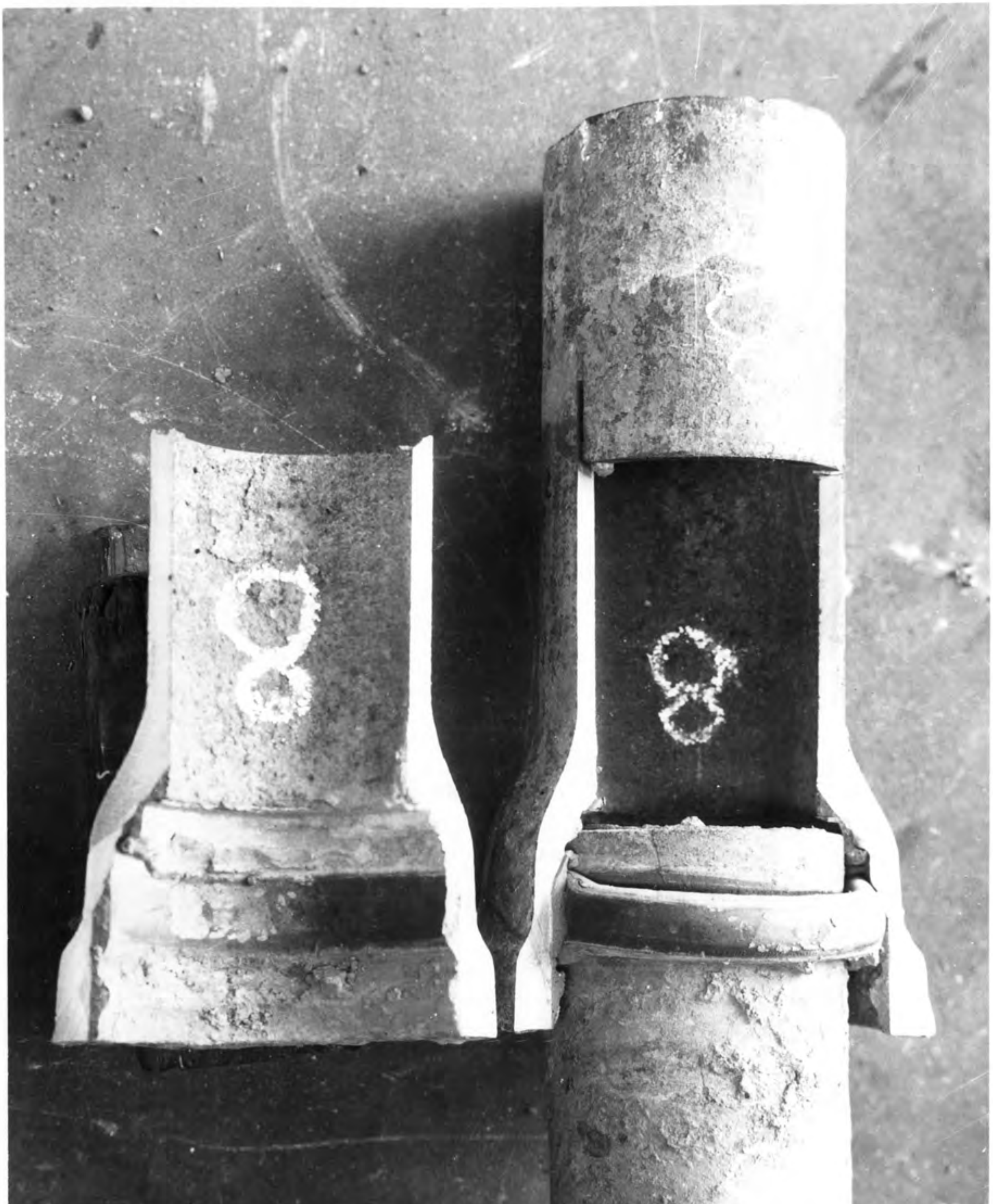
Some 400 yards of 4" main with rubber rings protected and held in place on the outside by cement and sand were laid in Kissing Point Road in September 1937. A leakage test was conducted on this main in March 1948 and it was found to be still gas tight.

Other sections of main were laid both in the city and the country employing this type of joint.

Between January to June 1941, the three gas works in Sydney were interconnected as a War Emergency. The 15" diameter main in Spooner Highway was tested for leakage in February 1948 and was found to be not leaking.

Plate 2 A cut away section of a rubber ring joint with the ring flattened by compression and backed by cement.

Section of pipe cut out in milling machine.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As natural rubber became in short supply, B.S.S. 674/42 was issued as a War Emergency Specification for rubber rings for water mains. The principal variation was in the Materials Clause 2 (b) which stated "the raw rubber content shall not exceed the following percentages by volume: - Type soft 60%, type medium 40%, type hard 40%". The remainder of the rubber content at this stage was to be reclaimed rubber.

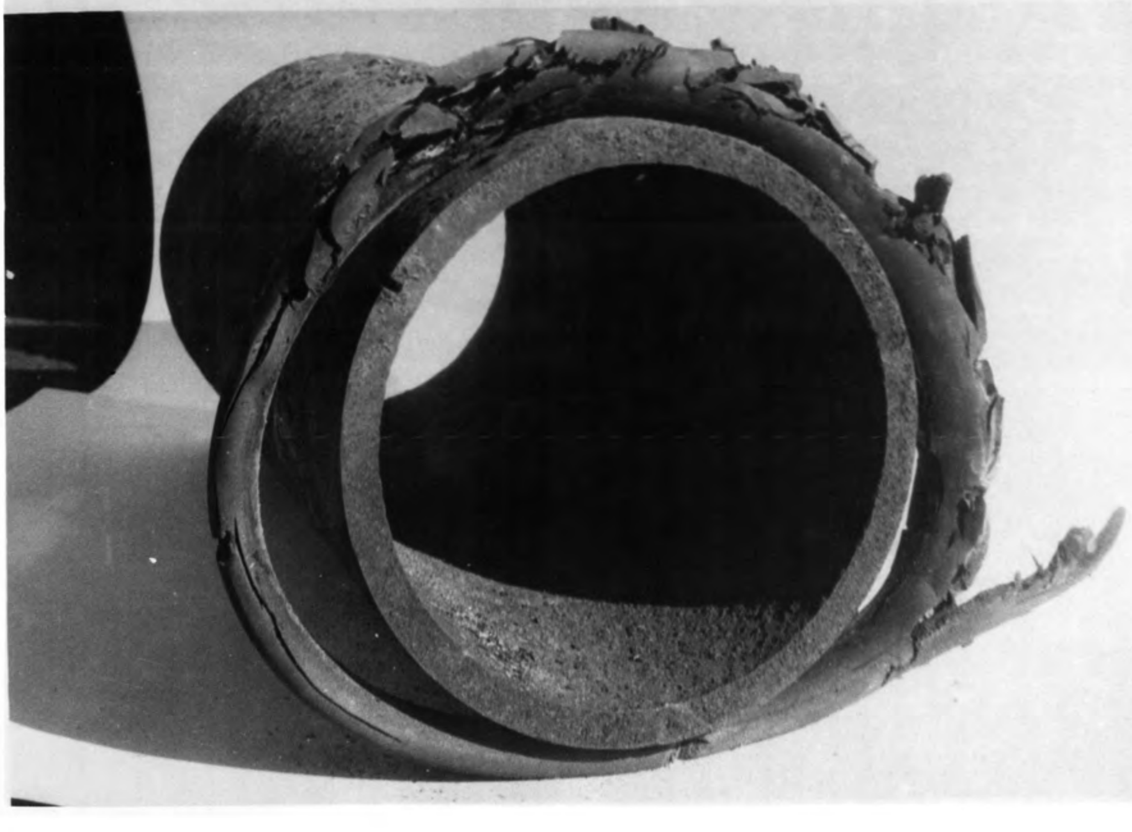
One section of main laid in May 1944 in the vicinity of Mascot Aerodrome was examined in February 1948 and found to be leaking. One ring removed for examination showed the presence of reclaimed rubber.

Another section laid in 1944 in Bestick Street, Kogarah was leaking badly in April 1948. Rings removed again showed the presence of reclaimed rubber. Several Sections of the main were removed and the sockets carefully cut away. Plate 3 shows the condition of the rubber rings. Reclaimed rubber never incorporates with the new rubber and remains as striations in the mass of the ring. Breakdown occurs along these striations.

A further War Emergency Specification B.S.S. 772/1945 which was issued in 1945, applied specifically to rubber rings for gas mains. This specification covered vulcanised rubber rings manufactured from General Purpose Synthetic rubber , GR - S (Government Rubber - Styrene). It stated that where considered necessary some natural rubber may be used but that is should not exceed the following percentages by volume:- Type soft 20%, type medium 15%, type hard 10%.

In November 1945, a 12" diameter main was laid from

Plate 3 Showing the condition of rubber rings removed from main in Bestick Street, Kogarah in 1948. Main was laid in 1944. The breakdown of the rings along the striations of reclaimed rubber can be clearly seen.

Holder Station to Fairfield. In February 1948 it was found to be leaking badly and about 24 rings were removed. Some of these rings because of markings and physical appearance appeared to contain GR - S rubber. Tests carried out on other rings which showed no markings indicated that GR - S was absent but reclaimed rubber was present.

In January 1946, rubber rings were again permitted to be manufactured to the pre-War specification using natural rubber. However a 12" main laid in Bunnerong Road in March 1947 was subsequently found to be leaking. One ring removed was badly crushed and its marking showed that it contained GR - S rubber. Another ring in good condition was marked natural rubber and this was subsequently determined by test to be correct.

The pattern of mains laying and materials used by the A.G.L. would have its parallel in every Country Gas Undertaking.

As a result of this investigation it would appear that , in general, rings manufactured from natural rubber provide a gas tight joint, but that mixtures of reclaimed or G.R. - S synthetic rubber are unsatisfactory.

The extent to which corrosion occurs in a cast iron main depends on the type of cast iron and the soil in which it is laid.

The old sand cast pipe had a hard skin due to the penetration of the sand in the mould. Corrosion occurred fairly evenly over the surface and the products were capable of being removed in layers. Plate 4 illustrates the appearance of a sand cast main after removal from the ground.

In the case of a spun pipe, however, corrosion is more localised and it is quite common to find deep pits over the surface of the pipe.

Plate 4 Illustrating the appearance of a sand cast main after removal from the ground. Corrosion has taken place fairly evenly over the whole surface.

Plate 5 illustrates the manner in which this corrosion takes place.

At the 1937 Soil Corrosion Conference of the United States National Bureau of Standards, several papers were presented, chiefly by Dutch investigators, describing the action of sulphate reducing bacteria in accelerating the corrosion of iron under certain conditions.

That such bacteria might influence the corrosion process was a relatively recent discovery. The apparent similarity of the nature of the corrosion described by the Dutch to that suffered in some parts of the distribution systems in Sydney indicated that it might be profitable to investigate local conditions.

Where iron is in contact with moist earth, small galvanic cells are set up due to various causes, the anodic areas on the surface of the iron being corroded while at the cathodic areas hydrogen is liberated. The hydrogen tends to collect on the cathodes and if it is not removed to polarise the cells and to reduce the rate of corrosion. In the sulphate reduction process the hydrogen is removed by micro-organisms which are present in the soil.

This process, with its accompanying phenomena, can proceed only when the following conditions exist:

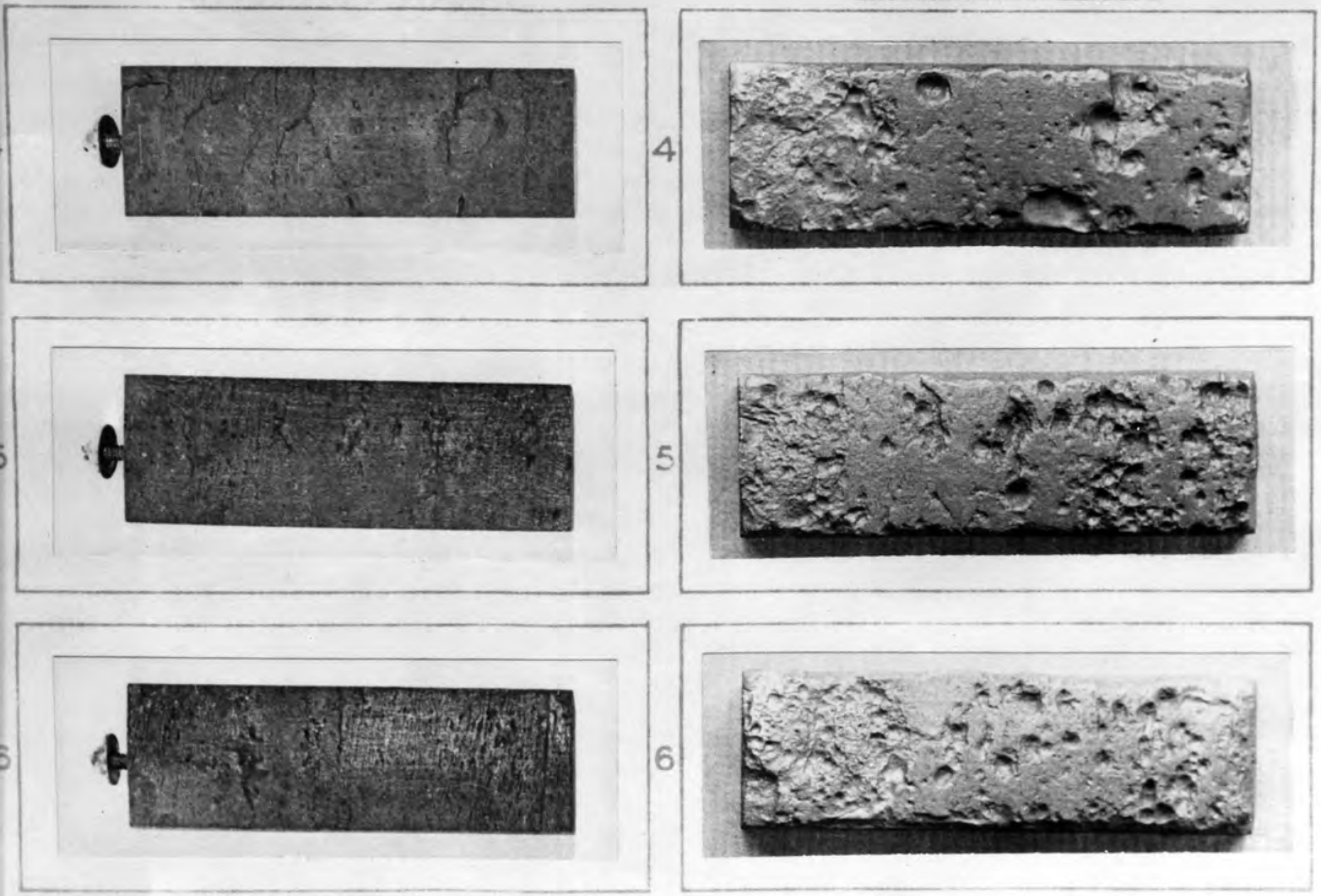
(1) There must be sulphates in the soil, and also certain bacteria.

(2) Organic substances assimilable by the bacteria must be available.

Plate 5 Showing the pitting type of corrosion occurring in the case of spun cast iron pipes.

CLAY SOIL — SPUN PIPE.

BEFORE TEST | AFTER TEST



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5 | 5

6 | 6

(3) The soil must be anaerobic.

(4) The soil must contain moisture and must not be strongly acid' or strongly alkaline.

There is some doubt as to the actual mechanism of this corrosion process but the following general description is accepted as satisfactory.

The action of the bacteria is to absorb free hydrogen or to derive this element from the organic matter in the soil and to act upon the sulphates reducing these to sulphides with the evolution of sulphuretted hydrogen. As a weak acid in water, the latter can attack iron to form ferrous sulphide.

The bacterial action is accelerated by the galvanic action as the hydrogen which is evolved on the cathode greatly increases the supply for the bacteria. Thus not only is the bacterial action accelerated but the galvanic cells are depolarised rapidly, greatly accelerating the corrosion process.

There are many types of sulphur bacteria, some tending to oxidise and others to reduce the sulphur element. It is only the latter that were of interest.

Various scientists who had investigated the influence of sulphur reducing bacteria on the corrosion process indicated that, of the different types in existance, the "vibrio desulphuricans" was the most important in this regard. This organism can be described as a spiral or comma shaped rod having a flagellum with several loops. It is motile, and essentially anaerobic.

Some soil samples were obtained near a corroded cast iron main and a pure culture of Vibrio Desulphuricans was prepared. The culture was smeared on a slide, stained with carbol fuchsine and examined under a microscope at a magnification of 1900 diameters.

The photograph in Plate 6 shows the typical flagellum of vibrio desulphuricans.

A total of 86 soil samples comprising all types of soil were examined. Of these 27 samples or 31% indicated the presence of high concentrations of bacteria, the remainder being practically free. Many of the samples were chosen where it was known that fairly severe corrosion existed and they may not be truly representative of average conditions throughout the area. With a larger number and more representative sampling, the cases where high concentrations of bacteria were present could be appreciably less than the 31% found above. It appears therefore that the sulphate reduction process is not very widespread in Sydney soils.

It was expected that there might be a relationship between the class of soil and the concentration of bacteria. Since they tend to thrive in anaerobic conditions it was thought the clays might show the greater number present.

However, of the 27 soils showing the greatest concentration of bacteria there were 4 clays, 8 sandy clays, 8 sandy clay loams, 2 sandy

Plate 6

MICRO PHOTOGRAPH SHOWING VIBRIO DESULPHURICANS STAINED WITH CARBOL-FUCHSINE x 1900 DIAMETERS

THIS PHOTOGRAPH WAS TAKEN FROM A PURE CULTURE OF THE SULPHATE-REDUCING BACTERIA OBTAINED AFTER THE ELIMINATION OF BACTERIUM COLI, AND SHOWS VERY CLEARLY THE SPIRAL-LIKE FLAGELLA OF THE ORGANISMS.

loams, 4 sands with one not classified. It would appear therefore that there is no relationship between the type of soil and the concentration of the bacteria.

During a previous investigation actual pitting rates due to corrosion had been measured on cast iron mains where soil samples were taken. It was found that no relationship existed between these rates and the bacterial concentration.

As a result of these tests it was concluded that

(1) Sulphate reduction due to the presence of Vibrio Desulphuricans does occur in Sydney soils but the process does not appear to be widespread nor to account for a great proportion of the corrosion experienced on mains.

(2) The occurrence of sulphate reduction apparently bears no relationship to soil type.

(3) Sulphate reduction does not appear to occur in well defined areas but rather in certain more or less isolated locations due to factors which were not determined.

Spun pipes must be thoroughly annealed to relieve any stresses that may be formed due to chilling in the metal mould. If this is not done properly the pipe is liable to fracture when subject to heavy vibration or laid too shallow at a road intersection.

Cast iron pipes with hemp-lead or roll-in rubber ring joints have been used as mains for low pressures of 6 - 7 ins wg. For higher pressures cast iron pipes with mechanical joints have been used for pressures up to 100 lbs/sq in while steel pipe has been employed for this pressure and upwards. Joints in the steel mains have, in general, been screwed up to and including 2" diameter and welded for larger diameters.

Steel pipes, with screwed joints, have been used exclusively in the past for services from main to meter and beyond. Originally parallel threaded sockets were employed with tapered threads on the end of the pipe. However, if the pipe was tightened up too much, a split and leaking socket resulted. It is now the practice to use a socket with threads tapered from each end, and a jointing compound to ensure a leak free joint.

By employing only good welders accustomed to welding pipes and checking the quality of the weld with gamma rays, it is possible to ensure that no leakage will occur from welded joints.

It is external corrosion of the pipe wall which accounts for the majority of leakage of gas from steel mains and services. Plate 7 shows a collection of service pipes in various stages of corrosion. In some cases it has been found that gas is being supplied through a hole in wet clay.

In Country areas in New South Wales very few steel mains and services have been protected against soil corrosion. In many cases black iron has been employed and this gives rise to both internal and external corrosion.

The above discussions and results of experimental work form the introduction to the present day problem of leakage of gas from underground structures when other gases are substituted for coal gas in the distribution system.

Plate 7 A collection of steel service pipes in various stages of corrosion.

As mentioned previously it was realised in the United States of America that when natural gas was substituted for manufactured gas it would be necessary to condition the new gas. It was decided to inject minute droplets of oil or fog into the gas together with some water vapour. This would keep hemp joints expanded and free from leaks and any rubber material in its expanded condition. An oil film on the interior surface of the pipe would retard internal corrosion and with the water vapour, settle dust which would otherwise be carried forward and block up pilots etc. It was also felt that oil fogging would tend to prevent the drying out of meter and governor leather diaphragms.

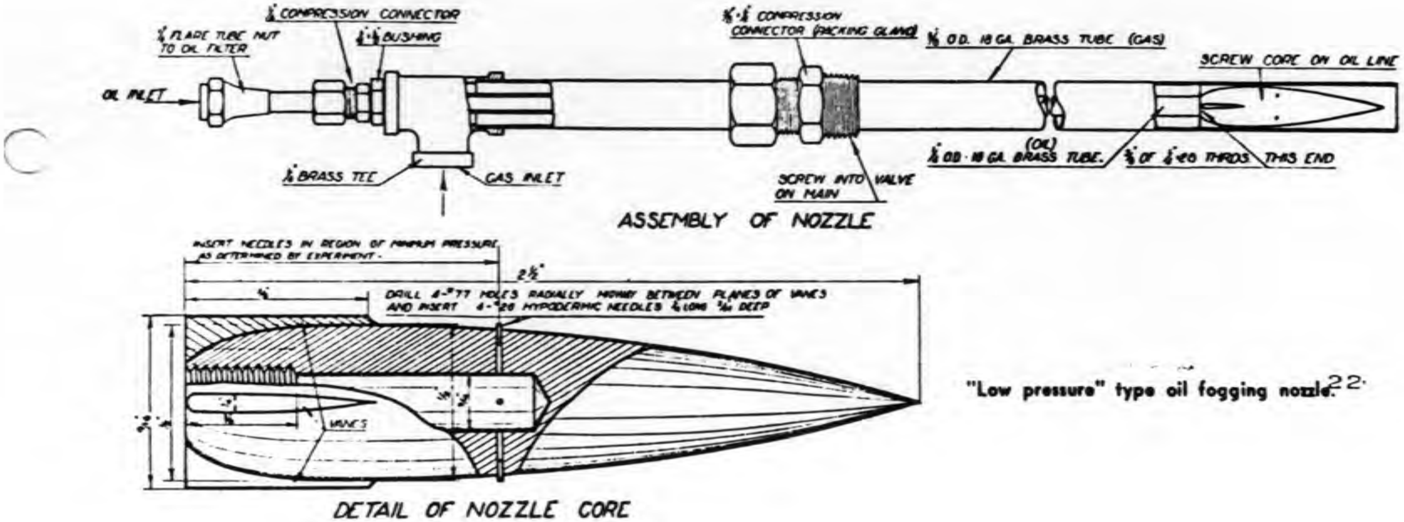
There are two basic approaches to the production of an oil fog.

"Cold" fogging is accomplished by atomising the oil through a suitable nozzle with high pressure gas. A high precentage of large droplets are produced which cannot be carried very far in the gas stream. They quickly fall out and must be removed in a convenient syphon pot.

To obtain the small droplet size required one type of nozzel, illustrated in Fig. 2, has short lengths of very fine hypodermic needles to feed the oil from the centre duct to the outside. The oil feed must be very carefully filtered to avoid blockage of the needles.

"Hot" fogging is accomplished by passing portion of the gas through hot oil. On returning the nearly saturated gas to the main stream it becomes supersaturated with oil and forms a fog. Alternately , to avoid overheating

Fig. 2 Nozzle assembly for cold fogging



"Low pressure" type oil fogging nozzle. 22.

and carbonisation of the oil, the side stream of gas is heated and passed through the oil

The distance a fog will be carried depends on the manner of its production and injection, and on the gas velocity, pressure, temperature and the configuration of the mains.

Distances of 2 - 3 miles up to 25 miles have been reported although an average would appear to be 5 - 6 miles.

Many different oils are reported to have been employed. In one case even spent transformer oil was used.

Anuskiewicz[4] in 1949 reported the results of a survey of gas conditioning practices in which the following oil specification was employed in hot fogging equipment:-

Chemical analysis	Olefines	9.7%
	Aromatics	7.7%
	Naphthenes	45.5%
	Paraffins	37.1%
Viscosity at 50°C	Say bolt seconds	178
Distillation range °C	First drop	318
	20%	336
	50%	352
	90%	390
	Dry	397
	Residue	2.5 ml

This survey also shows that a number of oils were in use at the time, with hot foggers operating at temperatures from 350°F to 500°F and fogging rates varying from 0.75 to 5.0 gallons per million cubic feet.

A typical method of controlling hot foggers is shown in Fig. 3. This control proportions fog production to gas sendout so as to maintain fog concentration at peak loads without flooding the system with fog at low rates.

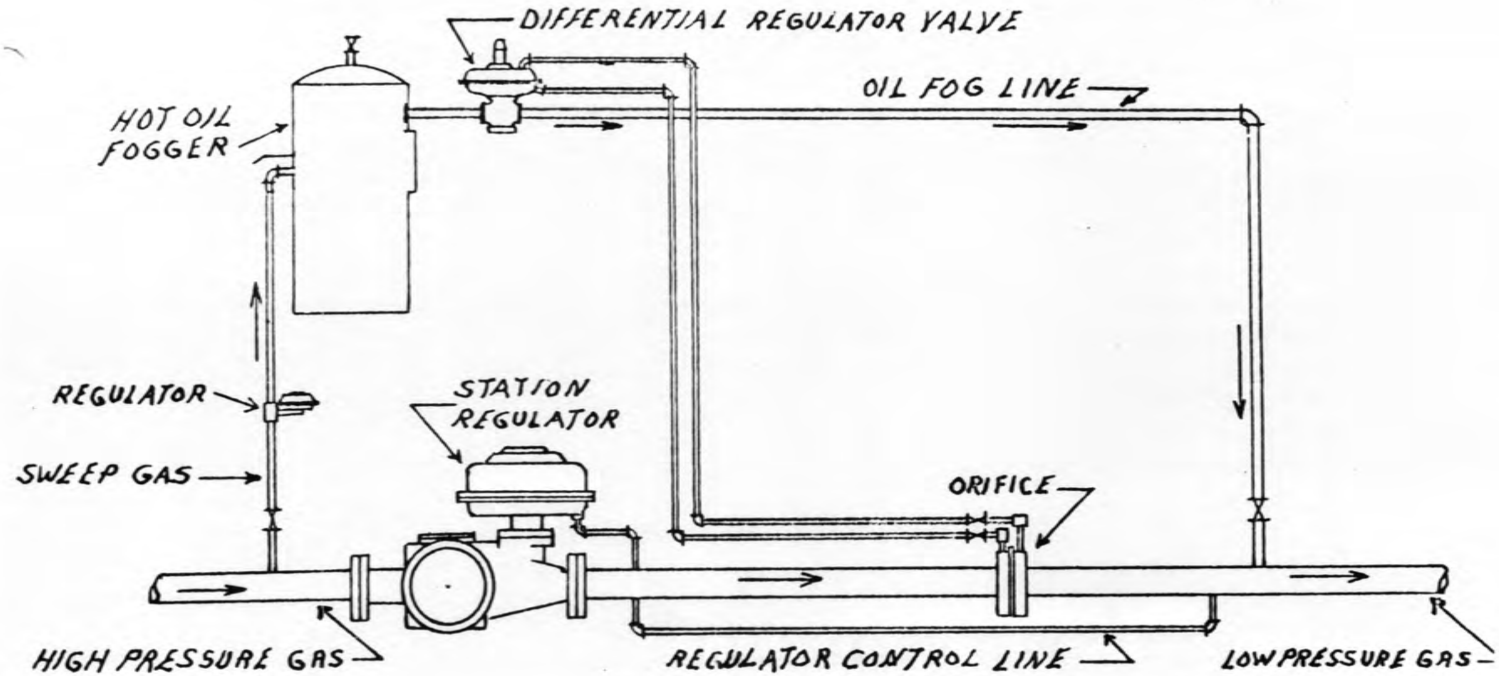
Humidification was almost universally accomplished by injecting steam into the gas, the major problem being to control the injection rate.

A satisfactory method of control is shown in Fig. 4 . A constant relative humidity of the gas is maintained at the control point. The extent of humidification employed varied from company to company. Some did not humidify; in the case of the others the extent varied from 35% to 100% relative humidity.

In general the oil fogging and humidification have proved successful. Hemp joints were kept gas tight providing the conditioning was carried out. simultaneously with the change in gas. The fogging oil appeared at pilots at the appliances showing that it had passed through the meters. The quantity of oil used was reduced so that it did not appear at the pilots. An examination of meter leathers showed that they had an oily look and feel.

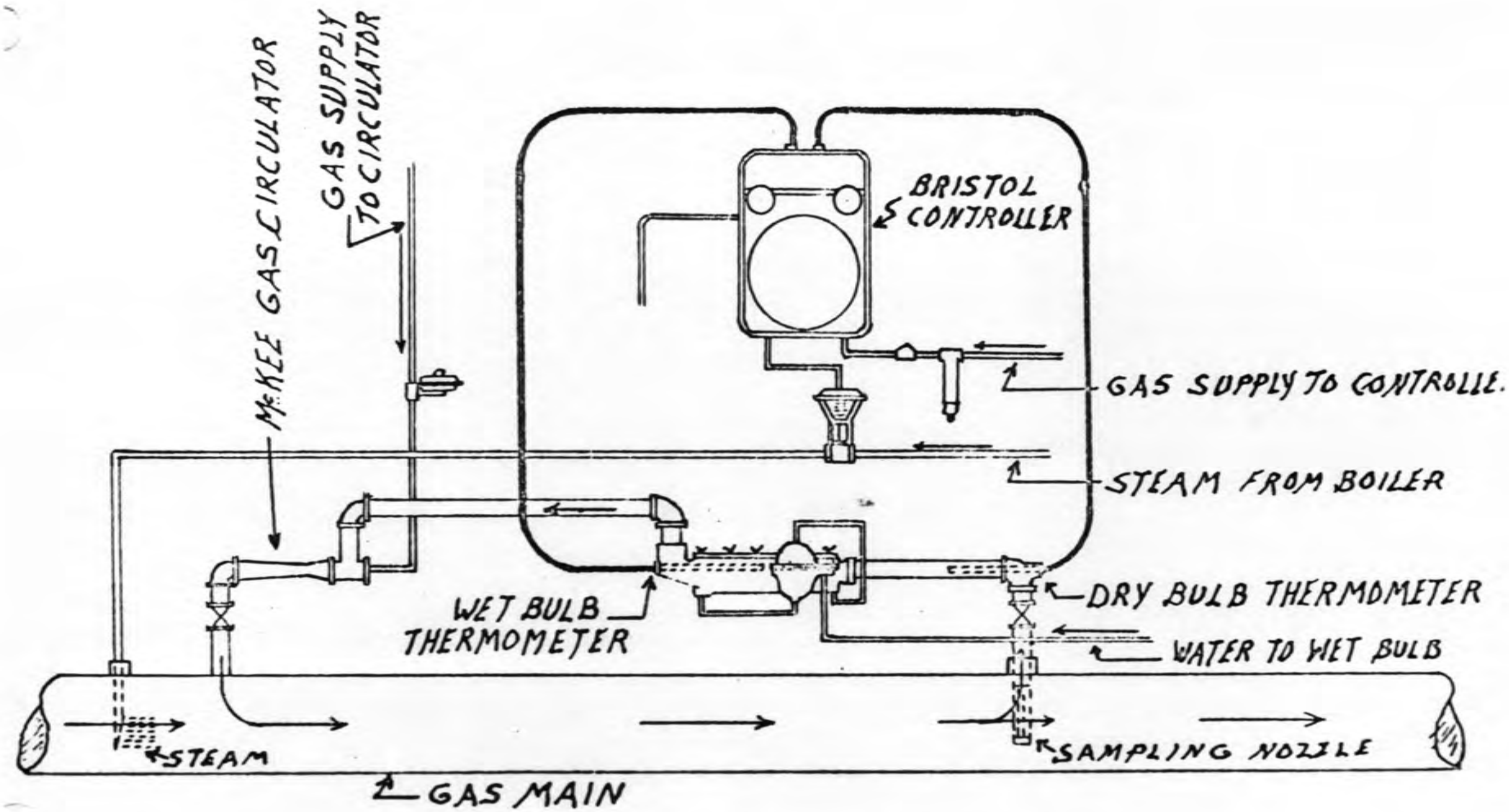
In 1944 L.J. Willien [5] carried out some experiments to prove the theory that light oils cause rubber to expand and to shrink when the oil evaporates.

Fig. 3



[illegible].-HOT OIL FOGGER CONTROL

Fig. 4



.-STEAM SATURATION CONTROL

Two rubber rings used in Dresser couplings were obtained and their outside diameter measured. They were immersed in toluol for 22 hours, removed and quickly measured. After atomspheric drying for 30 hours they were measured again.

One gasket (A) was then put in a high boiling mineral oil (38 API gravity) for 43 hours, removed and measured, dried atmospherically for 47 hours and measured. It was then put in gas oil (29 API gravity) for 68 hours, measured, after removal and again after 45 hours air drying.

The second gasket (B) after immersion in toluol and drying was placed in gas oil for 68 hours, removed, measured, dried for 45 hours and again measured.

The results are tabulated as follows:-

Original cross sectional diameter of both gaskets	1.83 inches
Cross section diameter of both gaskets	
after 22 hours in toluol	2.38 "
after 30 hours drying	1.83 "
after 43 hours in mineral oil	1.95 "
after 47 hours drying	1.95 "
after 68 hours in gas oil	2.05 "
after 45 hours drying	1.95 "
Gasket (B)	
after 68 hours in gas oil	2.03 "
after 45 hours drying	1.95 "

After immersion in toluol the rings increased 30% in size and returned to their original measurements. Gasket (A) increased 7% on immersion in mineral oil and did not shrink on drying. After immersion in gas oil it was 10% larger than originally and after drying it was still 7% larger. Gasket (B) showed the same results in gas oil as Gasket (A).

These results indicate that if a high boiling gas oil is used to treat the rubber rings, undue leakage should be prevented.

In July 1962 dehydration of coal gas by intense cooling was introduced at the Oyster Cove Works of the North Shore Gas Company. The swelling of rubber rings by condensable hydrocarbons had disintegrated them to some extent and forced sections into the main. Portions were torn off by the velocity of the gas and were found at the inlet to district governors.

The dehydrated gas low in condensable hydrocarbons, absorbed the oils from the partially disintegrated rings and the joints leaked.

In February 1963 D.E. Radford of the North Shore Gas Co. carried out an investigation to determine a suitable oil to swell the rings and keep them in a pliable condition.

It was postulated that the oil to be used should possess the following characteristics:-

(1) To cause the deteriorated rubber rings to expand to a sufficient degree

(2) Must not have an excessively aggressive action on rubber.

(3) Must have a fairly low vapour pressure so that once in the rubber it would not re-evaporate quickly.

(4) Must not contain any large amounts of gum forming hydrocarbons.

A number of oils were found to be capable of expanding the rubber, with the gas oil (condensable hydrocarbons) giving some spectacular results. This oil was ruled out since it had a high vapour pressure, a highly aggressive action on rubber and it contained a high proportion of gum forming hydrocarbons.

After testing a large number of oils, it was decided that the Shell Oil A L which contained about 50% aromatics, 5% unsaturateds and distilling between 200° and 300°C appeared to give the best all round results.

Samples of rubber were cut away from the good section of a ring which had failed and immersed in gas oil and Shell Oil A L. After 12 days the sample in gas oil had increased by 65% in length whereas that in A L oil had increased only 45%. Both samples were exposed to dry gas, the rate of shrinkage in the case of A L oil impregnated sample being 5% at 110 days compared to 65% in the same time with the gas oil sample. Figs. 5 and 6 show these test results.

They indicate that once the rubber has been treated with Shell Oil A L, joints are resealed in 2 - 3 weeks and they should remain so for some considerable time even if fogging is discontinued.

By late 1963 no further alarming leakage had occurred. It was then felt that it might be desirable to substitute a less aromatic and hence less aggressive oil for the highly aromatic Shell Oil A L.

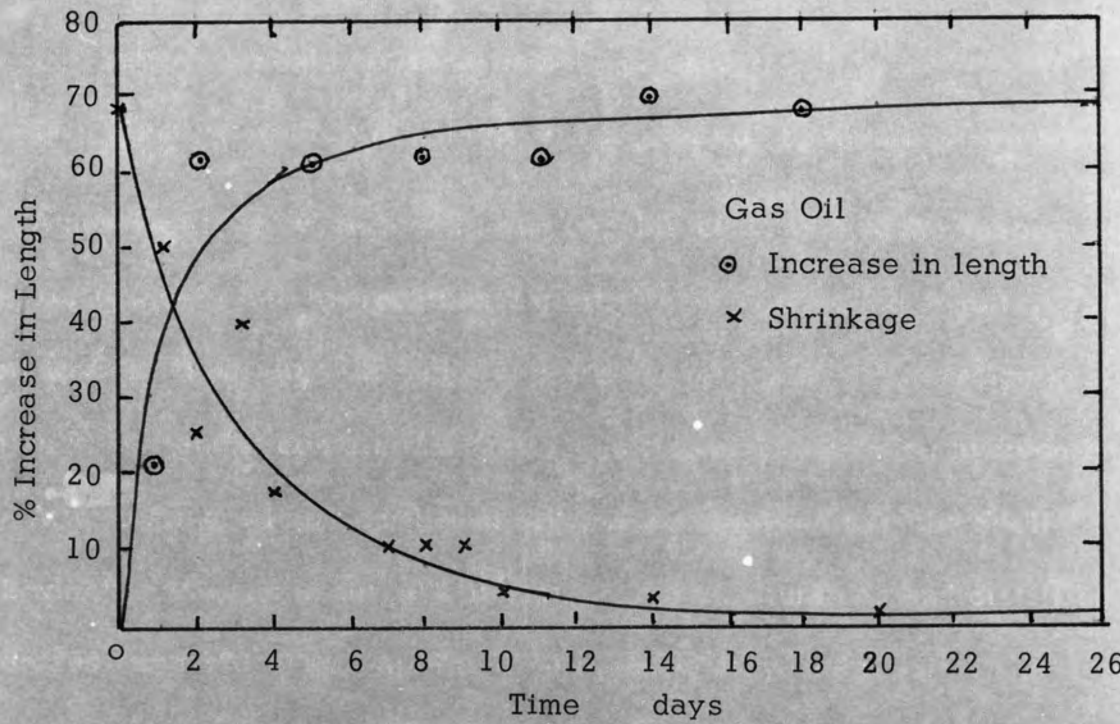


Fig. 5 Swelling of Rubber Sample in gas oil and subsequent shrinkage in dry gas

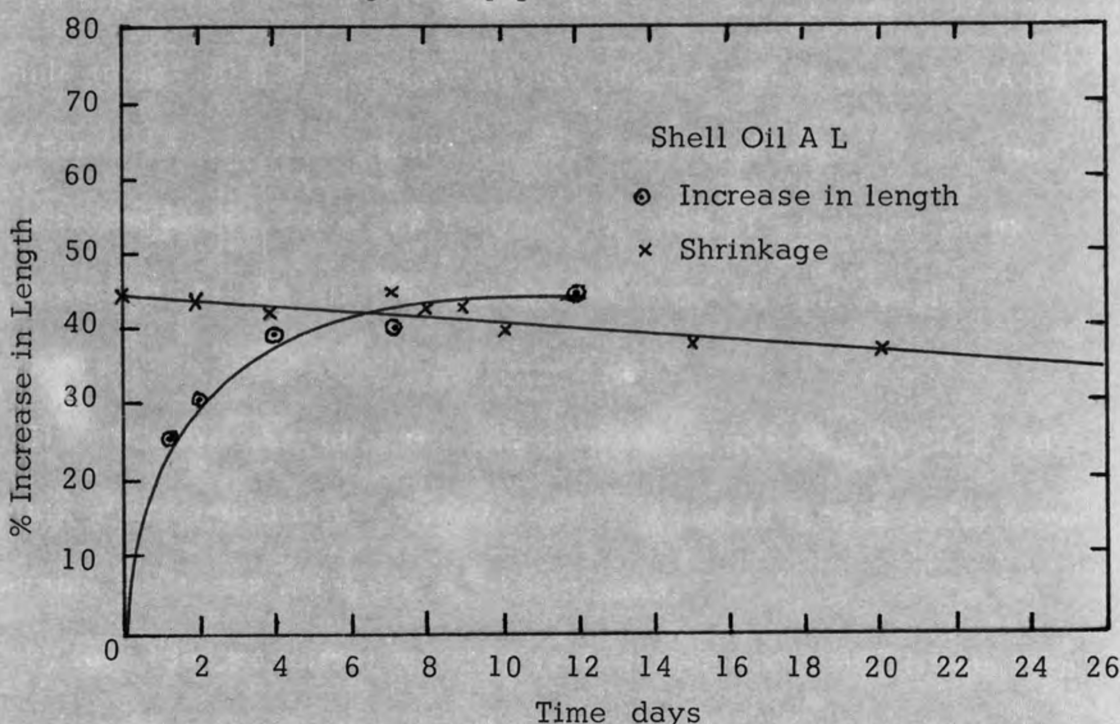


Fig. 6 Swelling of similar Rubber Ring sample in Shell Oil A L and subsequent shrinkage in dry gas

Finally Shell Oil P857, a naphthenic oil used as an extender in the rubber industry, was selected. Injection of a fifty-fifty mixture of A L and P857 was commenced in January 1964 and since that time little trouble has been experienced.

A comparison of the properties of the two oils is given in Table 7.

The properties of Shell Oil P857 are very similar to those of the oil stated by Anuskiewicz.

In the case of the North Shore Gas Co. and all gas conditioning in Country Towns "cold" oil fogging has been employed.

Originally a fuel injection pump from a diesel engine driven by an electric motor was employed. The oil under pressure of some 400 lbs/sq in was forced through a small nozzle inserted at the centre of the main. In some cases the pump was used at a governor in the district where a supply of electricity was available.

A second method employed was to mix the oil with propane in 100 lb bottle and spray the liquid mixture through a very small orifice into the gas. This method relies on the vapour pressure of the propane for atomisation and hence can be used anywhere in the district. The mixture comprises 4 parts of propane and 1 part of oil. The particles formed are somewhat smaller than in the case of the compressor, since 4/5 of the original particle in the form of propane evaporates into the gas. The method suffers from the disadvantage that frequent bottle changing is necessary.

In 1965 the Author presented a paper to the Institution of Gas Engineers,

Table 7

COMPARISON OF THE PROPERTIES
OF FOGGING OILS USED

		Carrier Oil A L	P857
Chemical Analysis			
Aromatics		60%	28%
Naphthenes			38%
Paraffins			34%
Specific gravity		0.9 - 0.92	0.925
Viscosity			
Centistokes	122°F	4.4	
	100°F		22.2
	210°F		3.5
Pour point °F		20 (max.)	-50
Flash point °F		170 (min.) - 206	340
Distillation range			
Initial °C		190 - 200	302
Final °C		300 - 320	396

Australia[6] wherein it was stated that if a change were made from coal gas to tempered liquefied petroleum gas and no precautions were taken, the quantity of gas lost by leakage would increase by 80%.

Experimental work has been carried out in a number of towns on different systems and under different conditions. The results of these tests may be conveniently discussed under the following headings:-

(1) Low pressure areas of supply, the whole distribution system which contains a considerable number of rubber ring joints.

(2) Low pressure area of supply, a small section with no rubber ring joints and all services shut off at meter cocks.

(3) High pressure of supply, trunk feeder main all rubber ring joints.

(4) High pressure area of supply, whole distribution system no rubber rings.

Low pressure area of supply. Whole system with some rubber ring joints

In spite of the warning regarding increased leakage mentioned above, on the 29th March 1966, T.L.P. gas was substituted for coal gas at Molong without any precautions being taken. By the end of December, the quarterly readings of consumers' meters showed that as much gas was being lost as was being sold.

This was understandable since there are some two miles of rubber ring jointed mains, $2\frac{1}{4}$ diameter adjacent to the Works. These joints received the full impact of the oil free gas, although it still had a water dew point which varied from $45.2^{o}F$ at midnight to $60.9^{o}F$ around mid-day.

On 31st January 1967 the gas losses were measured by means of a dry meter at varying pressures at the outlet of the Works. The test was carried out after midnight when pilots, storage water heaters and appliances at the Hospital should be the only consumers of gas. As this usage was all fed through appliance governors, it would not be affected by any variation in the pressure of gas in the mains. In order to supply this gas and to ensure that pilots are not extinguished it is necessary to maintain a minimum pressure of 3.0 ins w.g. at the outlet of the Works.

The pressure was set at the outlet of governor and the proving hand of the meter timed with a stop watch. This was repeated after altering the pressure and allowing sufficient time for conditions to stabilise. Obtaining practically constant measurement of time was an indication that this had occurred.

The quantity of gas leaving the Works (S cuft./hr.) was plotted against outlet pressure (h ins w.g.) as shown in Fig. 7 and Appendix 1. As some gas was being used the curve would cut the ordinate at a point equal to this usage.

Since 2.8 ins w.g. was the lowest pressure at which gas sent out was measured, it was necessary to devise some means of determining this

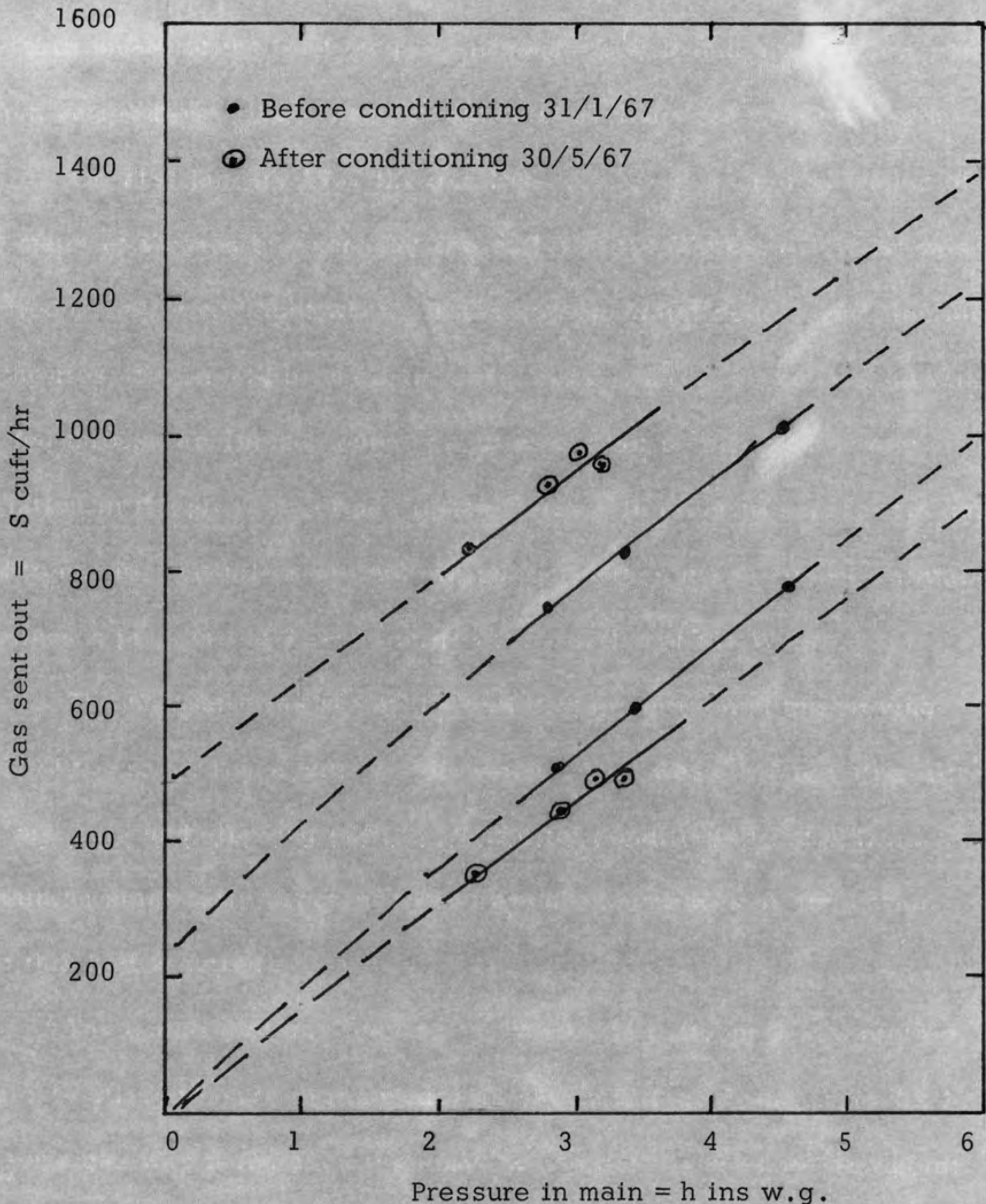


Fig. 7 Quantity of Gas leaving Molong Works between midnight and 2 a.m. and Quantity of Gas leaking from mains and services at various pressures

usage with accuracy.

On examining the results it was found that an equation of the form

$$S = A + Bh + Ch^2$$

would satisfy the experimental values.

The constants A, B and C using the data of Fig. 7 were evaluated to give the equation of the curve as

$$S = 240 + 205.9h - 7.5h^2$$

The usage of 240 cuft/hr is the rate at which gas was consumed during the period of the test.

The curve of actual leakage is

$$Q = 205.9h - 7.5h^2$$

and determines the rate at which gas is being lost each hour of the day and night.

This method of evaluating the usage of gas has been employed wherever it has not been possible to decrease pressures below the nominal 3.0 ins.w.g.

The leakage of gas at various pressures in the main is shown in Fig. 7.

Gas conditioning was then commenced using Shell Oil A L in a cold fogging system. A diesel engine fuel injection pump was employed the oil being fed at a pressure of about 400 lbs/sq in to a diesel injector inserted in the centre of the Works outlet main.

Prior to fogging the make of gas required to supply consumers' demand for gas and leakage was 42,500 cu ft/day. Ten days after fogging commenced the make required had fallen to 35,000 cuft/day. It was considered that during this period and at this time of the year, the demand for gas would not vary to any great extent and that the reduced make was indicative of reduced leakage.

After 3 weeks, a mixture of 50/50 Shell Oil A L and P 857 was used and after a further six weeks, P857 was used alone.

The test for leakage was repeated on 30/5/67 with the result shown in previous Fig. 7 and Appendix 1. By this time the weather was colder, gas heating appliances were in operation at the Hospital and it was anticipated that the usage would be greater than before.

The equation of the curve was now

$$S = 480 + 160h - 1.25h^2$$

As before subtracting the usage of 480 cuft/hr from the total quantity of gas measured gave the equation for leakage of gas from system as

$$Q = 160h - 1.25h^2$$

This leakage is lower than that obtaining before gas conditioning was carried out.

Unfortunately there has not been the opportunity to carry out a further leakage test on this system. However the loss of gas per quarter has now been reduced below what it was before the changeover to T.L.P. gas as shown in Figure 23 of the section on Thermal Content of Gas page 127

When the Aberdare County Council was formed, a new Works was constructed at Cessnock and the horizontal retort carbonizing plants at Maitland and East Maitland were closed down. While gas was still manufactured in horizontal retorts at the new plant, it was transmitted 18 miles to Maitland and a further 4 miles to East Maitland.

The gas is compressed at Cessnock at pressures up to 45 lbs/sq. in gauge. In this process parctically the whole of the condensable hydrocarbons are removed together with most of the water. On arrival at Maitland the gas is virtually oil and water free.

It is stored in a wet gas holder at the old Maitland Works. The wet holder is East Maitland disintegrated and the gas in reticulated through governors direct from the trunk main into the low and high pressure systems. The latter gas has a water dew point of 20.3°F and a condensable hydrocarbon content of 0.2 - 0.3 ml/cu.ft .

The same gas is automatically re-hydrated in the wet Maitland holder to a water dew point of 68.4°F, but its condensable hydrocarbon content remains at 0.2 - 0.3 ml/cu.ft.

Hence it would be anticipated that at

(a) East Maitland rubber ring joints would shrink and hemp and lead joints would dry out.

(b) Maitland rubber ring joints would shrink but hemp and lead joints would remain moist.

The East Maitland low pressure area of supply which is not interconnected with Maitland, consists of 33 miles of main and 1345 consumers whose services are approximately 16.5 miles long. The proportion of rubber ring jointed main in this length is not known exactly but it is certain that there are several miles of mostly 4" diameter, through which dry gas has been distributed for 6 years.

A leakage test was conducted on this whole low pressure system by varying pressures at the outlet of the station governor with the results shown in Fig. 8 and Appendix 2.

The calculated equation of this curve was

$$S = 240 + 170\,h - 10\,h^2$$

Subtracting the usage of 240 cuft/hr from the total quantity measured gave the leakage curve in Fig. 9 as

$$Q = 170\,h - 10\,h^2$$

Shell Oil A L was sprayed into the main at the outlet of the governor

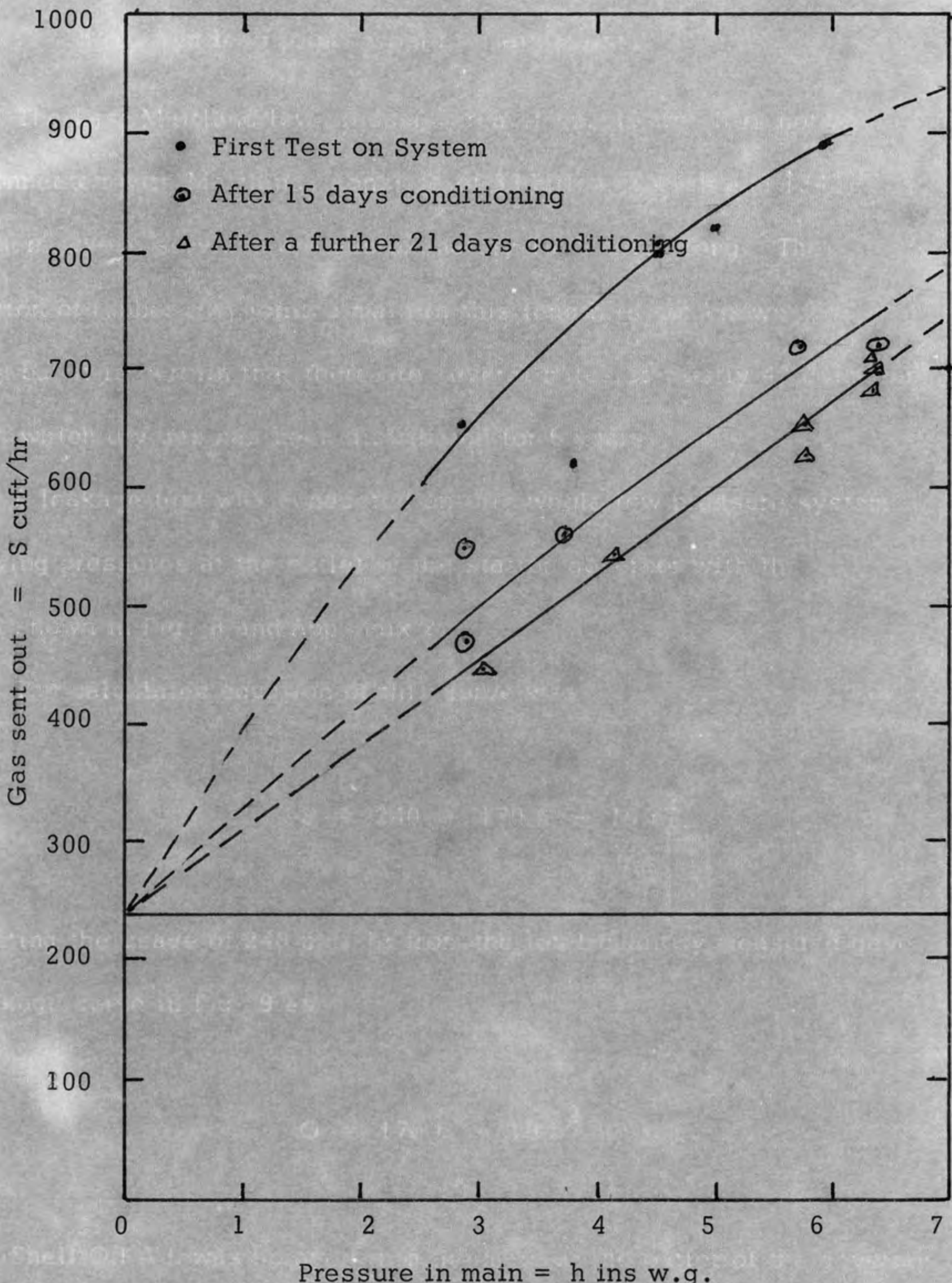


Fig. 8 Quantity of Gas leaving East Maitland Works between Midnight and 5 a.m. at various outlet pressures

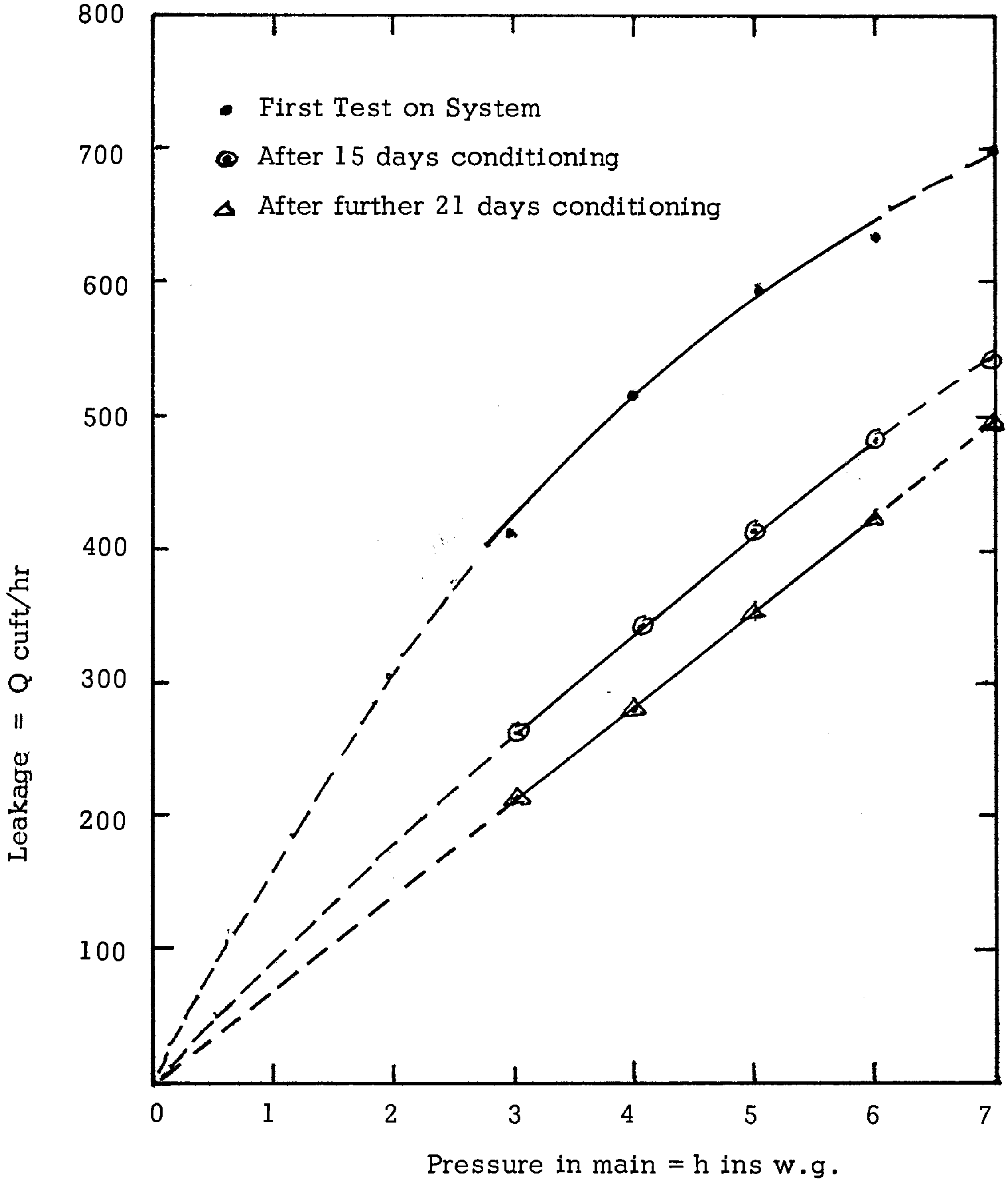


Fig. 9 Quantity of Gas leaking from the low pressure mains and services in East Maitland at various pressures

for 15 days over a period of 21 days and only during the hours of 7.0 a.m. - 9.0 p.m.

A further test gave the results shown in Fig. 8 with a calculated equation of

$$S = 240 + 93.3\,h - 2.2\,h^2$$

The leakage curve in Fig. 9 is now

$$Q = 93.3\,h - 2.2\,h^2$$

The fact that the usage remained the same is understandable since there is no industrial load and the appliances connected would be approximately the same.

The total quantity of oil sprayed into the system was 60 gallons. At the first syphon outside the Works 32 gallons of oil were recovered. All syphons past this point did not contain any oil, so that approximately 28 gallons had been carried forward into the system.

The oil was changed to P857 and gas conditioning was continued for 21 days during the next six weeks. The results of the third test are also shown in Fig. 8 and Appendix 2. It will be noted that these results lie on a straight line, its equation being

$$S = 240 + 72\,h$$

The equation of the leakage curve in Fig. 9 is

$$Q = 72\,h.$$

In the case of the first and second tests the relationships between loss and pressure were curves, whereas in the third test, it is a straight line. It is considered that so long as the line is curved, loss through rubber ring joints is indicated as well as other losses. As soon as tests show a straight line, all rubber ring joints are sealed. It is not yet known if further conditioning will seal other leaks. It is hoped to be able to carry out tests at a later date to ascertain if this is so.

At an average pressure of 4 ins w.g. in the distribution system the saving due to gas conditioning amounted to 2,000,000 cuft per annum. The value of this saving at $1.20 per 1000 cuft amounts to $2,400.

A third complete low pressure system distributing T.L.P. gas has been tested at Camden with the result shown in Fig. 10 and Appendix 3.

The equation of the curve is

$$S = 36.2 + 22.5\,h - 0.16\,h^2$$

That this curve is almost a straight line is only to be expected since there is only a relatively small quantity of rubber ring jointed main adjacent to the Works. The gas is being conditioned with a 50/50 mixture of A L and P857 but the effect has not yet been determined.

Plate 8 shows the layout of the test equipment at Camden. The station governor is on the right with the 400 cuft test meter and recording pressure gauge in the left foreground. In the centre of the main is the plate which diverts the gas leaving the Works through the test meter.

The West Tamworth area is isolated from the main township by the Peel River, and is fed by a main over the bridge. The gas distributed is a mixture of coal gas and reformed gas, and is sent out from the Works at

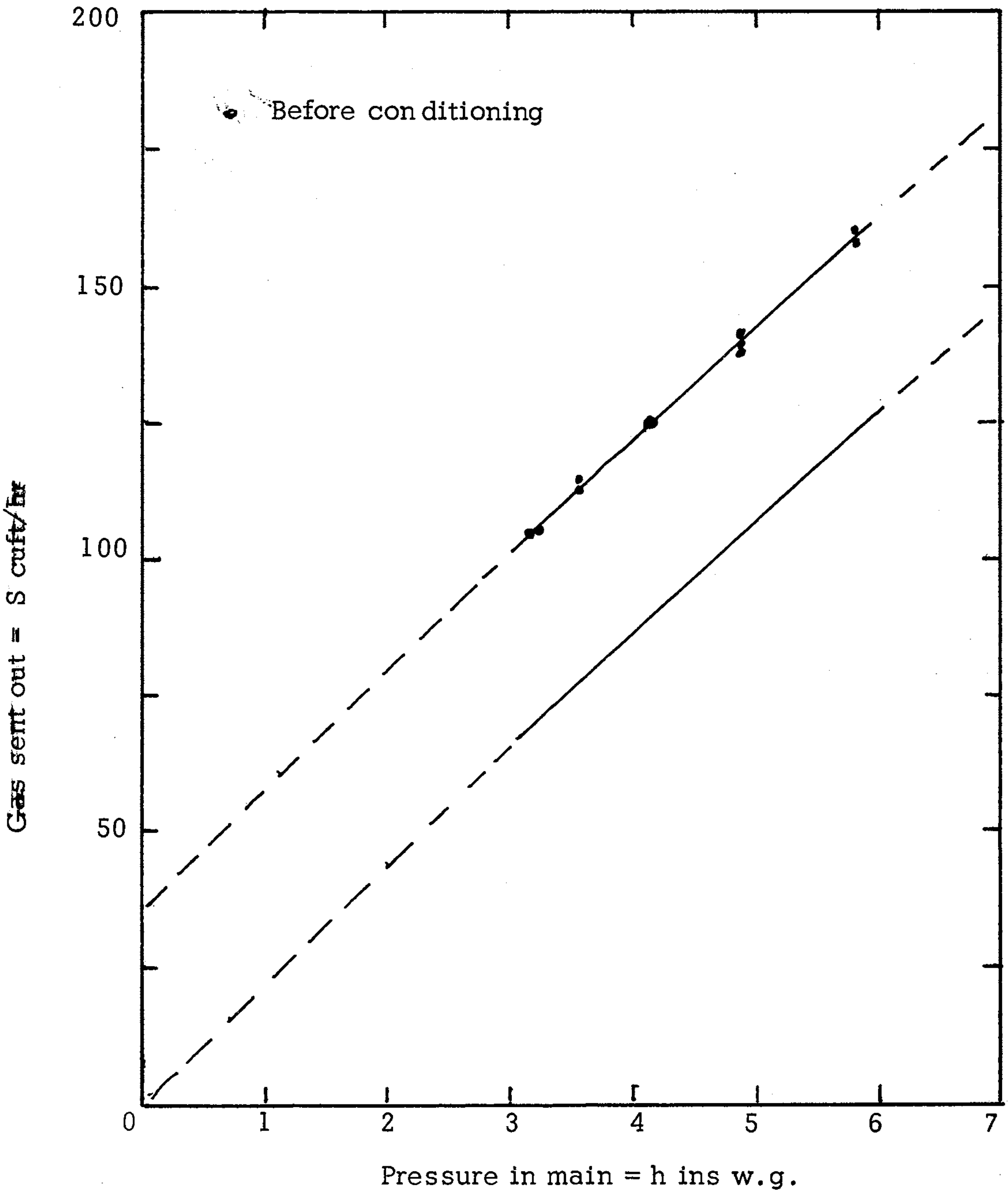


Fig. 10 Quantity of Gas leaving Camden Works between Midnight and 3 a.m. and Quantity of Gas leaking from low pressure mains and services at various pressures

Plate 8. The Layout of the Test Equipment at Camden.

pressures varying from 7.0 ins w.g. in summer to 11.0 ins w.g. in winter.

In this area there are 73,557 feet of main, 1386 feet of 6" diameter 22,572 feet of 4" diameter, 15,545 feet of 3" diameter and 34,056 feet 2" diameter and under.

In addition there are 650 services consisting of galvanised iron pipe with screwed and socketed joints with a total length of 42,250 feet.

The results of a test of leakage carried out before gas conditioning are shown in Fig. 11 and Appendix 4. Unlike the previous loss curves this one is concave upwards, losses increasing rapidly with increase in gas pressure in the main.

The equation of the curve is

$$S = 103.4 + 69.46\,h + 3.33\,h^2$$

Subtracting the usage of 103.4 cuft/hr from the total quantity measured gave the leakage curve in Fig. 11 as

$$Q \doteq 69.46\,h + 3.33\,h^2$$

This system is being conditioned but no results are as yet available.

The losses from a medium pressure trunk main at Bathurst were measured. This main which is 6,226 yards long has 4730 yards of roll in rubber ring jointed main. The remaining section has either hemp and lead or mechanical joints. There are 12 services connected to it.

During the hours of 11.30 p.m. and 5.30 a.m. gas is supplied through this main at a pressure of 5.0 ins w.g. from a low pressure holder. The maximum pressure during the test was limited to 9 ins w.g. to determine

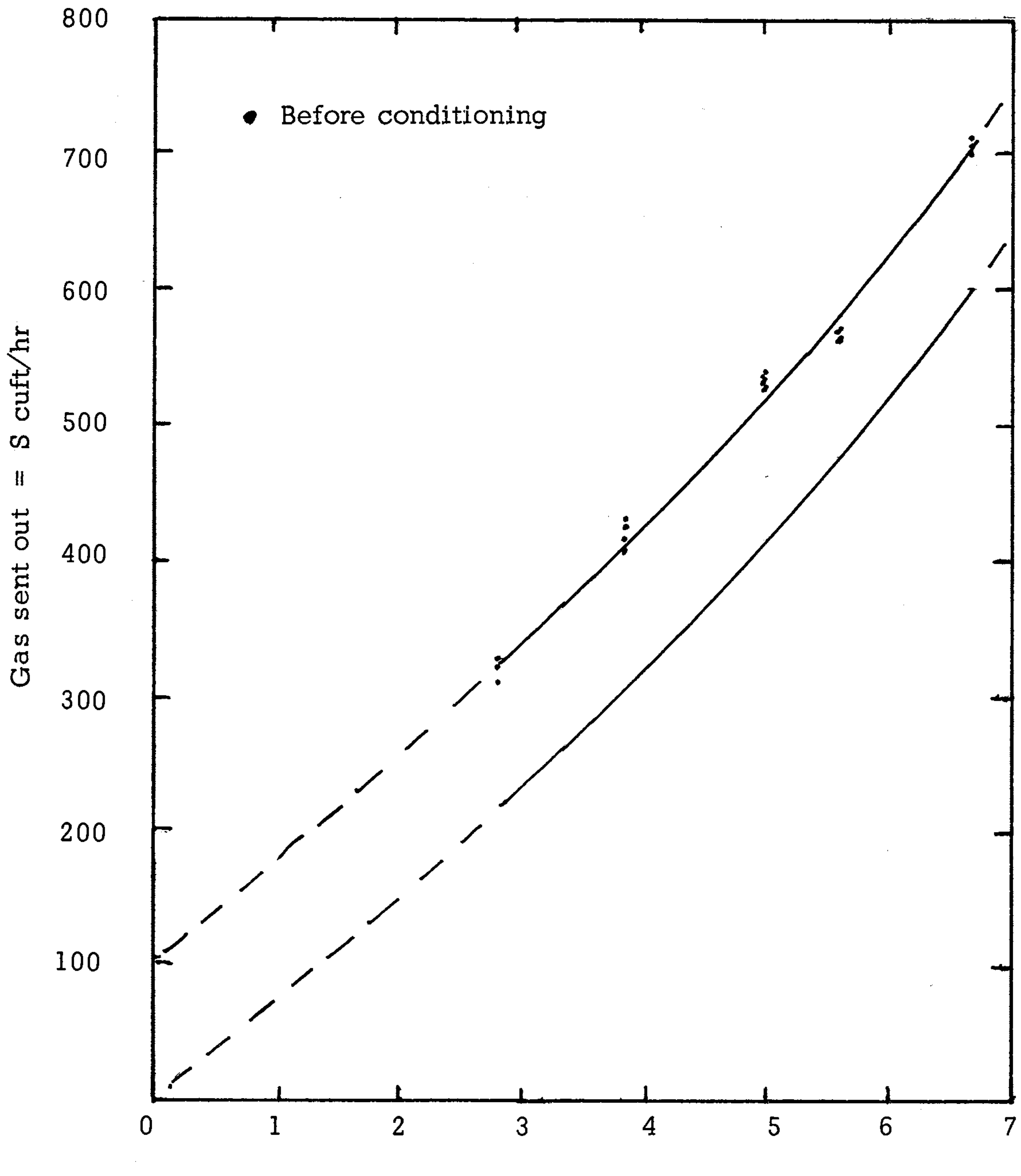


Fig. 11 Quantity of Gas entering West Tamworth area between 2 a.m. and 5 a.m. and Quantity of Gas leaking from low pressure mains and services at various pressures

the effect of this practice.

The results of the test are shown in Fig. 12 and Appendix 5. Again the loss curve is concave upwards in a system which comprises 76% roll in rubber ring joints.

The equation of the curve is

$$S = 24 + 28h + 0.5h^2$$

Difficulty was experienced in obtaining constant readings of gas sent out, even though the pressures at each setting remained constant. The only usage was the consumption of 12 storage hot water services whose aggregate consumption on standby pilots would be approximately 23 cuft/hr. This agrees closely with the 24 cuft/hr usage as determined from the average curve. The possibility of a thermostat operating a heater would account for the maximum recorded send outs giving an increased usage to 60 cuft/hr.

Subtracting the leakage of 24 cuft/hr from the total quantity measured gave the leakage curve in Fig. 12 as

$$Q = 28h + 0.5h^2$$

The leakage of 150 cuft/hr at 5.0 ins w.g. amounts to 328,000 cuft. annum for a 6 hour period each night. At a cost of \$1.50 per 1000 cuft this practice is at present costing approximately \$500 per annum in gas lost. Gas conditioning has commenced on this main but no results are yet available.

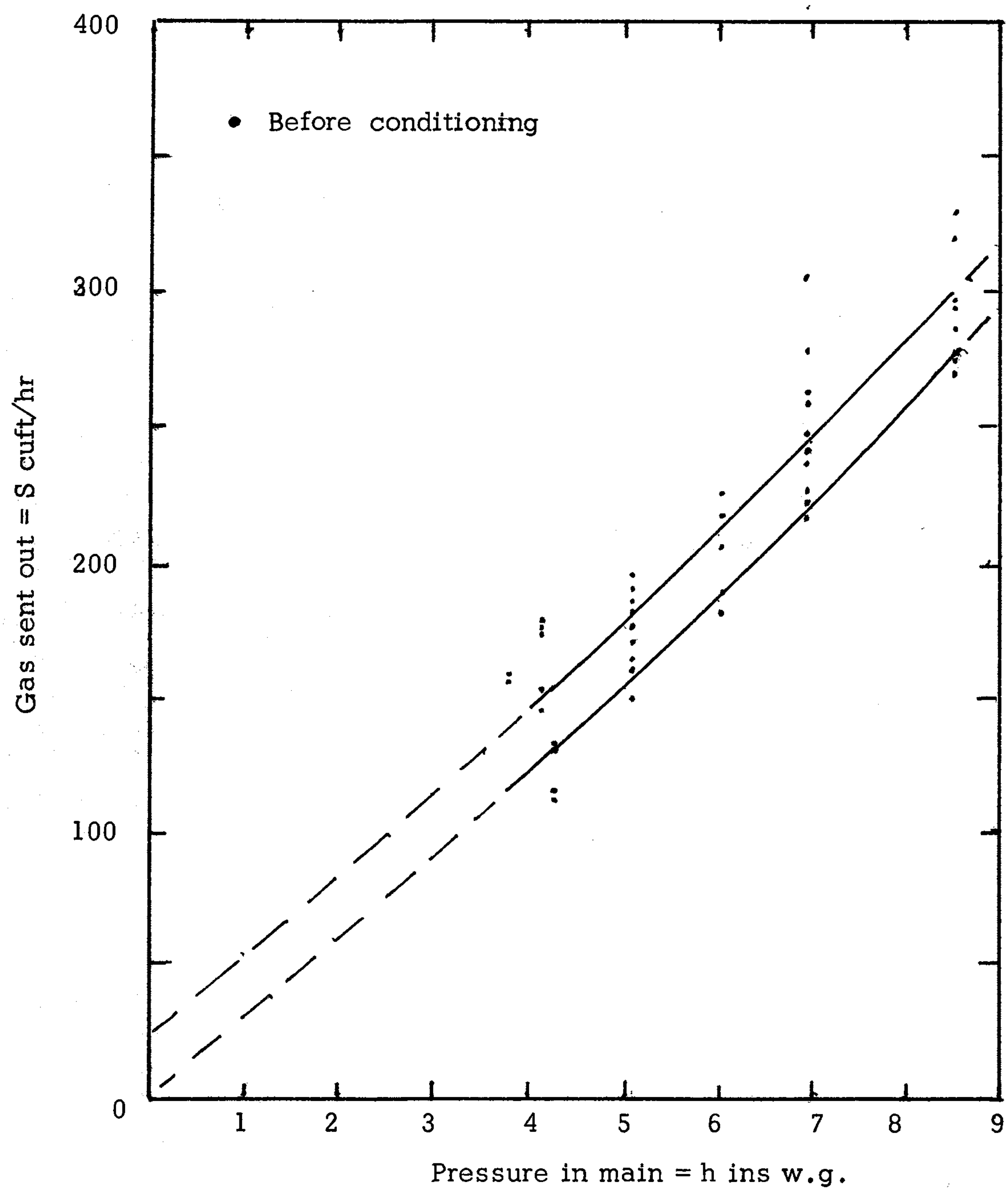


Fig. 12 Quantity of Gas leaving Bathurst Works between 1 a.m. and 4 a.m. through medium pressure main and Quantity of gas leaking from it at various pressures

Low Pressure Area of Supply. Isolated Sections, No Rubber Rings.

In the next series of tests it was possible to isolate the section of main and shut off the services at the meter cocks. Hence, in all these cases the gas measured is that due to leakage only.

At Molong a section of 3" diameter welded steel main 215 yards long was isolated and gas supplied through a meter into one end. There were 5 services with an aggregate length of 191 yards from the main to the point where they emerged from the ground.

The pressure at which the gas entered the test section was varied by means of a small appliance governor. Unfortunately owing to difficulties encountered in isolating the main it was not possible to obtain a full series of tests before it was necessary to restore supply to consumers.

The results are shown in Fig. 13 and Appendix 6, the pressure - loss curve passing through the origin since there is no usage included in the volume measured.

The equation of the curve is

$$Q = 3.362\,h - 0.225\,h^2$$

At Camden a section of 3" diameter cast iron main, 397 yards long with hemp and lead joints is fed through a governor from the high pressure system. There are 21 services with a total length of 904 feet connected to it, all of which were shut off at the service cock.

To carry out the test, it was only necessary to close the plug cock

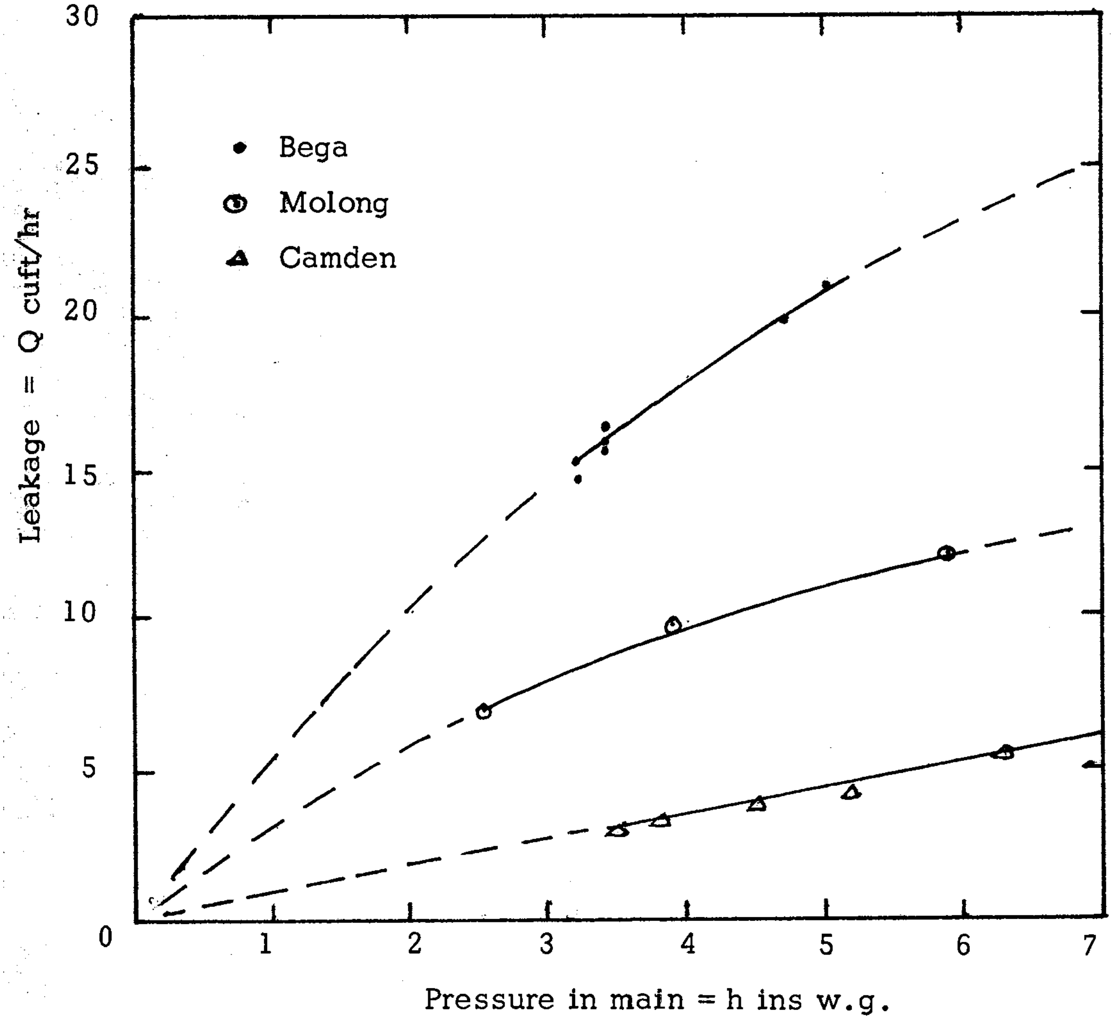


Fig. 13 Quantity of Gas leaking from isolated low pressure sections of main and services at various pressures

at the outlet of the governor and by pass it through a meter.

The results are also shown in Fig. 13 and Appendix 7. The points lie on a straight line passing through the origin since there is no usage. Its equation is

$$Q = 0.84\ h$$

A third test was carried out at Bega on 1910 feet of 2" diameter main and 200 feet of $1\frac{1}{4}$" diameter main with 1127 feet of 1" diameter service pipe. All joints are screwed and socketed. Again all service cocks were turned off so that the leakage curve shown in Fig. 13 and Appendix 8 passes through the origin. Its equation is

$$Q = 5.7\,h - 0.3\,h^2$$

<u>High Pressure Area of Supply. Trunk Main with Rubber Ring Joints.</u>

A 6" diameter cast iron main with rubber ring joints 8624 yards long was laid in 1942 to supply gas from the Maitland Works to the Munition Factory at Rutherford. Subsequently a 6" diameter cast iron main 765 yards long was laid from this main across the Belmore Bridge to a governor at Lorn. During the period midnight to 4.30 a.m. gas is supplied by this governor to 400 customers in Lorn at a constant pressure of 3.0 ins w.g.

Hence for the purposes of the test, this quantity of gas which comprises usage and leakage in the Lorn low pressure area will be a constant and independent of any variation in the high pressure main.

To this quantity of gas must be added any usage at the old Munition

Factory (now Burlington Mills) which in any case would be supplied through constant outlet pressure governors. Actually on the night on which the test was carried out, the mills were not working and the only gas consumed was by 2 bunsen burners in the laboratory and the maintenance rate of 12 Rheem hot water services.

The pressure of gas in the trunk main has a maximum value of approximately 2 lbs/sq in. Any gas meters with a capacity of 1200 or 3000 cuft/hour that were available had tin cases which would not withstand the above pressure. The only cast case meters available had a nominal capacity of 200.cuft/hour. It was decided to parallel 3 of these meters with common inlet and outlet manifolds. Gas cocks on the inlets allowed one or more to be operated at the one time. Simultaneous readings were made by two observers. Gas volumes were corrected for pressure to 2.0 ins w.g.

Gas pressures at the inlet to the main were read on a 72" water U gauge.

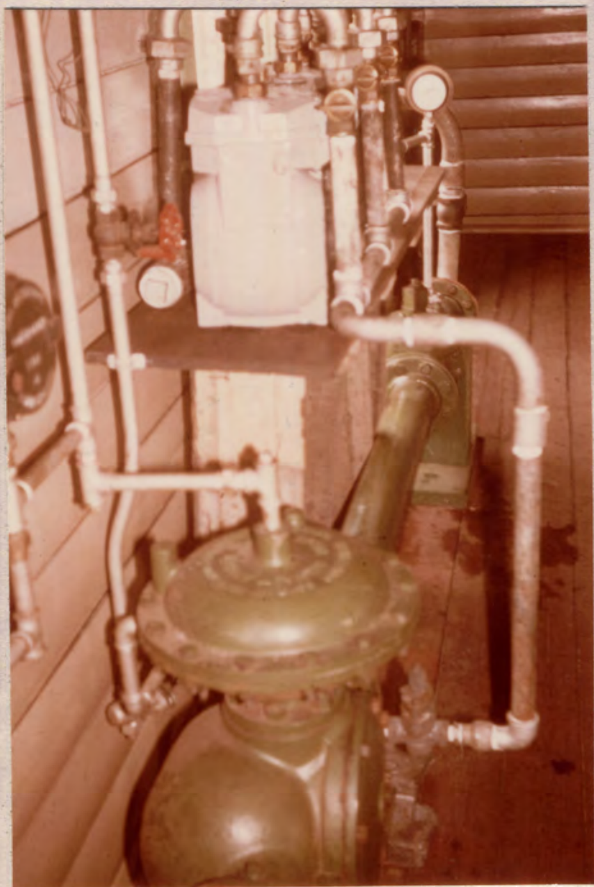
The arrangement of the testing equipment is shown in the two photographs of Plate 9.

The results of the tests are shown in the curve of Fig. 14 and Appendix 9. The equation being

$$S = 1425 + 1.75\,h + 0.225\,h^2$$

Subtracting the usage gives the loss curve in the trunk main also shown in the same figure.

The usage of 1425 cuft of gas per hour is made up of



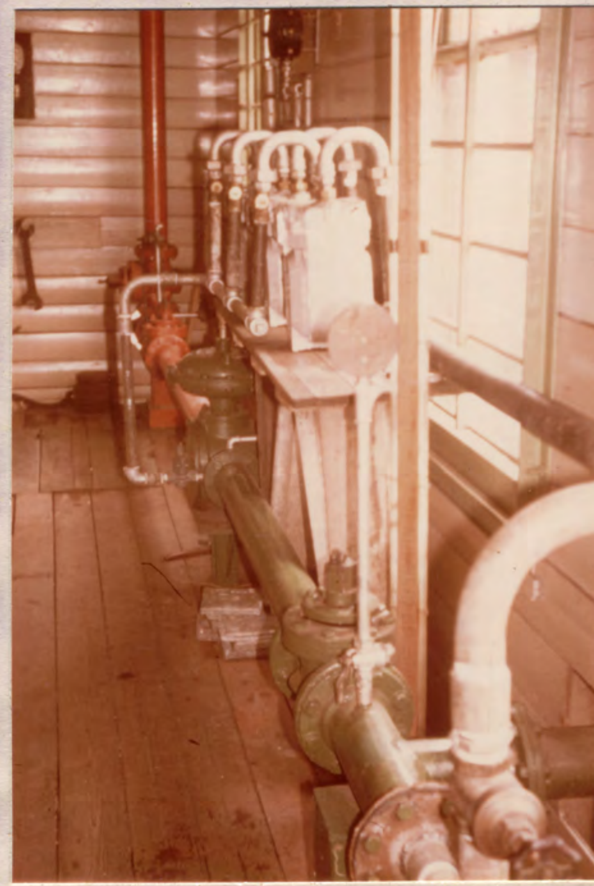


Plate 9. The Arrangement of the Test Equipment at the Old Maitland Works.

Governor and Clock Control in foreground

Test Meters in background U gauge in foreground

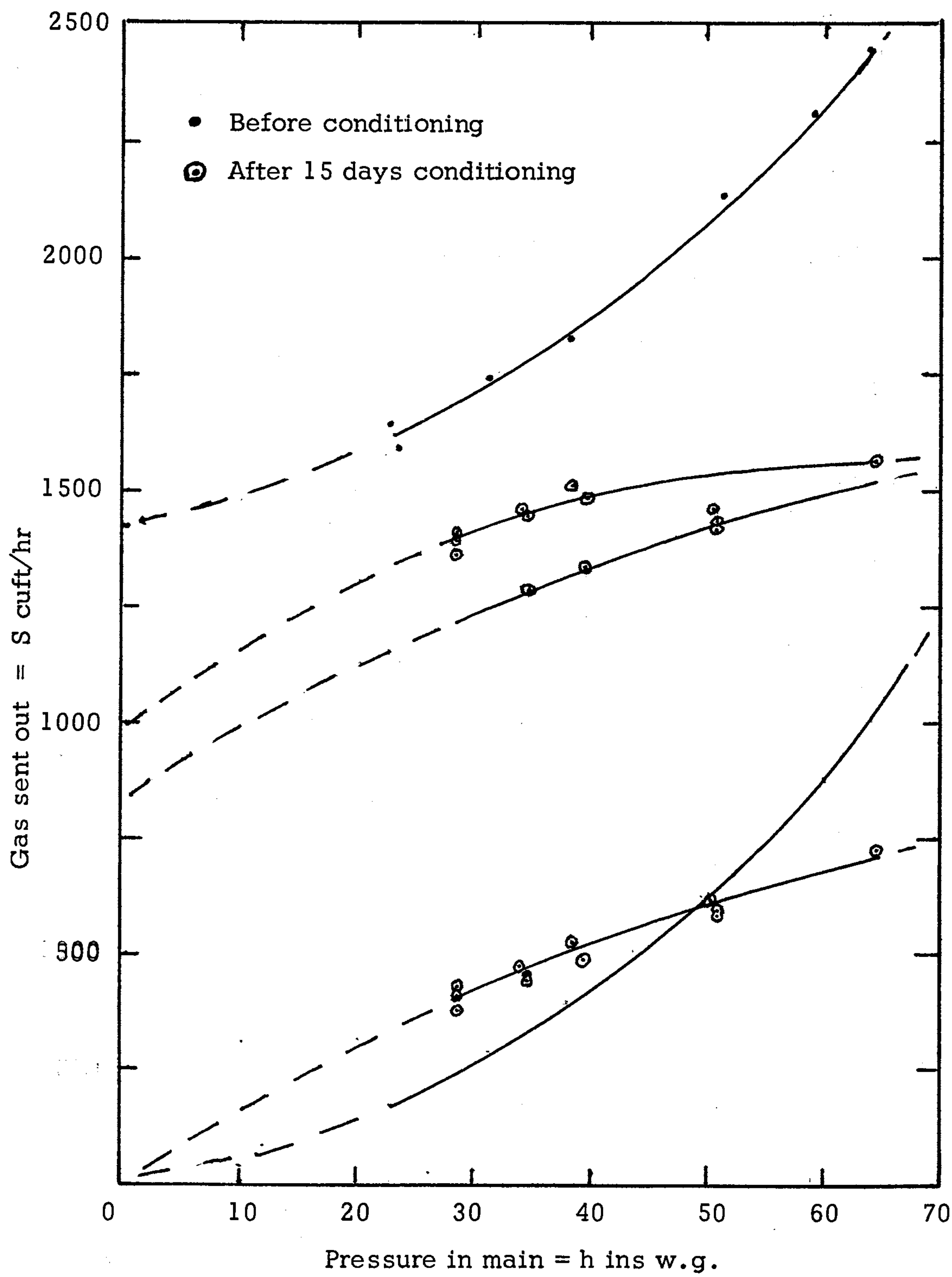


Fig. 14 Quantity of Gas leaving Old Maitland Works between Midnight and 4 a.m. through high pressure main and Quantity of Gas leaking from it at various pressures

(a) Usage on trunk high pressure line

(b) Gas passing through Lorn Governor

(i) Usage in Lorn

(ii) Losses in Lorn

(a) It is estimated that the 2 bunsen burners and the 12 Rheem Hot water services would consume 34 cuft /hour. Further that the pilots at the 40 customer's premises would consume 40 x 3 = 120 cuft/hour

(b) There are 38 appliances in the Lorn area fitted with pilots and at 3 cuft/hour they would consume a total of 114 cuft.hour.

It is estimated that the leakage of gas in the Lorn district is 1425 - 34 - 120 - 114 = 1157 cuft/hour at a pressure of 3.0 ins w.g.

From the pressure chart at the outlet of the governor the average pressure over the 24 hours is 5.3 ins w.g. The estimated annual losses in Lorn would be

$$\frac{5.3}{3.0} \times 1157 \times 8760 = 17{,}906{,}000 \text{ cuft.}$$

The high pressure governor supplying gas to the trunk main is clock controlled to furnish a low pressure of 1.0 lbs/sq in, a medium pressure of 1.5 lbs/sq in and a peak pressure of 2.0 lbs/sq in. From the curve of Fig. 14 the losses in cubic feet/hour at these pressures are determined and multiplied by the times at which they are operating to give the average loss per day.

Pressure lbs/sq in	Loss cuft/hr	Hours	Total Loss cuft
1.0	130	5.5	715
1.5	328	11.0	3608
2.0	625	7.5	4688

Average Loss = 9011 cuft/day

The estimated annual losses from the high pressure trunk main would be

9011 x 365 = 3,289,000 cuft.

From the knowledge that this main was laid in 1942, and the fact that a coal gas with a very low condensable hydrocarbon content has been distributed for nearly 6 years, it is certain that almost the whole of the above loss is due to leaking rubber ring joints and this can be eliminated by gas conditioning. The curve is concave upwards indicating that leakage from rubber ring joints preponderates.

The gas was conditioned for a period of 15 days. A further test gave the results also shown in Fig. 14 and Appendix 9.

A check with the personnel at the Burlington Mills revealed that a singeing machine was working intermittently during the period of this test and this variation in usage could account for the difficulty experienced in obtaining constant test figures.

Accordingly two curves were drawn through the experimental points. Their equations are

$$S_1 = 986 + 18.56\, h_1 - 0.147\, h_1^2$$

the usage of gas being 986 cuft/hour and

$$S_2 = 840 + 15.36\,h_2 - 0.0746\,h_2^{\,2}$$

with a usage of 840 cuft/hour.

The difference between the two values of usage of 146 cuft/hour would be the approximate consumption of the singeing machine.

Subtracting the above usages of gas from the gas sent out gave the new loss curve shown in Fig. 14. It will be seen that by adopting the above method of analysing the results a reasonably smooth curve of actual losses is obtained. Although losses have been reduced, further gas conditioning is required. It should be noted that the loss curve is now concave downwards indicating that some leaking rubber ring joints have been sealed.

High Pressure Area of Supply. Whole Town Without Rubber Ring Joints.

The outer areas of Camden are supplied from the Works with T.L.P. gas at a pressure of approximately 10 lbs/sq in. through screwed and socketed steel mains. Individual service governors are fitted at the inlet of each of the 275 meters. Some 20 of these were inspected at random and were found to be not leaking. The Service Fitter, who also reads the meters, stated that he checked governors, meter fittings and gas cocks at each reading and he was sure leakage from these sources did not exist.

Because of the pressure a cast case meter was again used , one being sufficient to measure the quantity of gas leaking. A lubricated plug cock was already fitted in the line and the meter was connected around it.

Pressures were varied by means of a spring loaded high pressure governor.

The quantities of gas recorded on the meter were corrected for pressure to 2 ins w.g.. The results are shown in Figure 15 and Appendix 10. The equation of the curve being

$$S = 144 + 0.984\,h - 0.00117\,h^2$$

The usage of 144 cuft/hour compared to 36.2 cuft/hour in the case of the low pressure system was anticipated since there are considerably more appliances with pilots in the high pressure area.

True leakage after deducting usage is also shown in Fig. 15. The equation being

$$Q = 0.984\,h - 0.00117\,h^2$$

The following general conclusions may be drawn from the test results:-

1) Where roll in rubber ring joints predominate as in the case of the trunk main from Maitland Works to Burlington Mills and the trunk main from the Bathurst Works, the leakage curve at various pressures is concave upwards.

2) At West Tamworth, the leakage curve is also concave upwards. Although roll in rubber ring joints do not predominate, it is possible that the majority of the leakage occurs from them.

3) Where no roll in rubber rings are present, the leakage curve at various pressures is either a straight line or slightly concave downwards.

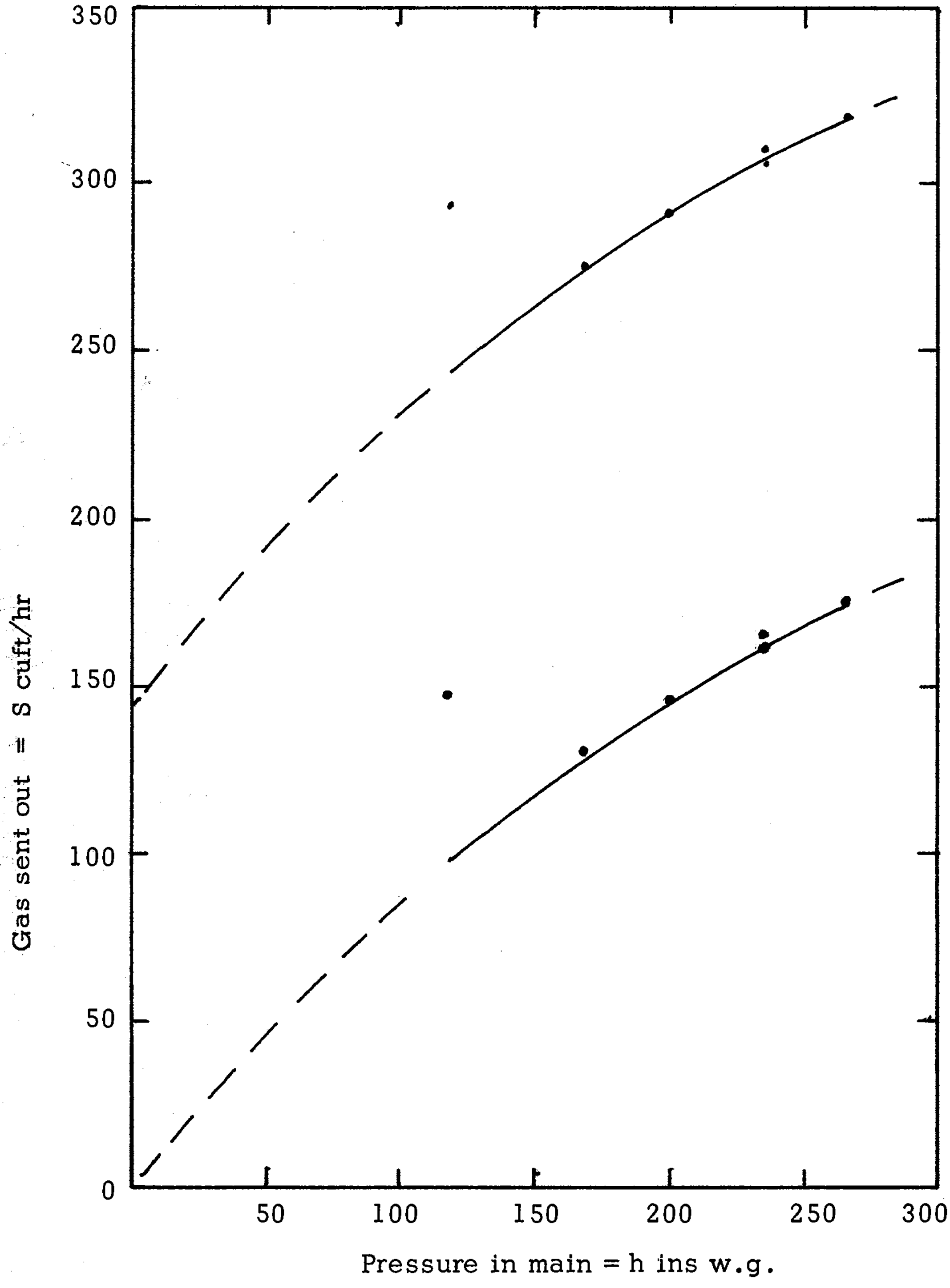


Fig. 15 Quantity of Gas leaving Camden Works through high pressure system between Midnight and 3.30 a.m. and Quantity of Gas leaking from it at various pressures

4) Where a mixture of all types of joints is present and roll in rubber rings do not predominate, the leakage curve has quite a large curvature downwards.

5) After gas passing through the mains of (1) above has been conditioned, the leakage curve for the Maitland main is now concave downwards. Gas at Bathurst is being conditioned but no results are yet available.

6) The best example of (4) above is the whole of the low pressure system at East Maitland. After 15 days conditioning the leakage curve was flatter; after a further 21 days it became a straight line. For a given pressure, the difference between the leakage before conditioning and that after conditioning represents the rate of leakage through the rubber ring joints. Unfortunately there are no records to show the length and size of mains in this area having roll in rubber ring joints.

7) It is not known whether further conditioning of gas in the mains in the East Maitland area will reduce the leakage to a still greater extent by sealing up the smaller leaks in hemp and lead joints or in the joints and pipe wall in the case of screwed and socketed steel pipes. Gas conditioning is being carried out at frequent intervals and further tests will be made as the opportunity occurs.

8) There is a possibility that leakage may be reduced for the reason mentioned in (7) in the case of mains and services where no rubber rings are present.

9) The substitution of condensable hydrocarbon free T.L.P. gas for a coal gas will increase leakage from the system. The same will apply to any other gas such as dehydrated coal gas, reformed gas or natural gas unless they are conditioned by the addition of a suitable oil vapour. This conditioning should be commenced at the time of changeover. Sufficient moisture is necessary in the gas to keep the hemp in hemp and lead joints in a swollen condition.

CALCULATION OF PERMEABILITY

In the initial stages of mainlaying, a trench is excavated to a width depending on the diameter of the main, its depth, the type of joint and the ease with which men can work in it. As mentioned previously in many cases the main is embedded in a 3" - 4" layer of sand and usually the soil from the excavation is back filled into the trench.

The degree of initial consolidation varies but after a period of time, the soil settles back into place. However it never consolidates to the same extent as the virgin ground except in the case of a pure sand and the ground around the trench remains largely impervious to the passage of gas. This is particularly so in the case of a main laid in rock.

Accordingly the sketch of Figure 16 can be assumed to be a reasonable representation of the conditions under which gas leaks from an underground structure.

After leaving the main the gas largely passes through the soil in the trench, and escapes to the atmosphere. The ability of porous media to conduct fluids through their interstices is known as permeability.

The permeability of a porous medium is its most useful property. It is a measure of the ease with which a fluid will flow through the medium, the higher the permeability the higher the fluid rate for a given pressure gradient.

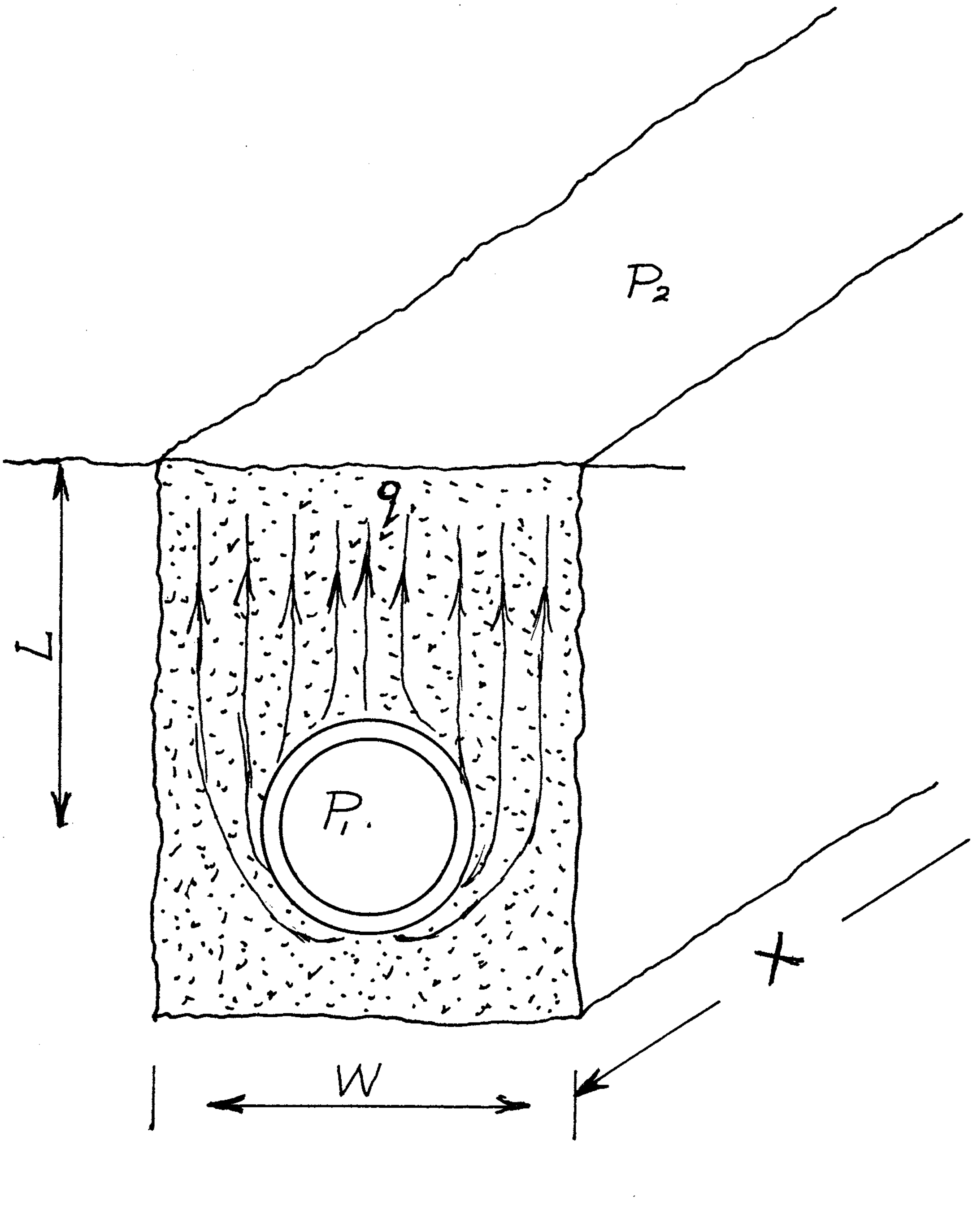
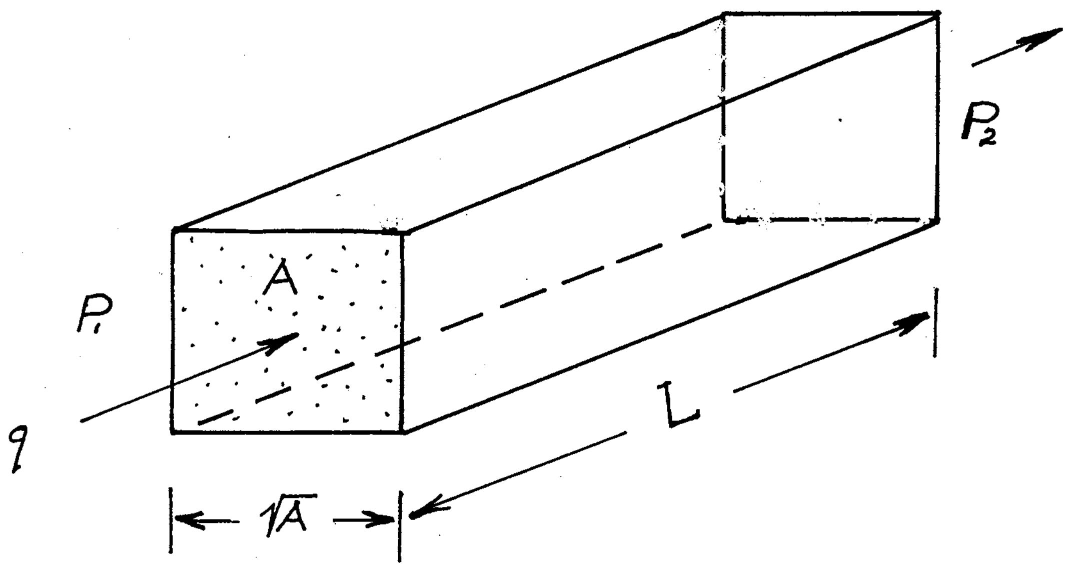


Fig. 16 Representation of Leakage of Gas from Underground Pipe

The most commonly used unit of permeability is the Darcy. The American Petroleum Institute gives the following definition of a Darcy:- "A porous medium has a permeability of one darcy when a single phase fluid of one centipoise viscosity that completely fills the voids of the medium will flow through it under conditions of viscous flow at the rate of one m l per second per sq. cm of cross-sectional area under a pressure equivalent hydraulic gradient of one atmosphere per cm at a temperature of 68°F.



For linear horizontal isothermal flow this can be expressed by the equation

$$q = -\frac{kA}{\mu} \cdot \frac{dP}{dL} \qquad (1)$$

where q = flow rate, m l /sec

k = permeability, darcys

A = cross sectional area, sq cms

μ = viscosity, centipoises

$\frac{dP}{dL}$ = pressure gradient, atm/cm

This equation is written in differential form and must be integrated to find a suitable equation to calculate permeability.

The volumetric flow rate q for liquids is a constant since the change in density is insignificant in flowing through the core plug. So for liquids flowing through a porous medium where q, A, μ and k are constant Equation (1) becomes

$$q = \frac{kA}{\mu} \left(\frac{P_1 - P_2}{L} \right) \qquad (2)$$

where P_1 = absolute pressure on upstream face

P_2 = absolute pressure on downstream face

$$k = \frac{L\mu}{A} \left(\frac{q}{P_1 - P_2} \right) \qquad (3)$$

For gases the volumetric flow rate q varies with pressure. Either the value of q at the average pressure in the core must be used in Equation (2) or Equation (1) must be integrated with volumetric flow rate q varying with pressure P.

Actually both methods give the same final equation for gases following ideal gas laws.

To convert measured gas volume Q at pressure P_b to gas volume q at the mean pressure $\frac{P_1 + P_2}{2}$

$$Q = q\left(\frac{P_1 + P_2}{2. P_b}\right) \tag{4}$$

Substituting in Equation (2)

$$Q = \frac{k.A.}{\mu L}\left(\frac{P_1^2 - P_2^2}{2P_b}\right) \tag{5}$$

or

$$k = \frac{Q.\mu.L}{A}\left(\frac{2P_b}{P_1^2 - P_2^2}\right) \tag{6}$$

where Q = measured gas flow rate m l/sec.

P_b = absolute base pressure of gas measurement, atm.

To facilitate calculation of permeability from the experimental results Equation (3) may be written

$$k = 104.86 \frac{\mu L}{A} \cdot \frac{q}{h} \quad (7)$$

where k = permeability in darcys

q = flow rate, cuft/hour

A = cross sectional area, sq. feet = W x X (Fig. 16)

h = pressure in main, ins w.g.

μ = viscosity, centipoises

L = depth of main, feet.

It can be seen from Fig. 16 that the flow path from the main through the soil is a complex one. In calculating the value of permeability the distance L has been taken from the centre of the main to the surface of the ground.

The pressure drop $P_1 - P_2 = h$ is determined in the usual manner by a gauge measuring the difference between the pressure inside the main and atmosphere.

It is stressed that the calculated values of permeability are overall ones covering the passage of gas through leaking joints and holes in the mains and services as well as through the soil.

The correction factor of Equation (4) to cover compressibility of the gas is negligible in the case of pressures up to 10 ins w.g. and has been applied only to experimental results where the pressures were in excess of this value.

The temperature of soil has been determined by the Sydney County Council as a basis for the current rating of underground cables. It has been found that for depths of 0 - 3 feet, the average summer temperature is 77°F and the average winter value 64°F.

No attempt has been made to correct gas volumes back to the 68°F of the definition of a darcy.

The values of $\frac{q}{h}$ leakage per hour per in w.g. have been calculated in the appropriate appendices and are plotted in Figs 17, 18, 19 and 20 against pressure of gas in the main, h.

The results of tests carried out on whole towns are shown in Fig. 17. In the case of Molong and East Maitland and to a lesser degree Camden the value of $\frac{q}{h}$ decreased with increase in pressure. As gas conditioning was carried out the slope of the curve became less acute until in the case of East Maitland $\frac{q}{h}$ became constant.

On the assumption that all the rubber ring joints had now been sealed and that no other leakage had been affected by gas conditioning, the difference between the curves of the first and third tests in Fig. 17 represents the effect of gas conditioning on rubber rings and hence the leakage rate through them.

The equation of this leakage is

$$\frac{q}{h} = 98 - 10h \qquad (8)$$

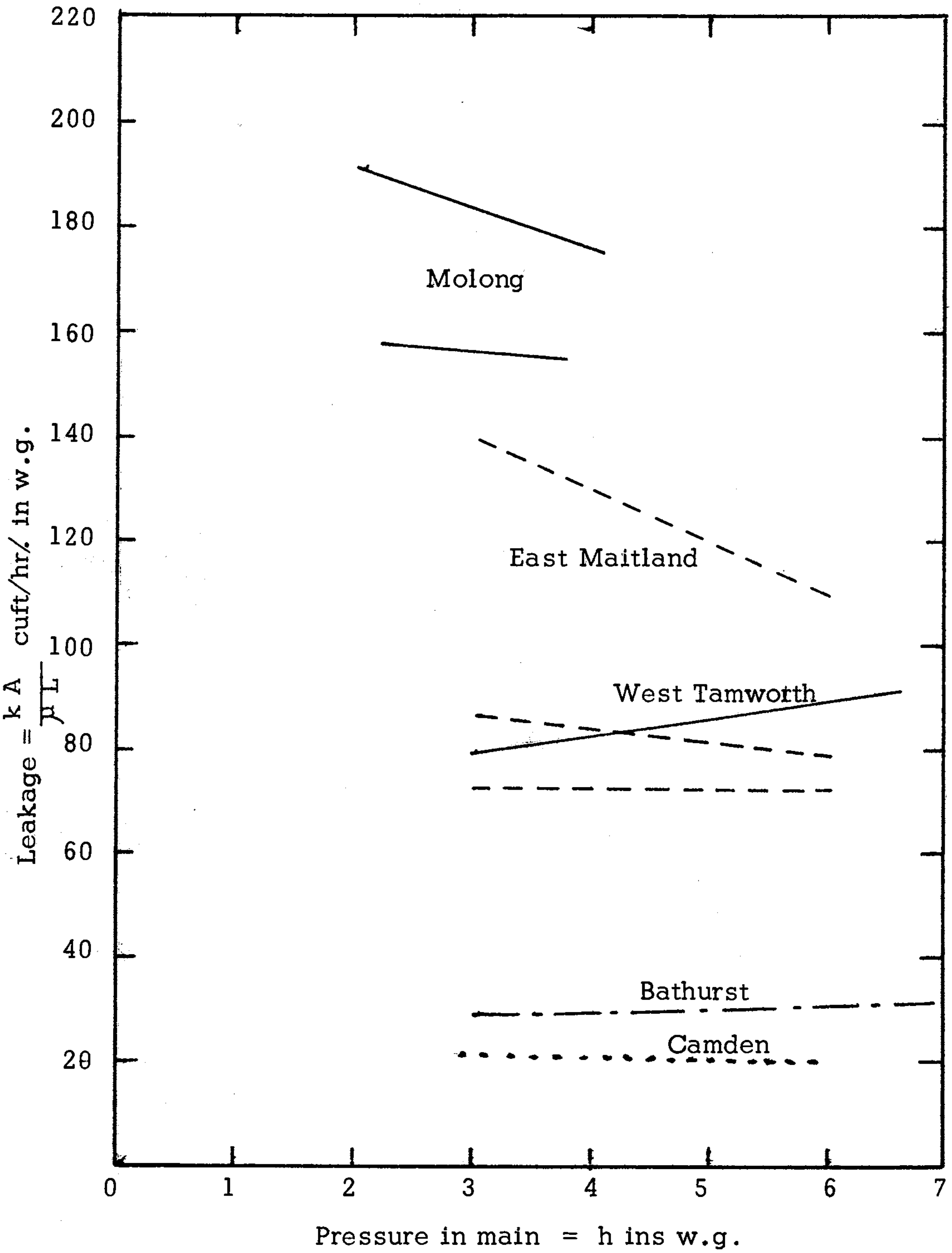


Fig. 17 Loss of Gas expressed as cubic feet/hour/ in w.g. for Molong, East Maitland, West Tamworth, Bathurst and Camden

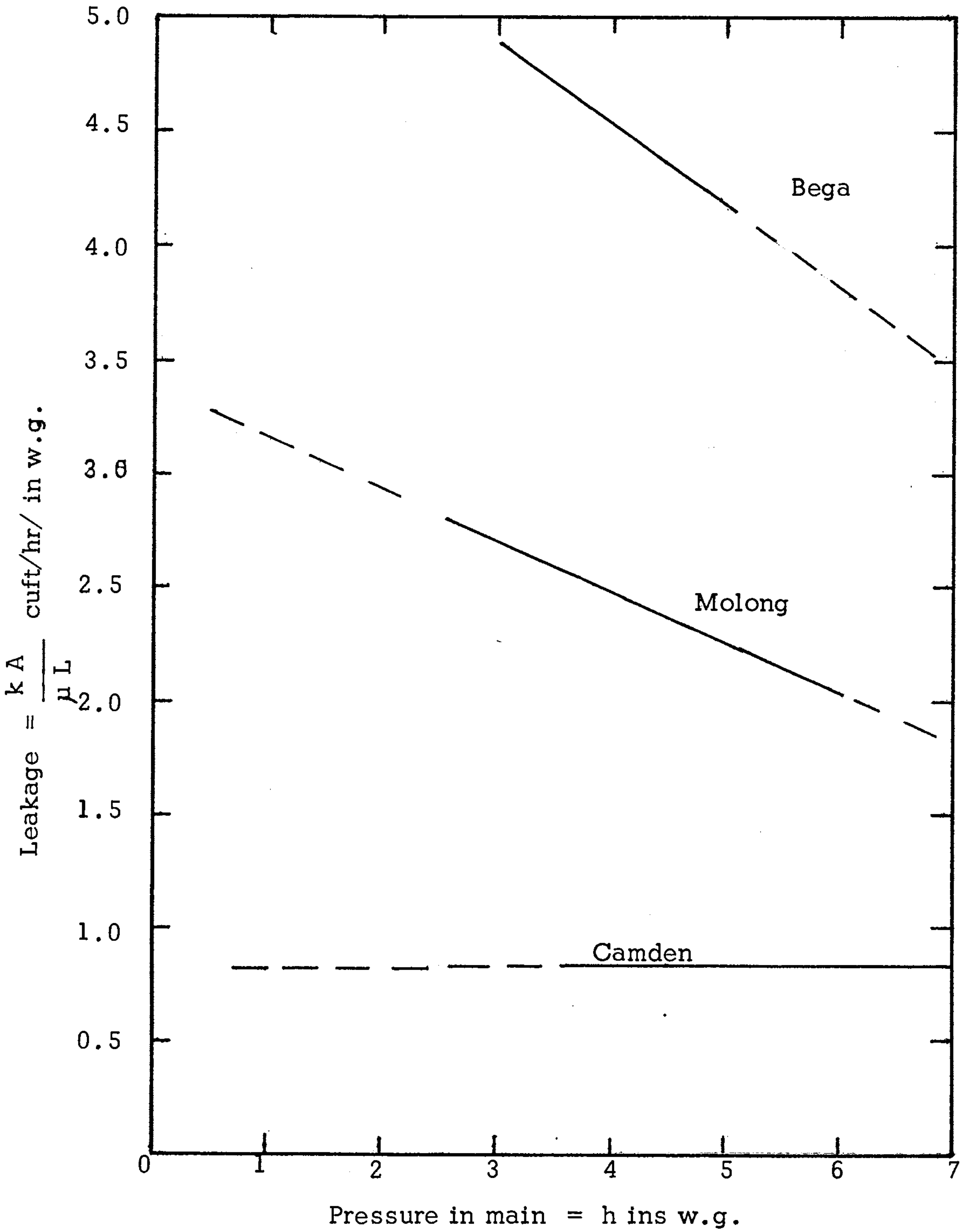


Fig. 18 Loss of Gas expressed as cubic feet/hour/in w.g. for isolated sections at Bega, Molong and Camden

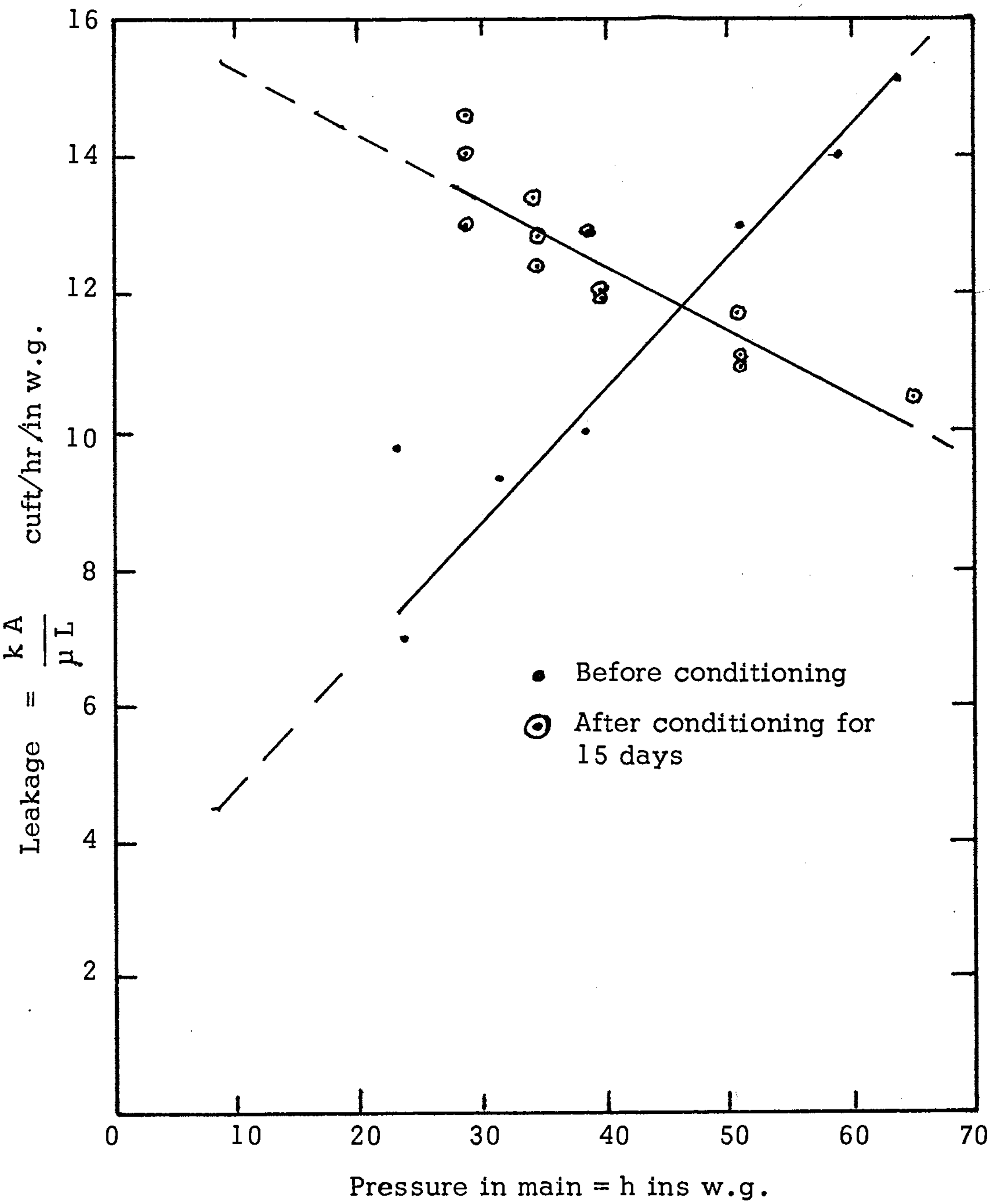


Fig. 19 Loss of Gas expressed as cubic feet/hour/ in w.g. for the high pressure main from Maitland to Burlington Mills

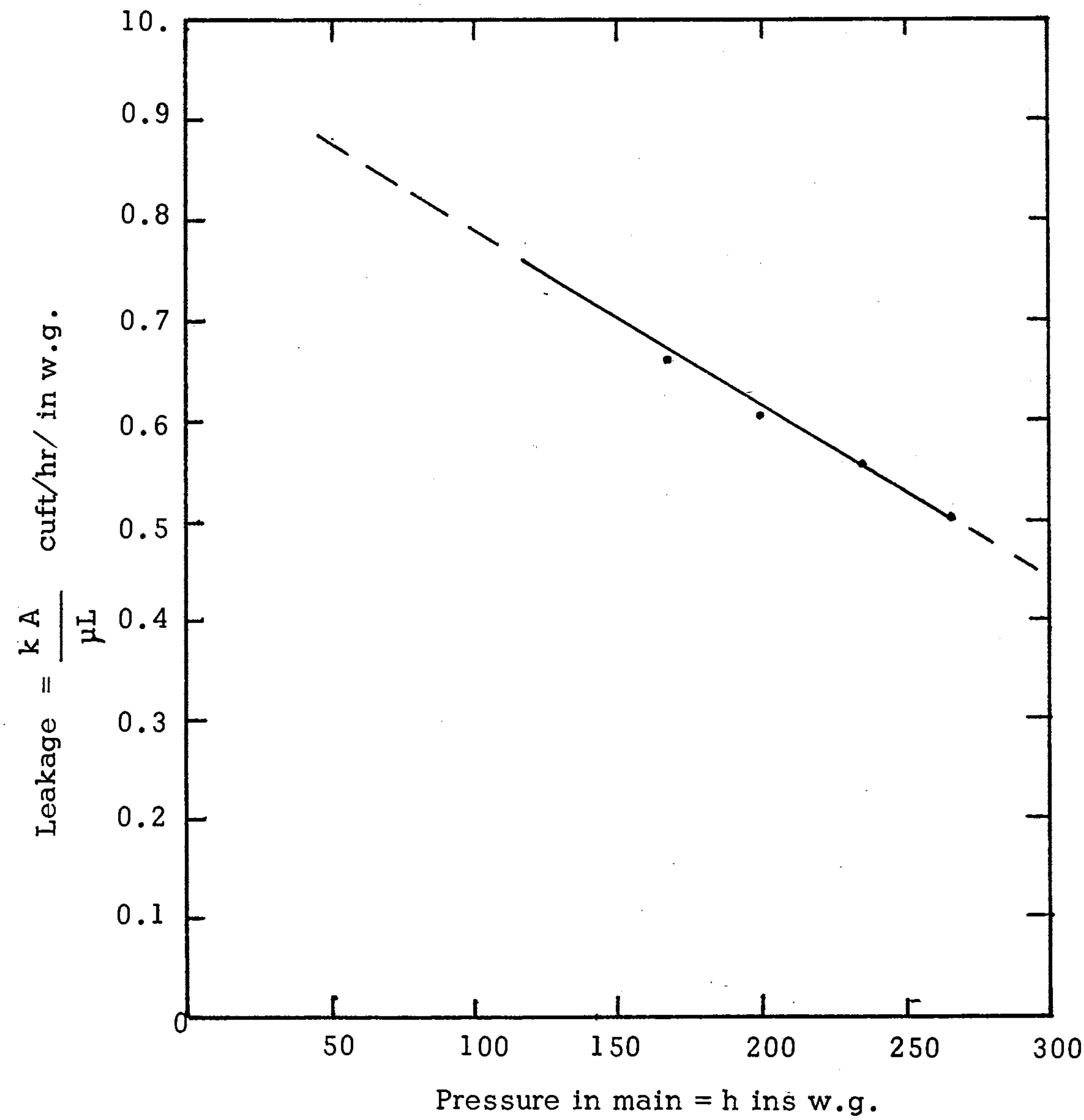


Fig. 20 Loss of Gas expressed as cubic feet/hour.in w.g. for the high pressure system at Camden.

Since $\frac{q}{h} = \frac{k A}{\mu L}$

$$\frac{k_r A}{\mu L} = 98 - 10\, h$$

$$\therefore \; k_r = \frac{\mu L}{A} (98 - 10\, h) \qquad (9)$$

where k_r = permeability of leaking rubber ring joints.

Equation (9) represents the manner in which k_r varies with pressure for the leakage of gas through a roll in rubber ring joint in the East Maitland area.

Since the length of rubber ring jointed main is not known, it is not possible to determine the value of A and hence values of k_r.

It has not been possible to make a final test on the whole systems at Molong and Camden. The quarterly values of unaccounted for gas indicate that the rate of leakage per in w.g., as a result of gas conditioning, is now a constant in these two towns.

In the case of Bathurst and West Tamworth the value of $\frac{q}{h}$ increased with increase in pressure. As previously stated this could be due to the preponderance of rubber ring joints at Bathurst and the majority of the leakage occurring from rubber ring joints at West Tamworth. Gas conditioning has just commenced in these towns and its effect will not be known for some weeks.

Fig. 18 shows similar curves for isolated sections of mains and services which do not contain any rubber ring joints and consist of steel pipe. In all cases the value of $\frac{q}{h}$ decreased with increase in pressure. The Camden section which was cast iron main with hemp and lead joints had very low leakage and $\frac{q}{h}$ was practically constant.

Fig. 19 depicts the results in the case of the high pressure trunk main between Maitland and Rutherford., where the joints are all of the roll in rubber ring type. An examination of the pipe showed that there was no corrosion so that it can be assumed all the leakage was taking place through the rubber rings.

Before conditioning $\frac{q}{h}$ increased rapidly with increase in pressure. After 15 days conditioning the reverse was the case. It is anticipated that further conditioning will decrease the leakage rate to a greater extent.

Fig. 20 shows the results of the experiments on the high pressure system at Camden where all the mains are mild steel with screwed and socketed joints. The result is similar to those shown in Fig. 18.

An analysis of the curves in Figs. 17 - 20 would appear to indicate that:

(a) where rubber ring joints predominate, or the leakage is predominately from rubber ring joints, the leakage rate increases with increase in pressure.

(b) where rubber ring joints do not predominate or are absent, the leakage rate decreases with increase in pressure.

In the case of Molong the permeability is calculated as follows:-

Total length of mains	= 28,578 feet
Total length of services 258 x 115 ft ea	= 29,670 feet
Length of mains and services	= 58,248 feet
Average depth of mains and services	= 1.5 feet
Average width of trench	= 1.0 feet
Viscosity	= 124.1 x 10^{-4} centipoises

$$\text{Then } k = 104.86 \times \frac{q}{h} \times 124.1 \times 10^{-4} \times \frac{1.5}{1.0 \times 58,248}$$

$$= 0.3351 \times \frac{q}{h} \times 10^{-4}$$

Before gas conditioning,

From Fig. 17 (a) $\frac{q}{h}$ = 183.4 at 3 ins w.g.

$$k = 0.3351 \times 183.4 \times 10^{-4}$$

$$= 0.00615 \text{ darcys.}$$

(b) $\frac{q}{h}$ = 160.9 at 6ins w.g.

$$k = 0.3351 \times 160.9 \times 10^{-4}$$

$$= 0.00539 \text{ darcys.}$$

After gas conditioning ,

From Fig. 17 (a) $\frac{q}{h}$ = 156.7 at 3 ins w.g.

$$k = 0.3351 \times 156.7 \times 10^{-4}$$

$$= 0.00525 \text{ darcys.}$$

(b) $\frac{q}{h}$ = 152.0 at 6 ins w.g.

$$k = 0.3351 \times 152.0 \times 10^{-4}$$

$$= 0.00509 \text{ darcys.}$$

The values of permeability for each of the experimental cases are calculated in the appropriate appendix and summarised in Table 8. The types of main, joints and a general classification of the soils are included.

Where gas conditioning has not been completed, values of permeability have been calculated to cover the general working range of pressures in the particular system.

The systems fall roughly into three groups according to permeability.

(a) Values of the order of 0.00002.

Camden high pressure area 0.0000223

0.0000145

(b) Values of the order of 0.0005

East Maitland whole town low pressure 0.000479

Chellaston Street, Camden low pressure 0.000501

Maitland, trunk main high pressure 0.000747

0.000509

TABLE 8

VALUES FOR PERMEABILITY

TABLE 8

VALUES FOR PERMEABILITY

LOCATION	Type of main	Type of joint	SOIL(21)	AT PRESSURE ins. w.g.	PERMEABILITY	
					Before Conditioning	After Conditioning
Molong whole town	cast iron steel	rubber ring screwed	Friable loamy soils with red clayey sub soils	3 6	0.00615 0.00539	0.00525 0.00509
East Maitland whole town	cast iron cast iron steel	rubber ring hemp, lead screwed	Loamy soils	3 6 all pressures	0.000931 0.000732	0.000578 0.000532 0.000479
Camden whole town low pressure	cast iron cast iron steel	rubber ring hemp, lead screwed	Hard setting loamy soils with red clayey subsoils	3 7	0.00441 0 00432	
West Tamworth whole area	cast iron	rubber ring	Hard setting loamy soils with red clayey subsoils	3 6	0.00114 0.00134	
Bathurst trunk main	cast iron cast iron	rubber ring mechanical	Hard setting loamy soils with red clayey subsoils	3 8	0.00226 0.00239	
Molong, Hill Street	steel steel	welded screwed	Friable loamy soils with red clayey subsoils	2 6	0.00414 0.00285	
Camden, Chellaston Street	cast iron steel	hemp, lead screwed	Hard setting loamy soils with red clayey subsoils	all pressures	0.000501	
Bega Upper, Eden, Peden and High Streets	steel	screwed	Brown friable earth	3 5	0.00281 0.00252	
Maitland, trunk main high pressure	cast iron	rubber ring	Hard setting loamy soils with mottled yellow clayey subsoils	10 60	0.000192 0.000693	0.000747 0.000509
Camden, high pressure area	steel	screwed	Hard setting loamy soils with red clayey subsoils	100 265	0.0000223 0.0000145	

(c) Values of the order of 0.001 - 0.005

Molong, whole town low pressure	0.00525
	0.00509
Hill Street, Molong low pressure	0.00414
	0.00285
Upper, Eden, Peden, and High Streets, Bega	0.00281
	0.00252
Bathurst trunk main at low pressure	0.00226
	0.00239
West Tamworth whole area low pressure	0.00114
	0.00134

There does not appear to be any correlation between the above results and the type of main or joint.

In (b) the leakage at East Maitland is probably occurring only from hemp and lead jointed cast iron mains and screwed and socketed steel mains and services, at Chellaston Street from hemp and lead joints and screwed and socketed steel services and from rubber ring joints in the trunk main at Maitland.

Similarly in (c) the leakage in the whole town and Hill Street, Molong and at Bega is taking place mainly from steel mains where as at Bathurst it is all from rubber ring joints and at West Tamworth from a mixture of rubber ring and screwed and socketed joints.

It is possible that the experimental values of permeability are mainly applicable to the soil, the effect of leakage through the main being negligible.

In Table 9, the locations at which permeability values have been obtained have been grouped according to soil type.

While there is some correlation, anomalies occur and it cannot be stated with certainty that a particular value of permeability can be attributed to any one soil type.

The results to be obtained after conditioned gas has been distributed through the systems already examined, and others it is proposed to examine, may enable a conclusion to be made.

Table 9

CORRELATION OF PERMEABILITY VALUES ACCORDING TO SOIL TYPE

Type of Soil	Permeability
Hard setting loamy soils with red clayey subsoils	
Camden high pressure area	0.0000223 - 145
West Tamworth	0.00114 - 134
Camden whole town low pressure	0.00441 - 432
Bathurst	0.00226 - 239
Chellaston Street, Camden	0.000501
Hard setting loamy soils with mottled yellow clayey subsoils	
Maitland trunk main	0.000747 - 509
Brown friable earth	
Bega	0.00281 - 252
Friable loamy soils with red clayey subsoils	
Molong whole town	0.00525 - 509
Hill Street, Molong	0.00414 - 285
Loamy soils	
East Maitland whole town	0.000479

GAS PRESSURE

Since leakage of gas is a function of pressure, it follows that the lower the average pressure of gas in any one system, the lower will be the losses. On the other hand, a minimum pressure must be supplied at the inlet of each consumer's meter at all times.

Three periods of peak demand for gas are experienced during the day, breakfast, luncheon and dinner. At these times peak pressure drops occur between the outlet of the Works and the extremities of the distribution system. It is therefore necessary to maintain an outlet of Works pressure at the value necessary to overcome this pressure drop and maintain the minimum pressure at consumers' premises. This is the peak pressure.

During the morning, afternoon and after the evening meal, the demand is much lighter and lower intermediate pressure is adequate.

Finally from about midnight to 6 am unless there is an industrial load, practically no gas is consumed. It has been found that a pressure of 3.0" w.g. at the outlet of Works is adequate during this period.

A typical outlet of Works pressure chart together with the corresponding extremity pressures are shown in Figure 21

A clock controlled governor is employed to maintain these pressures, the times at which pressure variations are made being adjusted to suit requirements of load.

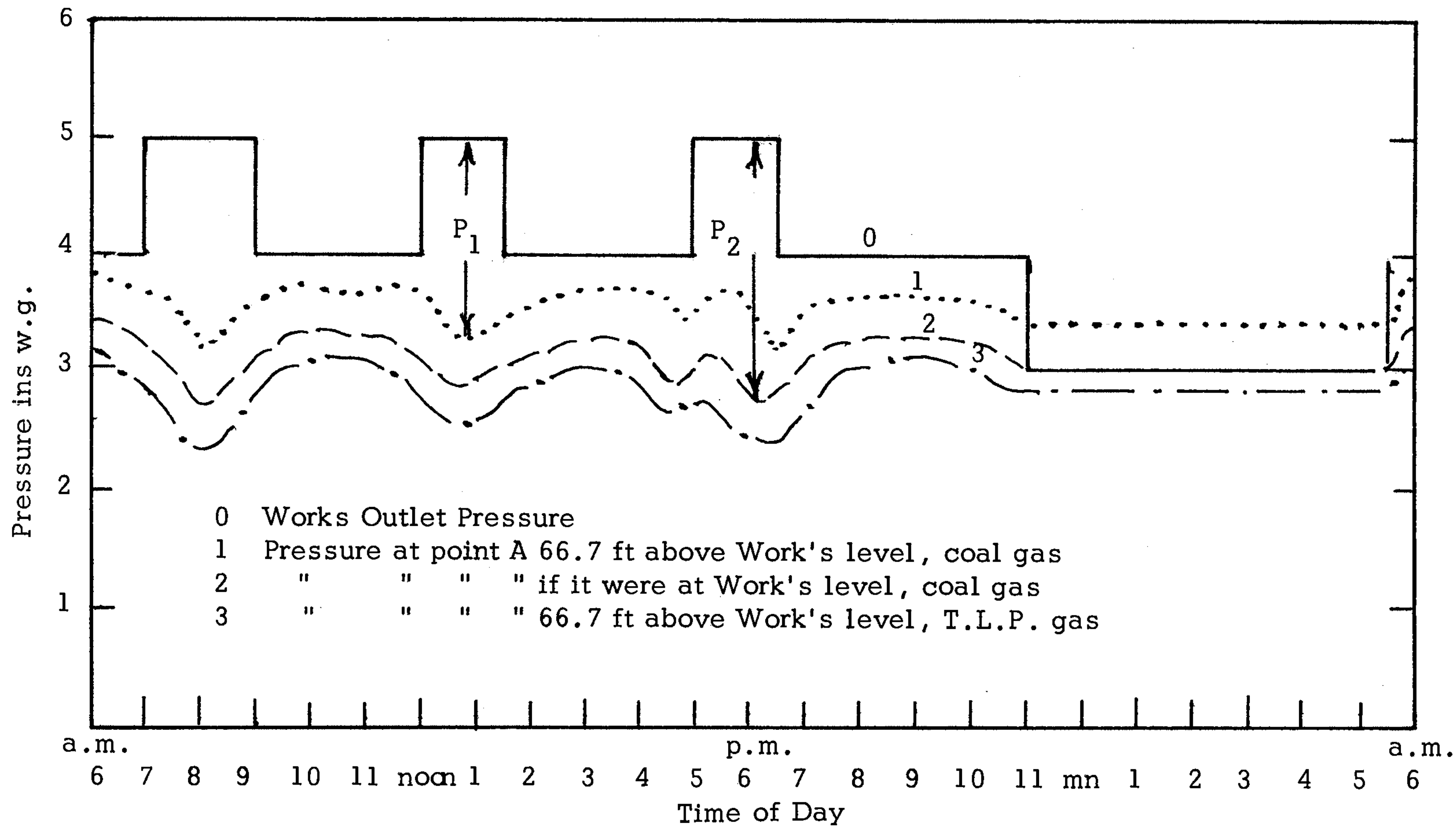


Fig. 21 Hourly Pressures of Gas at Outlet of Works and in the District

The increase in pressure per 100 feet of elevation is given by the equation

$$p = 1.5 (1 - S)$$

where S = specific gravity of the gas.

With coal gas of specific gravity of 0.6 and calorific value of 545.92 B.T.U./cu.ft. the pressure at any point elevated above the Works level automatically is increased 1.5 (1 - 0.6) = 0.6 ins w.g. for every 100 feet of elevation. The elevation of any point can be determined by comparing its pressure during the "all night" period with that of the Works. In Figure 21 the point A represented by curve 1 has an elevation equivalent to 0.4 ins w.g. or $100 \times \frac{0.4}{0.6} = 66.7$ feet. This means that if the pressure difference between the Works and point A during the luncheon period is p_1, the actual pressure drop due to gas flowing in the mains is $p_1 + 0.4$ ins w.g.

If point A were at the same level as the Works, its pressure curve would be curve 1 less 0.4 ins w.g. Curve 2 would then represent the true pressure drop between the Works and point A.

From the above discussion it will be apparent that elevated areas in a town assist in maintaining a low average pressure.

If coal gas is now replaced by tempered liquefied petroleum gas of 1.14 specific gravity and 682.4 B.T.U./cu.ft. calorific value the increase in pressure due to an elevation of 100 feet will be 1.5 (1 - 1.14) = -0.21 ins w.g. Hence the all "night pressure" at point A will now be $0.21 \times \frac{66.7}{100} = 0.14$ ins w.g. below that of the Work's pressure as shown in curve 3.

Gas mains in most Country Towns are small enough to ensure that the flow of gas is turbulent. The pressure drop under these conditions is given by the Fanning Equation:

$$\Delta p = \frac{2 f L \rho v^2}{gd}$$

where f = friction factor varying as $\frac{dv\rho}{\mu}$

L = length of main

ρ = density of gas

v = velocity of flow

d = internal diameter of main

g = gravitational constant

μ = viscosity

$$v = \frac{Q}{A}$$

where Q = quantity of gas flowing

A = cross sectional area of main

Substituting $\Delta p = C \cdot f \cdot \rho \cdot Q^2$

For the original coal gas

$$\Delta p_1 = C f_1 \cdot \rho_1 Q_1^2$$

and for a gas substituted for it

$$\Delta p_2 = C \cdot f_2 \cdot \rho_2 \; Q_2^2$$

Then the new pressure drop will be

$$\Delta p_2 = \Delta p_1 \left(\frac{f_2}{f_1} \cdot \frac{\rho_2}{\rho_1} \cdot \frac{Q_2^2}{Q_1^2} \right)$$

If tempered liquefied petroleum gas, specific gravity 1.14, calorific value 682.4 B.T.U./cu.ft. and viscosity 124×10^{-4} centipoises is substituted for a coal gas, specific gravity 0.6, calorific value 545.92 B.T.U./cu.ft. and viscosity 136×10^{-4} centipoises, and the same quantity of heat is transmitted, the new pressure drop will be

$$\Delta p_2 = \Delta p_1 \left\{ \frac{f_2}{f_1} \cdot \frac{1.14}{0.6} \left(\frac{545.92}{682.4} \right)^2 \right\}$$

$$= \Delta p_1 \cdot \frac{f_2}{f_1} \cdot 1.216$$

Now $(\text{modulus})_1 = \dfrac{d}{A} \cdot \dfrac{Q_1 \rho_1}{\mu_1}$

and $(\text{modulus})_2 = \dfrac{d}{A} \cdot \dfrac{Q_2 \rho_2}{\mu_2}$

Then,

$$\frac{(\text{modulus})_2}{(\text{modulus})_1} = \frac{Q_2}{Q_1} \cdot \frac{\rho_2}{\rho_1} \cdot \frac{\mu_1}{\mu_2}$$

$$= \frac{545.92}{682.4} \times \frac{1.14}{0.6} \times \frac{136}{124}$$

$$(\text{modulus})_2 = 1.672 \ (\text{modulus})_1$$

The graph for friction factor - modulus (Figure 22) shows than an increase in the modulus reduces the friction factor. From the curve for cast iron and steel pipes, an increase of 1.672 times in the modulus results in a decrease of 0.95 times in the friction factor.

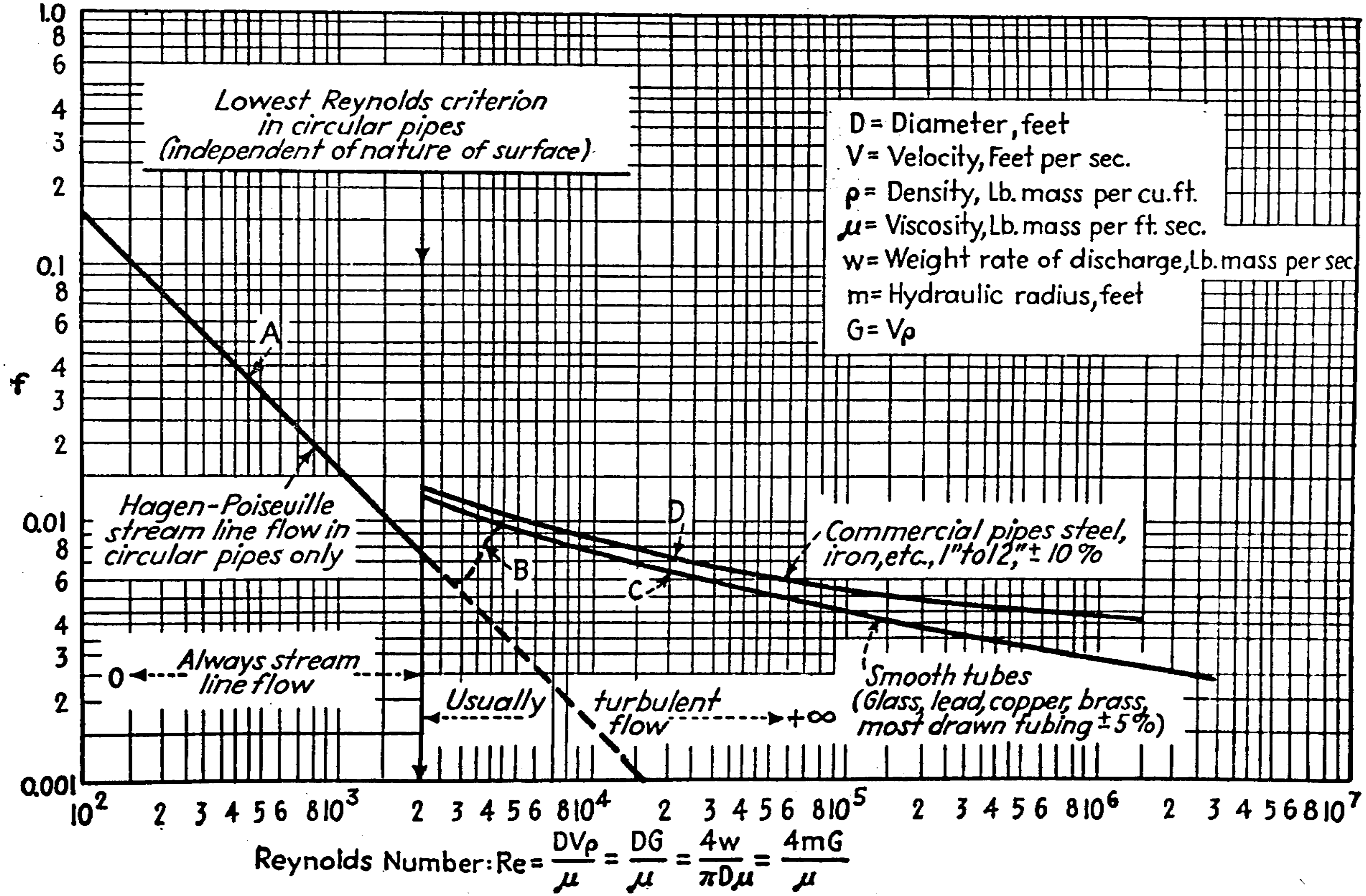
Hence it would be anticipated that the new pressure drop Δp_2 would be of the order of

$$\Delta p_1 \times 0.95 \times 1.216 = 1.155 \ \Delta p_1$$

If p_2 were the maximum pressure drop during the dinner load for coal gas in curve 2, the pressure drop for tempered liquefied petroleum gas would be $1.155 \ p_2 + 0.14$ ins w.g. as shown in curve 3 of Figure 21.

When distributing the latter gas it would be necessary to increase the outlet of Works pressures to maintain adequate supply with a

Fig. 22 Graph of friction factor for various values of modulus.



Lowest Reynolds criterion
in circular pipes
(independent of nature of surface)
D = Diameter, feet
V = Velocity, Feet per sec.
ρ = Density, Lb. mass per cu. ft.
μ = Viscosity, Lb. mass per ft. sec.
w = Weight rate of discharge, Lb. mass per sec.
m = Hydraulic radius, feet
G = Vρ
f
A
B
C
D
Hagen-Poiseuille
stream line flow in
circular pipes only
Commercial pipes steel,
iron, etc., 1" to 12," ± 10 %
Smooth tubes
(Glass, lead, copper, brass,
most drawn tubing ± 5 %)
0 ← Always stream
line flow
Usually turbulent
flow → +∞
1.0 8 6 4 3 2 0.1 8 6 4 3 2 0.01 8 6 4 3 2 0.001
10² 2 3 4 5 6 8 10³ 2 3 4 5 6 8 10⁴ 2 3 4 5 6 8 10⁵ 2 3 4 5 6 8 10⁶ 2 3 4 5 6 8 10⁷
Reynolds Number: Re = DVρ/μ = DG/μ = 4w/πDμ = 4mG/μ

corresponding increase in the average gas pressure over the whole district. This in turn would result in an increase in the quantity of gas lost.

It is anticipated that natural gas at the city gate will have a calorific value of the order of 1020 B.T.U./cu.ft. with a specific gravity of 0.6 and a viscosity of 108.5×10^{-4} centipoises.

The new pressure drop will now be

$$\Delta p_2 = \Delta p_1 \left\{ \frac{f_2}{f_1} \cdot \frac{0.6}{0.6} \left(\frac{545.92}{1020} \right)^2 \right\}$$

$$= \Delta p_1 \cdot \frac{f_2}{f_1} \cdot 0.296$$

and $\dfrac{(\text{modulus})_2}{(\text{modulus})_1} = \dfrac{545.92}{1020} \times \dfrac{0.6}{0.6} \times \dfrac{136}{108.5}$

$\therefore (\text{modulus})_2 = 0.671 \, (\text{modulus})_1$

From the cast iron and steel pipes curve, Figure 22 , a decrease in the modulus of 0.671 results in an increase in friction factor of 1.03 when the rate of flow is just turbulent to 1.08 for the higher values of modulus.

Hence it would be anticipated that the new pressure drop for natural gas could vary from

$$\Delta p_1 \times 1.03 \times 0.296 = 0.30 \Delta p_1$$

$$\Delta p_1 \times 1.08 \times 0.196 = 0.32 \Delta p_1$$

This would indicate that Work's pressures could be considerably reduced, while still maintaining the same pressures at the extremities.

In the above discussions it has been assumed that pressures at the inlet to appliances would remain the same as when coal gas was distributed.

In the early stages of changing over to natural gas in Holland[20] the normal appliance gas pressure was retained. It was soon realised that while this may have been desirable from a distribution view point, a higher pressure was necessary for good combustion. The theoretical air required for the combustion of coal gas was 4.23 cu.ft./cu.ft. of gas, whereas with the natural gases available it varied from 8.35 - 9.30 cu.ft./cu.ft. or double the quantity of air.

The modulus of a gas m is defined as

$$m = \frac{\sqrt{p}}{W}$$

where p = the gas pressure at the burner

W = Wobbe Index of the gas.

With different gases, their modulus must be the same in order that the same volume of air per therm may be injected. So that if natural gas with a Wobbe Index of 1280 is to replace coal gas with a Wobbe Index of 688 at a burner pressure of 2.5" w.g., its pressure should be

$$2.5 \times \left(\frac{1280}{688}\right)^2 = 8.7\text{" w.g.}$$

Until such time as the load increased, it would be necessary to increase the outlet of Work's pressures previously calculated by 6" w.g. to provide this pressure at the appliances. This means an increase in the average pressure of gas over the whole system with a corresponding increase in the volume of gas lost.

It is anticipated that, based on overseas experience, the quantity of natural gas sold will be many times the quantity of coal gas sold at present. It will be necessary to either

(a) increase the pressure to enable the increased quantities to be distributed through existing mains with the consequent higher losses, or

(b) lay a new system of feeder mains.

In either case a vigorous policy of searching for leaks and repairing them is required.

The Australian Gas Light Co. in Sydney have decided to adjust appliances in their area of supply to burn gas, at an inlet pressure of 4" w.g. and to lay new mains to distribute it.

In the case of T.L.P. gas, with a Wobbe Index of 639, its pressure at the burner should be

$$2.5 \times \left(\frac{639}{688}\right)^2 = 2.3'' \text{ w.g.}$$

Hence no additional pressure will be required at outlet of Works for appliance operation with this type of gas.

THERMAL CONTENT OF GAS

The quantity of gas used by consumers, according to the Gas and Electricity Act 1935 - 1967, must be measured by a meter. While the meter registers a volume in cubic feet, the gas account is computed on the basis of a cost per unit. This unit contains 3412 B.T.U. and is identical in heating power with the electrical kilowatt hour.

One thousand cubic feet of a gas of calorific value 545.92 B.T.U./cuft. contain 545920 B.T.U. Dividing by 3412 it will be seen that 1000 cu.ft. contain 160 units. The desirability of having an even number of units per 1000 cu.ft. for billing purposes, is responsible for the declared calorific value of gas being expressed with a decimal point.

The following table shows the thermal content per 1000 cu.ft. of the various gases under discussion:-

Gas		Declared calorific value B.T.U./cu.ft.	Units per 1000 cu.ft.
Coal		511.8	150
Coal		545.92	160
Propane/air			
	T.L.P.	682.4	200
	S.N.G.	1364.8	400
Natural		1023.6	300
Natural		1057.72	310

As yet no calorific value has been declared for S.N.G. or natural gas, but it is anticipated that the values will be of the order of those shown above.

If tempered liquefied petroleum gas is substituted for a coal gas containing 160 units per 1000 cu.ft., the thermal losses will be increased by $\frac{200}{160} = 1.25$ times. There will be an increase in thermal loss of 25% irrespective of any additional losses due to causes already discussed.

Similarly if natural gas is substituted for coal gas, the thermal loss could be increased by $\frac{310}{160} = 1.94$ times or a 94% increase.

The combined effect of increased volumetric leakage, and thermal losses for the town of Molong is shown in Figure 23. The volumetric losses quarter by quarter are shown in curve 1. The change to T.L.P. occurred on 29th March, 1966. A slight increase was evident by the September quarter with a violent increase by December. Gas conditioning was commenced on 1st February, 1967 and the March quarter readings indicated that the rate of increase had been arrested and thereafter there has been a steady downward trend.

Curve 2 shows the thermal losses. After the changeover ; curve 2a shows what the thermal losses would have been if the volumetric losses had increased but coal gas had continued to be distributed; curve 2b is the actual thermal loss experienced.

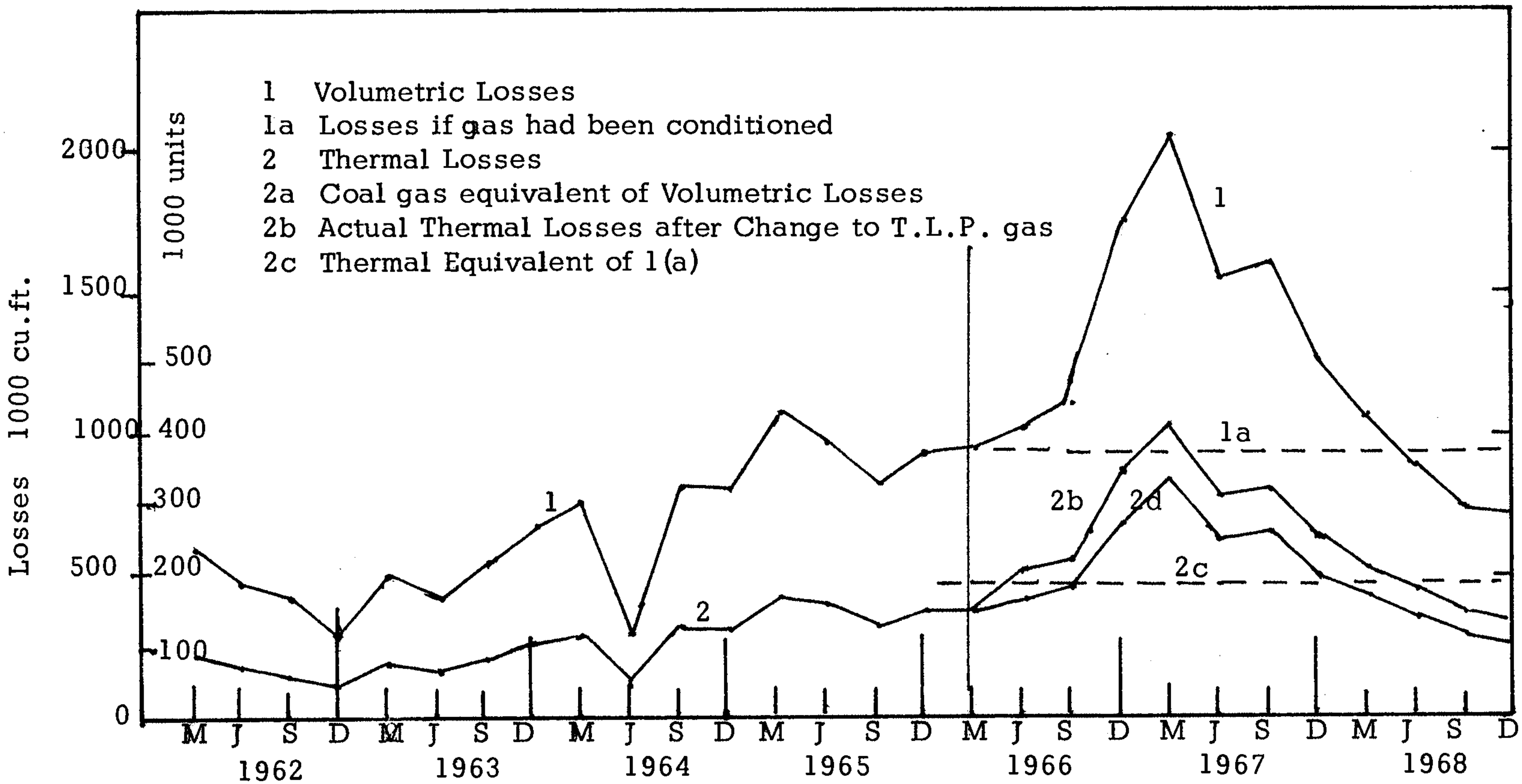


Fig. 23 Quarterly Losses of Gas at Molong, Changed over to T.L.P. gas on 29/3/66

Had gas conditioning been commenced coincidental with the changeover, the volumetric losses would have followed approximately curve 1 (a). The additional losses between the beginning of March 1966, and the end of March 1968 which were experienced as a result of not conditioning the gas amounted to approximately 3,820,000 cubic feet.

At 107.7c per 1000 cu.ft. to produce, this loss had a value of $4,110. To a small undertaking like Molong where the gross income is $14,360 per annum, the loss is a serious one.

Curve 2c is the thermal equivalent of the volumetric losses of curve 1a.

Without gas conditioning the thermal losses were estimated by the Author [(6)] to increase by 80% on changeover to T.L.P. gas. In the above case they increased from 152,000 units at the end of the March 1966 quarter when changeover took place to 412,400 units in the March 1967 quarter. This represents an increase of 1.7 times, a much greater one than was anticipated.

CONCLUSIONS

Unaccounted for gas losses can vary between 7% - 53% of the annual sales of gas when distributing coal gas depending on the condition of the distribution system.

The unaccounted for gas loss is affected by the accuracy of registration of consumers' meters. The investigation has shown that it is the moisture and oil content of the gas which affects this accuracy and not the gas itself. As a corollary any results obtained with T.L.P. gas which was the only new one it was possible to test, would be equally applicable if reformed or natural gas were substituted for coal gas.

While there is a tendency for meters originally measuring coal gas to register faster on change over, this could be mitigated or completely overcome by oil fogging the gas.

The accuracy of individual meters varies considerably but in the average for any one town the substitution of other gases for coal gas will not substantially affect the unaccounted for gas.

Above ground leakage can take place from corroded plates in wet holders. This however can be readily detected and remedial measures effected. Likewise losses at consumers' meter installations can be ascertained and the necessary action taken to stop them.. In this regard losses can amount to some 2% to 4% of annual sales and would make a small contribution to unaccounted for gas.

Below ground leakage which is responsible for the majority of unaccounted for gas is more difficult and more costly to locate and remedy.

The substitution of an "oil" dry gas for coal gas containing condensable hydrocarbons will cause roll in rubber ring joints in cast iron mains to leak at an alarming rate. In the case of one town the losses were doubled in 6 months.

This increase can be prevented at the time of change over by fogging the new gas with a suitable oil which will keep the rubber in a swollen condition. If oil dry gas has been distributed for periods of over 5 months, gas conditioning will commence effective sealing in about 15 days, and be reasonably complete within a further 21 days.

If the new gas is also "water" dry, hemp and lead joints will commence to leak and this necessitates humidification of the gas.

It is not known from the results of experiments to date whether gas conditioning will seal leaks from screwed and socketed steel mains and services either through the joints or small holes in the pipe wall.

All the experimental results have been obtained in cases where the new gas was substituted for coal gas without simultaneous gas conditioning.

The soil in the trench above the pipe structure acts as a porous medium through which the gas escapes to the atmosphere.

The quantity of gas lost follows Darcys Law for the flow of fluids through a porous medium. Permeability was calculated by applying this law to the experimental results. It is stressed that these values of permeability are overall ones covering the flow of gas through joints, holes in the mains and services and the soil. The difference between permeability values before and after conditioning could represent the permeability to gas flow of leaking rubber ring joints.

Attempts were made to correlate the experimental values of permeability with the type of joint, type of pipe or type of soil.

There does not appear to be any correlation with type of pipe or joint.

There is some indication of correlation with soil type. While the soil listed may be a fair average of a whole area there is a possibility that, in the case of the short isolated sections tested, the main may be laid in a different local type.

Due to the different physical characteristics of the new gases, pressure drops between the outlet of Works pressure and those at points in the district will vary. In the case of T.L.P. gas these pressure drops will increase, of natural gas they will be reduced.

With T.L.P. gas no additional pressure is required at the inlet of appliances for their satisfactory operation. Natural gas could require an increase of 6 ins w.g. in pressure at their inlet resulting in an increase in average pressure over the whole system and a corresponding increase in the volume of gas lost.

Gas lost from an underground system is essentially a volumetric one and hence the distribution of gases having a greater calorific value than coal gas will result in a corresponding increase in thermal losses.

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APPENDIX 1

RESULTS OF LEAKAGE TESTS ON WHOLE OF LOW PRESSURE AREA AT MOLONG

The distribution system contains approximately 1782 yards of 4" diameter and 2376 yards of $2\frac{1}{4}$" diameter cast iron main with rubber ring joints. The remaining 5351 yards are comprised of 3", 2" and smaller diameter steel mains with screwed and socketed joints.

There are 258 services having a total length of 9890 yards.

The results of the first test which was carried out before gas conditioning, on 31/1/67 are as follows:-

Time a.m.	Pressure ins w.g.	Gas measured by test meter cu.ft.	Time min.sec	Gas sent out cuft/hr.
12.00	2.8	26.55	2 - 6.0	
12.03			2 - 7.0	
12.07			2 - 7.0	
12.11			2 - 6.6	
12.14			2 - 6.4	755
12.30	3.4	26.55	1 - 53.0	
12.33			1 - 52.0	
12.36			1 - 52.0	
12.40			1 - 51.5	
12.43			1 - 52.0	
12.47			1 - 52.0	853
1.00	4.6	26.66	1 - 33.0	
1.05			1 - 33.5	
1.10			1 - 33.5	
1.13			1 - 33.0	1025

The above results are plotted in Fig. 7. The equation of the curve is

$$S = 240 + 205.9\,h - 7.5\,h^2$$

the usage being 240 cuft/hr.

The equation for the leakage of gas from the system is therefore

$$Q = 205.9\,h - 7.5\,h^2$$

By substituting various values of pressure in the equation, the following table is calculated.

Pressure ins w.g.	Gas sent out cuft / hr.	Leakage cuft/hr.	Leakage cuft/hr./ins.w.g.
0	240	-	-
1	438.4	198.4	198.4
2	621.8	381.8	190.9
3	790.2	550.2	183.4
4	943.6	703.6	175.9
5	1082.0	842.0	168.4
6	1205.4	965.4	160.9

The values of leakage in cubic feet/hour are plotted in Fig. 7.

The values of leakage in cubic feet/hour/in w.g. are shown in Fig. 17.

Gas conditioning was commenced on 1/2/67 and a further test of leakage was made on 30/5/67 with the following results:-

Time a.m.	Pressure ins w.g.	Gas measured by test meter cu.ft.	Time min.sec	Gas sent out cuft/hr.
12.10	2.2	20	1 - 22.6	
12.13			1 - 23.9	
12.15			1 - 25.7	
12.17			1 - 26.8	
12.19			1 - 26.6	
12.21			1 - 26.5	831
12.44	2.8	20	1 - 18.5	
12.46			1 - 18.6	
12.49			1 - 18.6	916
12.52	2.8	20	1 - 17.8	
12.55			1 - 17.6	
12.58			1 - 17.7	928
1.15	3.0	20	1 - 10.4	
1.17			1 - 10.0	
1.19			1 - 11.0	
1.22			1 - 12.6	
1.25			1 - 13.5	980
1.45	3.2	20	1 - 15.6	
1.47			1 - 15.4	
1.50			1 - 15.3	
1.52			1 - 15.2	955

The above results are plotted in Fig. 7. The equation of the curve is

$$S = 480 + 160\,h - 1.25\,h^2$$

the usage being 480 cuft/hr. It was expected that the usage would be greater than during the previous test since the weather was colder and space heaters were in operation at the Hospital

The equation for leakage of gas from the system is now

$$Q = 160\,h - 1.25\,h^2$$

By substituting various values of pressure in the equation, the following table is calculated.

Pressure ins w.g.	Gas sent out cuft / hr.	Leakage cuft/hr.	Leakage cuft/hr./ins.w.g.
0	480	-	-
1	640	160	160.0
2	795	315	157.5
3	950	470	156.7
4	1100	620	155.0
5	1250	770	154.0
6	1392	912	152.0

The values of leakage in cubic feet/hour are plotted in Fig. 7.

The values of leakage in cubic feet/hour/in w.g. are plotted in Fig. 17.

CALCULATION OF PERMEABILITY

Total length of mains	=	28578 feet
Total length of services 258 x 115 ft. ea.	=	29670 feet
Length of mains and services	=	58248 feet
Average depth of mains and services	=	1.5 feet
Average width of trench	=	1.0 feet
Viscosity	=	124.1×10^{-4} centipoises

$$k = 104.86 \times \frac{q}{h} \times 124.1 \times 10^{-4} \times \frac{1.5}{1.0 \times 58248}$$

$$= 0.3351 \times \frac{q}{h} \times 10^{-4}$$

Before gas conditioning

From Fig. 17 (a) $\frac{q}{h} = 183.4$ at 3 ins w.g.

$$k = 0.3351 \times 183.4 \times 10^{-4}$$

$$= 0.00615 \text{ darcys}$$

(b) $\frac{q}{h} = 160.9$ at 6 ins w.g.

$$k = 0.3351 \times 160.9 \times 10^{-4}$$

$$= 0.00539 \text{ darcys}$$

After gas conditioning

From Fig. 17 (a) $\frac{q}{h} = 156.7$ at 3 ins w.g.

$$k = 0.3351 \times 156.7 \times 10^{-4}$$

$$= 0.00525 \text{ darcys}$$

(b) $\frac{q}{h} = 152.0$ at 6 ins w.g.

$$k = 0.3351 \times 152 \times 10^{-4}$$

$$= 0.00509 \text{ darcys.}$$

The above values are summarised in Table 8.

APPENDIX 2

RESULTS OF LEAKAGE TESTS OF WHOLE OF LOW PRESSURE AREA AT EAST MAITLAND

There is a total length of approximately 33 miles of main in this area. The lengths of the various sizes of main and the exact types of joint are not known. However it is known that a considerable area was reticulated within the last 15 years with 4" dia cast iron main with rollin rubber ring joints.

The services total 1345 with a length of 29,142 yards.

The results of the first test carried out on 17/10/67 before the gas was conditioned, are as follows:-

Time a.m.	Pressure ins w.g.	Gas measured by test meter cu.ft	Time min. sec	Gas sent out cuft/hr.
12.25	2.8	20	1 - 50.4	
12.28	2.7		1 - 51.6	
12.33	2.8		1 - 52.1	
12.36	2.8		1 - 52.1	646
1.10	3.8	20	1 - 55.4	
1.13			1 - 56.0	
1.18			1 - 56.2	
1.22			1 - 56.8	621
1.35	4.55	20	1 - 35.0	
1.37			1 - 27.8	
1.40			1 - 24.8	809
1.43			1 - 30.2	
1.45			1 - 30.4	
1.48			1 - 30.2	800
2.15	5.0	20	1 - 29.4	
2.18			1 - 26.6	
2.21			1 - 29.0	815

Time a.m.	Pressure ins.w.g.	Gas measured by test meter cu.ft	Time min. sec	Gas sent out cuft/hr.
2.54	5.95	20	1 - 17.0	
2.57	5.95		1 - 20.6	
3.00	5.95+		1 - 23.0	898
3.03	6.0	20	1 - 23.8	
3.06			1 - 24.0	
3.10			1 - 23.8	860

These figures are shown in the curve of Figure 8. The equation of the curve is

$$S = 240 + 170\,h - 10\,h^2$$

the usage of gas being 240 cuft/hour.

The equation for the leakage of gas from the system is therefore

$$Q = 170\,h - 10\,h^2.$$

By substituting various values of pressure in the equation, the following table is calculated:

Pressure ins w.g.	Gas sent out cuft/hr.	Leakage cuft/hr.	Leakage cuft/hr./ins w.g.
0	240	-	-
1	400	160	160
2	540	300	150
3	660	420	140
4	760	520	130
5	840	600	120
6	900	660	110
7	940	700	100

The quantity of gas leaking in cubic feet/hour from the low pressure mains and services is shown in Fig. 9.

The quantity of gas leaking in cubic feet/hour/in w.g. is shown in Fig. 17

After conditioning the gas for 15 days, a further test was carried out on 2/4/68.

Time a.m.	Pressure ins w.g.	Gas measured by test meter cuft	Time min. sec	Gas sent out cuft/hr
12.46	2.85	20.3	2 - 14	
12.50			2 - 12	
12.54			2 - 12	551
1.09	2.9	20.3	2 - 37.5	
1.12			2 - 31.5	
1.15			2 - 40.5	
1.18			2 - 36.8	467
1.47	3.7	20.3	2 - 15.6	
1.50			2 - 16.5	
1.53			2 - 4.3	
1.57			2 - 3.4	
2.00			2 - 10.0	563
2.30	5.6	20.3	1 - 41.4	
2.33			1 - 42.1	
2.35			1 - 42.1	717
2.40	5.5	20.3	1 - 40.7	
2.42			1 - 38.4	
2.45			1 - 38.2	
2.48			1 - 39.3	736
2.59	6.4	20.3	1 - 44.9	
3.02			1 - 41.3	
3.05			1 - 39.6	717
3.25	6.4	20.3	1 - 39.4	
3.27			1 - 42.8	
3.29			1 - 48.0	
3.32			1 - 49.8	
3.35			1 - 50.0	
3.37			1 - 46.9	
3.40			1 - 45.1	690

These figures are shown in Fig. 8. The equation of the curve is

$$S = 240 + 93.3h - 2.2h^2$$

the usage again amounting to 240 cuft/hour.

The equation for the leakage of gas from the system is

$$Q = 93.3h - 2.2h^2$$

By substituting values of pressure in the equation, the following table is calculated:

Pressure ins w.g.	Gas sent out cuft/hr.	Leakage cuft/hr.	Leakage cuft/hr./ins w.g.
0	240	-	-
1	331	91	91
2	418	178	89
3	501	261	87
4	576	336	84
5	650	410	82
6	720	480	80
7	786	546	78

The quantity of gas leaking in cuft/hour from the low pressure mains and services is shown in Fig. 9 and in cuft/hour/ in w.g. in Fig. 17.

After conditioning the gas for a further 21 days, the test results on 14/5/68 were as follows:

Time a.m.	Pressure ins w.g.	Gas measured by test meter cuft	Time min. sec	Gas sent out cuft/hr
12.52	3.0	20.3	2 - 34.4	
12.55			2 - 39.0	
12.58			2 - 47.2	
1.01			2 - 54.1	447
1.28	4.1	20.3	2 - 10.4	
1.31			2 - 16.2	
1.34			2 - 18.0	
1.37			2 - 21.6	
1.40			2 - 14.5	
1.43			2 - 14.5	
1.46			2 - 18.0	540
2.10	5.7	20.3	1 - 52.1	
2.12			1 - 55.2	
2.14			1 - 57.2	
2.17			1 - 58.5	
2.20			1 - 57.2	
2.22			1 - 55.7	
2.24			1 - 58.5	629
2.52	5.7	20.3	1 - 51.1	
2.54			1 - 52.1	
2.56			1 - 52.7	652
3.08	6.4	20.3	1 - 42.0	
3.11			1 - 43.0	
3.13			1 - 43.3	
3.15			1 - 42.1	
3.17	6.4	20.3	1 - 40.7	713
3.19			1 - 43.3	
3.21	6.4	20.3	1 - 44.4	704
3.25			1 - 46.8	684
3.27			1 - 49.5	676

These figures are plotted in Fig. 8. The equation for the curve is

$$S = 240 + 72\,h$$

the usage again amounting to 240 cuft/hour. The equation for the leakage of gas from the system is $Q = 72\ h$. This is a straight line and is shown in Fig. 9 as cubic feet/hour, and in Fig. 17 as cubic feet/hour/in w.g.

CALCULATION OF PERMEABILITY

Total length of mains = 33 miles = 174,240 ft

Total length of services = 1345 x 65 ft ea = 87,425 ft

Total length of mains and services = 261,665 ft

Average width of trench = 1.25 ft

Average depth of pipes = 1.5 ft

Viscosity = 138.3×10^{-4} centipoises

$$k = 104.86 \times \frac{q}{h} \times 138.3 \times 10^{-4} \times \frac{1.5}{1.25 \times 261{,}665}$$

$$= 0.06651 \times \frac{q}{h} \times 10^{-4}$$

Before gas conditioning,

From Fig. 17 (a) $\frac{q}{h}$ = 140 at 3 ins w.g.

$$k = 0.06651 \times 140 \times 10^{-4}$$

$$= 0.000931 \text{ darcys.}$$

(b) $\frac{q}{h}$ = 110 at 6 ins w.g.

$$k = 0.06651 \times 110 \times 10^{-4}$$

$$= 0.000732 \text{ darcys}$$

After gas conditioning for 15 days,

From Fig. 17 (a) $\frac{q}{h}$ = 87 at 3 ins w.g.

$$k = 0.06651 \times 87 \times 10^{-4}$$

$$= 0.000578 \text{ darcys}$$

(b) $\frac{q}{h}$ = 80 at 6 ins w.g.

$$k = 0.06651 \times 80 \times 10^{-4}$$

$$= 0.000532 \text{ darcys}$$

After further 21 days conditioning,

From Fig. 17

$\frac{q}{h}$ = 72 constant for all pressures

$$k = 0.06651 \times 72 \times 10^{-4}$$

$$= 0.000479 \text{ darcys.}$$

The above values are summarised in Table 8.

APPENDIX 3

RESULTS OF LEAKAGE TEST ON WHOLE OF LOW PRESSURE AREA AT CAMDEN

There is a total length of approximately 1161 yards of main in this area together with 100 services having a total length of 1000 yards.

The results of the first test carried out on 7/8/68 prior to gas conditioning are as follows:-

Time a.m.	Pressure ins w.g.	Gas measured by test meter cu.ft	Time min. sec	Gas sent out cuft/hr.
12.43	3.25	2.0	1 - 8.0	
			1 - 8.0	
			1 - 8.1	
			1 - 7.9	106.0
12.50	3.2	2.0	1 - 7.6	
			1 - 7.5	
			1 - 7.3	
			1 - 8.3	
			1 - 9.7	
			1 - 9.5	105.4
1.05	3.6	2.0	1 - 3.0	
			1 - 3.4	
			1 - 3.2	
			1 - 3.4	114
1.15	3.6	2.0	1 - 2.2	
			1 - 2.4	
			1 - 2.0	
			1 - 2.6	115
1.25	4.1	2.0	57.2	
			57.4	
1.45			57.1	126
2.05	4.9	2.0	50.4	
			50.6	142
	4.9	2.0	51.5	
			51.6	139

Time a.m.	Pressure ins w.g.	Gas measured by test meter cu.ft	Time min. sec	Gas sent out cuft/hr.
2.15	4.9	2.0	52.2	
			52.3	
			52.0	
			51.9	138
2.25	5.8	2.0	45.9	
			45.9	156.8
2.30	5.8		45.8	
			45.8	157.2
2.35	5.8		45.7	
			45.6	157.7

These figures are shown in the curve of Fig. 10. The equation of the curve is

$$S = 36.2 + 22.47\,h - 0.16\,h^2$$

the usage of gas being 36.2 cuft/hour.

The equation for the leakage of gas from the system is therefore

$$Q = 22.47\,h - 0.16\,h^2$$

The leakage is calculated by substituting various values of pressure in the equation.

Pressure ins w.g.	Leakage cuft/hr.	Leakage cuft/hr/in w.g.
1	22.31	22.31
2	44.30	22.15
3	65.97	21.99
4	87.32	21.83
5	108.35	21.67
6	129.06	21.51

The quantity of gas leaking in cubic feet/hour is shown in Fig. 10 and in cubic feet/hour/in w.g. in Fig. 17.

CALCULATION OF PERMEABILITY

Total length of mains	=	3483 feet
Total length of services = 100 x 30 ft ea	=	3000 feet
Total length of mains and services	=	6483 feet
Average width of trench	=	1.25 feet
Average depth of pipes	=	1.25 feet
Viscosity	=	124.1×10^{-4} centipoises

$$k = 104.86 \times \frac{q}{h} \times 124.1 \times 10^{-4} \times \frac{1.25}{1.25 \times 6483}$$

$$= 2.007 \times \frac{q}{h} \times 10^{-4}$$

Before gas conditioning,

(a) $\frac{q}{h} = 21.99$ at 3 ins w.g.

$$k = 2.007 \times 21.99 \times 10^{-4}$$

$$= 0.00441 \text{ darcys.}$$

(b) $\frac{q}{h} = 21.51$ at 6 ins w.g.

$$k = 2.007 \times 21.51 \times 10^{-4}$$

$$= 0.00432 \text{ darcys.}$$

APPENDIX 4

RESULTS OF LEAKAGE TEST ON WHOLE OF LOW PRESSURE AREA AT WEST TAMWORTH

The mains in this area comprise 1386 feet of 6" diameter, 22572 feet of 4" diameter and 15543 feet of 3" diameter cast iron pipe together with 34,056 feet of 2" and smaller diameter steel mains making a total of 73,557 feet.

Most of the 6" and 4" diameter cast iron mains have roll in rubber ring joints. About 25% of the 3" diameter mains have rubber ring joints, the remainder being hemp and lead. The steel mains are screwed and socketed.

The services total 650 with an overall length of 42,250 feet.

The results of the test carried out on 5/2/69 prior to gas conditioning are as follows:

Time a.m.	Pressure ins w.g.	Gas measured by test meter cu.ft	Time min. sec	Gas sent out cuft/hr.
2.12	2.7	21.1	3 - 52.6	326.6
2.16			3 - 52.3	327.0
2.20	2.8	21.1	3 - 57.7	311.1
2.25			3 - 57.0	320.5
2.37	2.8	21.1	3 - 55.9	322.0
2.50	3.8	21.1	3 - 1.6	418.3
2.55	3.8	21.1	3 - 2.5	
			3 - 2.5	416.2
3.00	3.8	21.1	3 - 6.2	408.0
			3 - 6.9	406.4
3.05	3.8	21.1	2 - 56.7	430.0
			2 - 57.0	429.2
3.10	3.8	21.1	2 - 58.8	424.8
			2 - 58.7	425.1

Time a.m.	Pressure ins w.g.	Gas measured by test meter cu.ft.	Time min. sec.	Gas sent out cuft/hr.
3.35	5.0	21.1	2 - 21.4	537.2
			2 - 22.2	534.2
3.38	5.0	21.1	2 - 23.8	528.2
			2 - 23.6	528.9
3.41	5.0	21.1	2 - 22.1	
			2 - 22.6	532.7
3.44	5.0	21.1	2 - 20.8	539.4
			2 - 20.8	
4.15	5.6	21.1	2 - 13.1	
			2 - 13.2	570.3
4.18	5.6	21.1	2 - 10.0	583.4
			2 - 10.6	581.6
4.21	5.6	21.1	2 - 13.6	568.5
			2 - 14.5	564.8
4.24	5.5	21.1	2 - 8.3	592.0
			2 - 8.5	591.1
4.45	6.6	21.1	1 - 47.5	
			1 - 47.5	706.6
4.47	6.6	21.1	1 - 47.0	710.0
			1 - 46.7	711.9
4.50	6.6	21.1	1 - 48.3	700.1

These figures are shown in the curve of Figure 11. The equation of the curve is

$$S = 103.4 + 69.46\,h + 3.334\,h^2$$

the usage of gas being 103.4 cuft/hour.

The equation for the leakage of gas from the system is therefore

$$Q = 69.46\,h + 3.334\,h^2.$$

By substituting various values of pressure in the equation, the following table is calculated:-

Pressure ins w.g.	Gas sent out cuft/hr.	Leakage cuft/hr.	Leakage cuft/hr./ins w.g.
0	103.4	-	-
1	176.2	72.8	72.8
2	255.7	152.3	76.2
3	341.8	238.4	79.5
4	434.5	331.1	82.8
5	534.0	430.6	86.1
6	640.0	536.6	89.4
7	752.8	649.4	92.8

The quantity of gas leaking in cubic feet/hour from the low pressure mains and services is shown in Fig. 11.

The quantity of gas leaking in cubic feet/hour/ in w.g. is shown in Fig. 17.

CALCULATION OF PERMEABILITY

Total length of mains	=	73,557 feet
Total length of services	=	42,250 feet
Total length mains and services	=	115,807 feet
Average width of trench	=	1.25 feet
Average depth of pipes	=	1.5 feet
Viscosity	=	132.9×10^{-4} centipoises

$$k = 104.86 \times \frac{q}{h} \times 132.9 \times 10^{-4} \times \frac{1.5}{1.25 \times 115{,}807}$$

$$= 0.1444 \times \frac{q}{h} \times 10^{-4}$$

Before gas conditioning,

(a) $\frac{q}{h}$ = 79.5 at 3 ins w.g.

$k = 0.1444 \times 79.5 \times 10^{-4}$

$= 0.001148$ darcys.

(b) $\frac{q}{h}$ = 92.8 at 7 ins w.g.

$k = 0.1444 \times 92.8 \times 10^{-4}$

$= 0.001340$ darcys.

The above values are summarised in Table 8.

APPENDIX 5

RESULTS OF TEST ON MEDIUM PRESSURE TRUNK MAIN AT BATHURST

This main is 6226 yards long of which 4730 yards are roll in rubber ring joints and the remaining 1496 yards are either hemp and lead or mechanical rubber ring joints. It is all cast iron, the majority being 6" diameter, with some 9" and 4" diameter pipe.

There are 5 governors feeding gas into the low pressure system. The inlet and outlet valves of these governors were shut off for the period of the test. In addition in one area there are 12 consumers each having a storage hot water service installed.

Although this main normally carries pressures up to 10 lbs/sq.in, it is fed from a low pressure holder at 5 ins w.g. between the hours of 11.30 p.m. and 5.30 a.m. In order to determine the effect of this practice, test pressures were limited to 9" w.g.

The results of the test carried out on 18/2/69 prior to gas conditioning were as follows:-

Time a.m.	Pressure ins w.g.	Gas measured by test meter cu.ft.	Time min.sec	Gas sent out cuft/hr.
12.15	3.8	5	1 - 54.2	158
12.17			1 - 56.4	155
12.20			1 - 54.0	158
1.15	4.1	5	1 - 40.7	179
1.18			2 - 5.5	143
1.20			1 - 42.8	175
1.22			1 - 43.9	173
1.25			1 - 58.8	152

Time a.m.	Pressure ins.w.g.	Gas measured by test meter cuft.	Time min.sec	Gas sent out cuft/hr.
1.26	4.2	5	2 - 17.9	131
1.27			2 - 20.1	129
1.30			2 - 39.1	113
1.33			2 - 39.1	113
1.36			2 - 43.4	110
1.39	4.2	5	2 - 43.9	110
2.00	5.1	5	1 - 53.3	159
2.03		5	1 - 50.4	163
2.06		5	1 - 38.0	184
2.07		5	1 - 39.5	181
2.09		5	1 - 35.9	188
2.11		5	2 - 2.0	148
2.13		10	3 - 5.3	194
2.16		10	3 - 23.8	177
2.19		10	3 - 4.4	195
2.22		10	3 - 30.6	171
2.25		5	1 - 52.4	160
2.27		5	1 - 34.6	190
2.30	5.1	5	1 - 37.3	185
2.35	6.0	10	2 - 46.1	217
2.36		10	2 - 40.4	224
2.37		5	1 - 40.5	179
2.39		5	1 - 40.1	180
2.43		10	2 - 55.9	205
2.45		10	3 - 11.2	188
2.48		5	1 - 23.5	216
2.50	6.0	5	1 - 28.2	204
2.59	7.0	5	1 - 20.3	224
3.03	6.9	10	2 - 17.6	262
3.05		5	1 - 16.4	236
3.08		10	2 - 25.8	247
3.09		10	2 - 20.2	257
3.10		10	1 - 58.2	305
3.12		10	2 - 29.1	241
3.13		5	1 - 23.7	215
3.16		10	2 - 10.0	277
3.18		10	2 - 25.7	247

Time a.m.	Pressure ins.w.g.	Gas measured by test meter cuft.	Time min.sec	Gas sent out cuft/hr.
3.19	6.9	5	1 - 21.4	221
3.28	8.5	10	2 - 14.0	269
3.30			2 - 11.2	274
3.32			2 - 6.0	286
3.33			2 - 11.6	274
3.35			2 - 1.8	296
3.36			2 - 5.9	286
3.38			2 - 2.8	293
3.40			1 - 52.8	319
3.41			2 - 10.0	277
3.43	8.5	10	1 - 49.7	328

The above figures are shown in the curve of Fig. 12. While the pressures at each setting remained constant, the quantity of gas sent out varied considerably. This was due to the only usage being the consumption of 12 hot water services. At an average standby consumption of 1000 B.T.U. per appliance, the average usage would amount to $\frac{12 \times 1000}{511.8} = 23.4$ cuft/hr for a gas of 511.8 B.T.U./cuft.

The equation of a reasonably average curve drawn through the experimental points is

$$S = 24 + 28\,h + 0.5\,h^2$$

the usage of 24 cuft/hr closely corresponding with the calculated figure above.

A curve drawn parallel to this curve through the maximum experimental points cuts the ordinate to give a usage of 60 cubic feet/hour. This increased usage above 24 cuft/hr could be due to one appliance cutting in at full rate.

The equation for the leakage of gas from the trunk main is

$$Q = 28\,h + 0.5\,h^2$$

By substituting various values of pressure in the equation, the following table is calculated:-

Pressure ins w.g.	Gas sent out cuft/hr.	Leakage cuft/hr.	Leakage cuft/hr/ins w.g.
0	24	-	-
1	52.2	28.5	28.5
2	82	58	29.0
3	112.5	88.5	29.5
4	144	120	30.0
5	176.5	152.5	30.5
6	210	186	31.0
7	244.5	220.5	31.5
8	280	256	32.0
9	316.5	292.5	32.5

The quantity of gas leaking in cubic feet/hour from the main is shown in Fig. 12.

The quantity of gas leaking in cubic feet/hour/in w.g. is shown in Fig. 17.

CALCULATION OF PERMEABILITY

Total length of main	=	19678 feet
Total length of services = 12 x 65 ft ea	=	780 feet
Total length of mains and services	=	19458 feet
Average width of trench	=	1.5 feet
Average depth of main	=	1.5 feet
Viscosity	=	138.7×10^{-4} centipoises

$$k = 104.86 \times \frac{q}{h} \times 138.7 \times 10^{-4} \times \frac{1.5}{1.5 \times 19458}$$

$$\doteqdot 0.748 \times \frac{q}{h} \times 10^{-4}$$

Before gas conditioning,

(a) $\frac{q}{h} = 29.5$ at 3 ins w.g.

$$k = 0.748 \times 29.5 \times 10^{-4}$$

$$= 0.00221 \text{ darcys}$$

(b) $\frac{q}{h} = 32.0$ at 8 in w.g.

$$k = 0.748 \times 32.0 \times 10^{-4}$$

$$= 0.00239 \text{ darcys}$$

These values are summarised in Table 8.

APPENDIX 6

RESULTS OF LEAKAGE TEST ON AN ISOLATED SECTION

OF MAIN IN HILL STREET, MOLONG

A section of 3" diameter welded steel main 645 feet long was isolated and gas fed into one end through an appliance governor, spring loaded to give the required pressure.

Five services of a total length of 573 feet are connected to the main. All service cocks were shut off at the inlet to meters during the test.

The results of the test carried out on 27/6/67 are as follows:-

Time p.m.	Pressure ins.w.g.	Gas measured by test meter cu.ft	Time secs.	Leakage cuft/hr.	Leakage cuft/hr/in w.g.
4.00	2.5	0.1	51.4	7.0	2.8
4.05			51.4	7.0	2.8
4.15	3.9	0.1	36.7	9.8	2.5
4.17			36.5	9.9	2.5
4.19			36.8	9.8	2.5
4.25	5.8	0.1	27.7	13.0	2.24
4.27	5.9	0.1	30.0	12.0	2.03
4.30			30.0	12.0	2.03
4.32			30.0	12.0	2.03

These figures are shown in the curve of Fig. 13. The equation of the curve is

$$Q = 3.362\,h - 0.225\,h^2$$

the usage of gas being zero since all cocks were turned off.

The quantity of gas leaking in cuft/hour from the section of main and the services is shown in Fig. 13. The quantity of gas leaking in cubic feet/hour/in w.g. is shown in Fig. 18.

CALCULATION OF PERMEABILITY

Length of section of main	= 645 feet
Average width of trench	= 1.25 feet
Area for main 1.25 x 645	= 806 sq. feet
Length of 5 services	= 573 feet
Average width of trench	= 1.0 feet
Area for services 1.0 x 573	= 573 sq. feet
Total Area	= 1379 sq. feet
Average depth	= 1.5 feet
Viscosity	= 124.1×10^{-4} centipoises

$$k = 104.86 \times \frac{q}{h} \times 124.1 \times 10^{-4} \times \frac{1.5}{1379}$$

$$= 0.00142 \times \frac{q}{h} \times 10^{-4}$$

(a) $\frac{q}{h} = 2.925$ at 2 ins w.g.

$$k = 0.00142 \times 2.925 \times 10^{-4}$$

$= 0.00414$ darcys

(b) $\frac{q}{h} = 2.012$ at 6 ins w.g.

$$k = 0.00142 \times 2.012 \times 10^{-4}$$

$= 0.00285$ darcys.

The above values are summarised in Table 8.

APPENDIX 7

RESULTS OF LEAKAGE TEST ON AN ISOLATED SECTION OF MAIN AT CHELLASTON STREET, CAMDEN

The main carries low pressure gas and is hemp and lead jointed cast iron, 3" in diameter. It is 397 yards long and has 21 services of a total length of 904 feet connected to it. In carrying out the test, all service cocks, at the inlet to meters, were shut off.

The results of the test carried out on 19/8/68 are as follows:-

Pressure ins w.g.	Gas measured by test meter cu.ft.	Time min.sec	Leakage cuft/hr.	Leakage cuft/hr/in w.g.
3.5	0.1	2 - 7.3	2.83	0.81
3.8		1 - 52.5	3.20	0.84
4.5		1 - 37.3	3.70	0.82
5.15		1 - 20.0	4.50	0.87
6.3		1 - 9.9	5.30	0.84
7.35		58.4	6.20	0.84

These figures are shown in Fig. 13. Since there is no usage the curve passes through the origin and has the equation

$$Q = 0.84\,h$$

The quantity of gas leaking in cubic/feet/hour/in w.g. is shown in Fig. 18.

CALCULATION OF PERMEABILITY

Length of main	=	1191 feet
Length of 21 services	=	904 feet
Total length of main and services	=	2095 feet
Average width of trench	=	1.25 feet
Average depth of main and services	=	1.2 feet
Viscosity	=	124.1×10^{-4} centipoises

$$\frac{q}{h} = 0.84 \text{ constant for all pressures}$$

$$k = 104.86 \times 0.84 \times 124.1 \times 10^{-4} \times \frac{1.2}{1.25 \times 2095}$$

$$= 0.000501 \text{ darcys.}$$

APPENDIX 8

RESULTS OF LEAKAGE TEST ON AN ISOLATED SECTION OF MAIN IN EDEN, PEDEN, UPPER & HIGH STREETS, BEGA

These mains are all steel with screwed and socketed joints. They comprise 1910 feet of 2" diameter, 200 feet of $1\frac{1}{4}$" diameter and 1127 feet of 1" diameter service pipe. During the test all service cocks were turned off at the inlet to the meters.

The results of the test carried out on 25/5/66 were as follows:-

Time a.m.	Pressure ins w.g.	Gas measured by test meter cuft in 5 mins	Leakage cuft/hr	Leakage cuft/hr/in w.g.
2.30	3.0	-	-	-
2.35	3.2	1.27	15.24	4.92
2.40	3.4	1.31	15.72	4.76
2.45	3.7	1.12	13.44	3.79
2.50	3.4	1.38	16.56	4.66
2.55	3.4	1.30	15.60	4.60
3.00	3.2	1.22	14.64	4.44
3.30	5.0	-	-	-
3.35	5.0	1.75	21.0	4.20
3.40	5.0	1.75	21.0	4.20
3.45	4.7	1.65	19.8	4.21
3.50	4.7	1.65	19.8	4.21

Unfortunately sufficient time was not available to carry out the test at other pressures since it was necessary to restore the supply to consumers.

The above figures are shown in Fig. 13. Since there is no usage the curve passes through the origin and has the equation

$$Q = 5.7\,h - 0.3\,h^2$$

The quantity of gas leaking in cubic feet/hour/in w.g. is shown in Fig. 18.

CALCULATION OF PERMEABILITY

Length of 2" mains = 1910 feet

Length of $1\frac{1}{4}$" mains = 200 feet   2110 feet

Length of services = 1127 feet

Total length of mains and services = 3237 feet

Average width of trench = 1.0 feet

Average depth of pipes = 1.5 feet

Viscosity = 123.6×10^{-4} centipoises

$$k = 104.86 \times \frac{q}{h} \times 123.6 \times 10^{-4} \times \frac{1.5}{1 \times 3237}$$

$$= 6.006 \times \frac{q}{h} \times 10^{-4}$$

Before gas conditioning

(a) $\frac{q}{h} = 4.67$ at 3 ins w.g.

$$k = 6.006 \times 4.67 \times 10^{-4}$$

$$= 0.00281 \text{ darcys}$$

(b) $\frac{q}{h} = 4.2$ at 5 ins w.g.

$$k = 6.006 \times 4.2 \times 10^{-4}$$

$$= 0.00252 \text{ darcys}$$

The above values are summarised in Table 8 .

APPENDIX 9

RESULTS OF LEAKAGE TESTS ON HIGH PRESSURE

TRUNK MAIN FROM OLD MAITLAND WORKS

This system consists of a 6" diameter cast iron main with roll in rubber ring joints 8624 yards long conveying gas from the Old Maitland Works to the Bradmill Factory at Rutherford. A spur line feeds gas over the new Belmore Bridge to a district governor at Lorn. This section comprises 483 yards of the original 6" diameter cast iron main with 282 yards of steel main over the new bridge. There is no leakage in the latter section and it is not included in the length of main from which leakage is occurring. There are 40 consumers connected to the main.

The results of the first test carried out on 22/10/68 before gas was conditioned, are as follows:-

Time a.m.	Pressure ins w.g.	Gas measured by test meter cu.ft.	Time sec.	Gas sent out cuft/hr at measuring pressure	Gas sent out cuft/hr Corrected to 2" w.g.
12.17	22.8	10.0	44.3		
		10.2	48.0		
12.18	22.8	10.0	44.6		
		10.2	48.3		
12.20	22.8	10.0	44.3		
		10.2	48.3	811	
				761	
12.22	22.8	10.0	44.5		
		10.2	48.4	1572	1652

Time a.m.	Pressure ins w.g.	Gas measured by test meter cuft.	Time secs	Gas sent out cuft/hr at measuring pressure	Gas sent out cuft/hr Corrected to 2" w.g.
12.38	23.4	10.0	46.5		
		10.2	49.8		
12.40	23.4	10.0	46.3		
		10.2	49.9	776	
12.42	23.4	10.0	46.5	736	
		10.2	50.2	1512	1591
1.08	31.3	10.0	43.3		
		10.2	47.0		
1.10	31.3	10.0	43.3		
		10.2	47.0		
1.12	31.3	10.0	43.5		
		10.2	47.1	830	
1.15	31.3	10.0	43.5	780	
		10.2	47.2	1610	1725
1.38	38.0	10.0	41.2		
		10.2	45.0		
1.40	38.0	10.0	41.2		
		10.2	45.1		
1.43	38.0	10.0	41.3		
		10.2	45.5		
1.44	38.0	10.0	41.6		
		10.2	45.0		
1.45	38.0	10.0	45.4		
1.46	38.2	10.0	41.6		
		10.2	45.4	868	
1.48	38.2	10.0	41.6	809	
		10.2	45.5	1677	1924
2.32	51.2	10.0	36.8		
		10.2	40.0		
2.34	51.2	10.0	36.7		
		10.2	40.1		

Time a.m.	Pressure ins.w.g.	Gas measured by test meter cuft.	Time secs.	Gas sent out cuft/hr at measuring pressure	Gas sent out cuft/hr Corrected to 2" w.g
2.35	51.2	10.0	36.3		
		10.2	40.1		
2.36	51.2	10.0	36.7		
		10.2	40.0		
2.37	51.2	10.0	36.7		
		10.2	40.1		
2.38	51.2	10.0	36.9		
		10.2	40.0	981	
2.40	51.2	10.0	36.7	916	
		10.2	40.1	1897	2125
3.17	59.0	10.0	49.6		
		10.2	54.3		
		10.1	61.2		
3.19	59.0	10.0	48.6		
		10.2	53.5		
		10.1	60.2		
3.22	59.1	10.0	49.0		
		10.2	53.6		
		10.1	60.3		
3.25	59.1	10.0	48.7	739	
		10.2	53.5	686	
		10.1	60.6	603	
				2028	2310
3.50	63.5	10.0	46.2		
		10.2	50.5		
		10.1	57.3		
3.52	63.6	10.0	46.6		
		10.2	50.5		
		10.1	57.4		
3.54	63.7	10.0	46.4		
		10.2	50.7		
		10.1	57.6		
				776	
3.56	63.7	10.0	46.5	726	
		10.2	50.9	632	
		10.1	57.5	2134	2456

These figures are shown in the curve of Fig. 14. The equation of the curve is

$$S = 1425 + 1.75\,h + 0.225\,h^2$$

The usage of gas is 1425 cuft/hour and comprises:-

(a) Usage of gas from high pressure line.

(b) Gas passing through Lorn governor at a constant outlet pressure of 3.0" w.g. being the sum of the usage and loss in the Lorn low pressure area of supply.

The equation for the leakage of gas from the high pressure main is

$$Q = 1.75\,h + 0.225\,h^2$$

The following table showing actual losses of gas from the main has been drawn up by subtracting the usage from the gas sent out in each case.

Pressure ins w.g.	Gas sent out cuft./hr	Leakage cuft / hr.	$\frac{(P_1^2 - P_2^2)}{2P_b}$	Leakage cuft/hr/ins wg
0	1425	-	-	-
22.8	1652	227	23.3	9.70
23.4	1591	166	24.0	6.92
31.3	1725	300	32.3	9.29
38.2	1824	399	39.8	10.00
51.2	2125	700	54.1	12.94
59.1	2310	885	63.1	14.02
63.7	2456	1031	68.3	15.10

The quantity of gas leaking in cubic feet/hour from the high pressure main is also shown in Fig. 14.

The quantity of gas leaking in cubic feet/hour/ in w.g. is shown in Fig. 19.

After conditioning the gas for 15 days a further test was carried out on 29/1/69 with the following results:-

Time a.m.	Pressure ins w.g.	Gas measured by test meter cuft.	Time secs.	Gas sent out At measuring pressure	cuft/hr. Corrected to 2" w.g.
12.40	28.5	10.0	53.4	674	
		10.2	57.6	638	
				1312	1397
12.44	28.5	10.0	53.6	672	
		10.2	57.8	635	
				1307	1367
12.46	28.4	10.0	53.6		
		10.2	57.7		
12.50	27.9	10.0	52.6		
		10.2	57.1		
12.52	28.5	10.0	52.7		
		10.2	57.0		
12.54	28.5	10.0	52.8	681	
		10.2	57.0	646	
				1327	1413
12.56	28.5	10.0	52.8		
		10.2	57.0		
1.20	34.1	10.0	51.4		
		10.2	55.8		
1.22	34.2	10.0	51.7	696	
		10.2	55.9	656	
				1352	1459
1.26	34.5	10.0	52.4	687	
		10.2	56.5	650	
				1337	1443

Time a.m.	Pressure ins w.g.	Gas measured by test meter cuft.	Time secs.	Gas sent out At measuring pressure	cuft/hr. Corrected to 2" w.g.
1.28	34.5	10.0	52.5		
		10.2	56.5		
1.32	35.0	10.0	58.7		
		10.2	64.5		
1.34	34.6	10.0	58.6		
		10.2	64.0		
1.36	34.5	10.0	58.6	614	
		10.2	64.1	573	
				1187	1281
1.38	34.5	10.0	58.7		
		10.2	64.1		
2.05	39.5	10.0	51.7	696	
		10.2	56.0	656	
				1352	1472
2.07	39.5	10.0	51.7		
		10.2	56.0		
2.20	39.4	10.0	56.9		
		10.2	62.5		
2.22	39.1	10.0	56.8	634	
		10.2	62.6	585	
				1219	1329
2.25	39.2	10.0	57.1		
		10.2	62.9		
2.28	39.0	10.0	56.6		
		10.2	63.0		
2.30	39.0	10.0	56.8		
		10.2	62.8		
2.45	38.7	10.0	50.3		
		10.2	54.7		
2.47	38.7	10.0	50.6	713	
		10.2	55.0	669	
				1382	1506
2.49	38.9	10.0	50.6		
		10.2	55.2		
3.18	50.3	10.0	53.2	677	
		10.2	58.5	628	
				1305	1459

Time a.m.	Pressure ins w.g.	Gas measured by test meter cuft.	Time secs.	Gas sent out At measuring pressure	cuft/hr Corrected to 2" w.g.
3.20	50.4	10.0	53.4		
		10.2	58.7		
3.22	50.5	10.0	54.2		
		10.2	59.6		
3.24	50.6	10.0	54.4	662	
		10.2	59.6	616	
				1278	1430
3.26	50.6	10.0	54.4		
		10.2	59.8		
3.28	50.6	10.0	54.6		
		10.2	60.0		
3.30	50.6	10.0	54.6	660	
		10.2	60.2	610	
				1270	1422
3.32	51.0	10.0	54.8		
		10.2	60.3		
3.34	51.0	10.0	54.6		
		10.2	60.3		
4.01	64.0	10.0	49.6		
		10.2	54.1		
4.03	64.3	10.0	50.3		
		10.2	55.4		
4.05	64.5	10.0	51.2		
		10.2	56.1		
4.07	64.5	10.0	51.3	702	
		10.2	56.1	655	
				1357	1564
4.09	64.5	10.0	51.4		
		10.2	56.3		
4.11	64.6	10.0	51.3		
		10.2	56.2		
4.13	64.5	10.0	51.4		
		10.2	56.3		

These figures are shown in the curves of Fig. 14.

It would appear that during the period of the test the usage of gas varied. A check with the personnel at the Bradmil Factory revealed that a Singeing machine was working intermittently during the night.

Accordingly two curves have been drawn through the experimental points. The equations are

$$S_1 = 986 + 18.56\, h_1 - 0.147\, h_1^2$$

the usage of gas being 986 cuft/hour and $S_2 = 840 + 15.36\, h_2 - 0.0746\, h_2^2$ with a usage of 840 cuft/hour.

The following table showing actual losses of gas from the main has been drawn up by subtracting the usage from the gas sent out in each case.

Pressure ins w.g.	Gas sent out cuft/hr	Leakage cuft/hr	$\frac{(P_1^2 - P_2^2)}{2P_b}$	Leakage cuft/hr./ in w.g.
0	986	-	-	-
28.5	1397	411	29.35	14.00
28.5	1367	381	29.35	12.98
28.5	1413	427	29.35	14.55
34.2	1459	473	35.46	13.34
34.5	1443	457	35.79	12.78
38.7	1506	520	40.34	12.89
39.5	1476	490	41.20	11.89
0	840	-	-	-
34.5	1281	441	35.79	12.32
39.1	1329	489	40.78	11.99
50.3	1459	619	53.15	11.65
50.6	1430	590	53.48	11.03
50.6	1422	582	53.48	10.88
64.5	1564	724	69.27	10.45

The quantity of gas leaking in cubic feet/hour from the high pressure main is also shown in Fig. 14. A reasonably smooth curve through all the test points is obtained by analysing the results in the foregoing manner.

The quantity of gas leaking in cubic feet/hour/ in w.g. is shown in Fig. 19.

CALCULATION OF PERMEABILITY

Total length of mains	= 27321 feet
Total length of services = 40 x 65 ft ea	= 2600 feet
Total length of mains and services	= 29921 feet
Average width of trench	= 1.25 feet
Average depth of pipes	= 1.25 feet

Viscosity = 138.3×10^{-4} centipoises

$$k = 104.86 \times \frac{q}{h} \times 138.3 \times 10^{-4} \times \frac{1.25}{1.25 \times 29921}$$

$$= 0.485 \times \frac{q}{h} \times 10^{-4}$$

Before gas conditioning,

(a) $\frac{q}{h}$ = 4.50 at 10 ins w.g.

$$k = 0.485 \times 4.50 \times 10^{-4}$$

$$= 0.000219 \text{ darcys}$$

(b) $\frac{q}{h}$ = 14.3 at 60 ins w.g.

$$k = 0.485 \times 14.3 \times 10^{-4}$$

$$= 0.000693 \text{ darcys}$$

After 15 days gas conditioning

(a) $\frac{q}{h}$ = 15.4 at 10 ins w.g.

$k = 0.485 \times 15.4 \times 10^{-4}$

$= 0.000747$ darcys

(b) $\frac{q}{h}$ = 10.5 at 60 ins w.g.

$k = 0.485 \times 10.5 \times 10^{-4}$

$= 0.000509$ darcys

The above values are summarised in Table 8.

APPENDIX 10

RESULTS OF LEAKAGE TEST ON WHOLE OF HIGH PRESSURE AREA AT CAMDEN

The high pressure area comprises 13,587 yards of steel main with screwed joints and 1375 yards of steel service pipe again with screwed joints. A service governor is fitted at the inlet of each consumer's meter.

Time a.m.	Pressure ins w.g.	Gas measured by test meter cu.ft.	Time secs.	Gas sent out cuft/hr At measuring pressure	Gas sent out cuft/hr Corrected to 2" w.g.
12.29	115.5	2	29.2		
			29.4		
			29.2		
12.30	116.0	2	29.3		
			30.8		
12.33	116.0	2	30.8		
			30.8		
12.35	117.0	2	31.4		
			31.4		
12.37	117.5	2	31.5		
			31.8		
			31.8	227	
12.40	118.0	2	31.5		
			31.8	227	291
1.20	166.0	4	71.0		
			71.6		
			71.5		
			71.9		
			72.0		
1.24	167	4	72.2		
			72.1		
			72.2		
			72.5		
1.26	167	4	73.0		
			73.0		
			73.6		
			73.3	196	275
1.59	200	4	72.7		
			72.9		

Time a.m.	Pressure ins.w.g.	Gas measured by test meter cu. ft.	Time secs.	Gas sent out cuft/hr At measuring pressure	Corrected to 2" w.g.
			73.3		
			73.2		
2.03	200	4	73.3		
			73.5		
2.05	200	4	73.6		
			73.7		
2.07	200	4	73.4		
			73.4		
2.10	200	4	73.7	195.6	290
2.27	232	4	68.7		
			68.1		
			69.0		
2.30	233	4	69.7		
			70.0		
			70.1		
2.32	234	4	70.9		
			70.6		
2.33	234	4	71.8		
			72.0		
			72.6	198.0	310
2.35	235	4	73.4		
			73.6		
2.37			74.0		
			73.8		
2.40			73.8		
2.41	235	4	73.7	195.0	306
3.07	265	4	73.7		
			73.8		
			73.9		
			74.2		
			74.1		
			74.5		
			74.6		
			74.7		
			74.7		
3.14			74.6	194.0	319

These figures are shown in the curve of Fig. 15. The equation of the curve is

$$S = 144 + 0.984\,h - 0.00117\,h^2$$

The usage of gas being 144 cuft/hour.

The equation for the leakage of gas from the system is therefore

$$Q = 0.984\,h - 0.00117\,h^2$$

By substituting various values of pressure in the equation the following table is calculated:-

Pressure ins w.g.	Gas sent out cuft/hr.	Leakage cuft / hr.	$\frac{(P_1^2 - P_2^2)}{2P_b}$	Leakage cuft/hr/ins w.g.
0	144	-	-	-
50	190	46	52.8	0.87
100	230	86	111.7	0.77
125	247	103	143.5	0.72
167	275	131	200.3	0.65
200	290	146	248.0	0.59
235	310	166	301.4	0.55
265	319	175	347.1	0.50

The quantity of gas leaking from the high pressure mains and services in cubic feet / hour is shown in Fig. 15. While the leakage in cubic feet / hour / in w.g. is shown in Fig. 20.

CALCULATION OF PERMEABILITY

Total length of mains	= 40762 feet
Total length of sercices 275 x 15 ft ea	= 4125 feet
Total length of mains and services	= 44887 feet
Average width of trench	= 1 foot
Average depth of pipes	= 1.0 feet
Viscosity	= 124.1×10^{-4} centipoises

$$k = 104.86 \times \frac{q}{h} \times 124.1 \times 10^{-4} \times \frac{1.0}{1.0 \times 44887}$$

$$= 0.2899 \times \frac{q}{h} \times 10^{-4}$$

Before gas conditioning,

(a) $\frac{q}{h} = 0.77$ at 100 ins w.g.

$$k = 0.2899 \times 0.77 \times 10^{-4}$$

$$= 0.0000223 \text{ darcys}$$

(b) $\frac{q}{h} = 0.50$ at 265 ins w.g.

$$k = 0.0000145 \text{ darcys}$$

APPENDIX 11

THE INSTITUTION OF GAS ENGINEERS (AUSTRALIA)

THE 42ND ANNUAL CONFERENCE

"PEAK LOAD GAS"

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INTRODUCTION

To-day it can truly be said that "A Gas Engineer's life if not a happy one". He is faced with just as many problems as in the past, but the possible solutions to them have increased many times.

Perhaps the greatest problem is that of supplying the peak days' requirement for gas. Of recent years undertakings have connected more and more space heating loads to their line of mains. This has increased the winter peak demand but there has not been a corresponding summer load to balance it. Where the ratio of the winter to summer peak was two, it is now three or more depending on the severity of the weather and the size of the town. The position is generally aggravated by the holder storage capacity being too small.

Once it was a matter of one raw material, coal, and he had to decide whether to install hand charged or machine charged horizontal retorts or vertical retorts. Now he also has available various oil products from local refineries which he can distribute either in their original form or use as feedstocks for gas manufacturing processes. The choice of plant at one time was purely a matter of economics. To some extent this is still true to-day.

However, in at least one locality it was impossible to retain labour to operate the retorts and the Gas Engineer found that he was spending long hours stoking to keep up the supply of gas.

The economics of coal carbonisation is dependent on the return from the sale of by-products, coke and tar. Coke burning slow combustion cookers are being replaced with oil or L.P. gas burning equipment. Some Council or Shire Engineers will use Gas Work's tar as a primer on their roads, others will not.

So that while it is possible to sell a limited quantity of by-products, it is extremely doubtful if the quantity produced from any coal carbonising plant extensions would be saleable.

Most Gas Undertakings installed machine charged retort settings containing 8 - 14 feet long straight through retorts to replace hand charged benches. In general this did little more than exchange machine for hand charging, and any increased capacity was soon absorbed by normal increases in sales.

METHODS OF GAS PRODUCTION

Some of these Undertakings are now faced with the alternative of (1) Installing additional carbonising plant, or

(2) Producing gas from some source other than coal.

Additional carbonising plant poses the problem of the sale of by-products already mentioned and in some cases could mean that the capacity of ancillary plant would be too small to deal with the increased make.

A blue water gas plant would use some of the surplus coke, the low calorific value gas being enriched with propane to the declared calorific value of the gas issued.

If oil products are used as fuel sources they may be employed in the following ways:-

1. Liquefied petroleum gas either in bottles at each consumers premises or piped from a common tank and metered in the usual way.

2. Liquefied petroleum gas mixed with air to reduce its calorific value.

3. Liquefied petroleum gas or a distillate as feedstock for a catalytic reforming plant.

4. Natural gas in its neat state, or as a feedstock for a catalytic reforming plant.

Items 1, 2 and 4, if natural gas is used neat would require the burners on appliances to be adjusted to burn the different type of gas, whereas reformed gas is interchangeable with the present gas.

For the purposes of comparison it has been assumed that the existing carbonizing plant consists of two benches of 8 - 14 feet machine charged retorts, one being three years old and the other two years. The present peak day's sendout is 220,000 cu.ft. of 511.8 B.T.U. per cu.ft. of gas which is equivalent to an annual sendout of 53,500,000 cu.ft. These figures are based on an unaccounted for loss of 15%.

1. Liquefied Petroleum Gas.

Consumers within the Undertaking's area may be supplied with L.P. gas in bottles at the same rate per unit as the ordinary towns' gas. As the demand for gas grows, mains could be laid and the supply changed over to reticulated gas or bottles could be allowed to remain. However, at the present time the Undertaking does not possess the sole right to supply such consumers with L.P. gas and any outside organisation may enter the sales field. This situation calls for an urgent amendment to the Gas Act to protect an Undertaking's rights.

With this type of installation the L.P. gas may be sold by weight or through a dry meter in the ordinary way.

If gas is to be supplied to an area of new development such as a Housing Commission project, it may be more convient to install a bulk tank and reticulate L.P. gas to each consumer through a governor and a meter. Again it would be necessary to charge the same price per unit as for the ordinary gas.

The only additional capital cost would be that for the tank, reticulation mains, governors and meters being common. At the present time it is possible for an Undertaking to negotiate for the purchase of a bulk supply of L.P. gas at a price which makes it economical to distribute it at coal gas prices.

2. Coal Carbonising Plant

A number of Undertakings have been carbonising a relatively low grade coal at a medium price. In a bench of 8 - 14 feet through retorts this coal has given a capacity of 101,500 cu.ft. per day of 511.8 B.T.U. per cu.ft. gas or a yield of 71.5 therms per ton. If a good northern coal such as Aberdare, having a screen analysis between $1\frac{1}{4}$" and $\frac{1}{4}$" is employed, the capacity is increased to 130,000 cu.ft. per day, a yield of 91 therms per ton. A further increase can be obtained by diluting with more producer gas and adding 5% of propane to obtain 136,500 cu.ft. per day of 511.8 B.T.U. per cu.ft. gas. This represents an increase in capacity of 34% over that obtained with the lower grade coal and will in general be sufficient to supply demands for some 2 to 3 years at least, with safety.

In the example postulated, the maximum capacity of the plant would be 273,000 cu.ft. per day an increase of 24% on the present peak day's sendout. This is equivalent to an annual sendout of 66,200,000 cu.ft.

By increasing the daily sendout curve by 24% the coal carbonising plant will meet a peak day of 273,000 cu.ft. An examination of the sendouts shows that the plant can meet the requirements when carbonising say Liddell coal for 8 months of the year. During the 4 months May to August, Aberdare coal and the addition of propane would be required.

The sendout for the 4 winter months totalled 27,500,000 cu.ft leaving 38,700,000 cu.ft. to be produced for the remaining 8 months.

The annual cost of gas production is £19,200, nett into holder, after allowing for the sale of 1,370 tons of coke and 47,700 gallons of tar. This is equivalent to 69.7d per 1,000 cu.ft. or 0.465d, per unit.

Since the propane requirements would be only 15 tons this would be supplied in cylinders, and there would not be any additional capital cost.

3. Carbonising Liddell Coal and Producing the Additional Gas from Water Gas Enriched with Propane.

If the coal gas plant is worked to produce a maximum of 203,000 cu.ft. of gas per day from Liddell coal, the additional gas to be produced during the months May to August, as determined from the send out curve, amounts to 1,670,000 cu.ft.

The smallest water gas unit available has a capacity of 250,000 cu.ft. per day and is estimated to cost £25,000. Installation and one 10 ton storage tank makes the total capital expended £28,500.

The estimated annual cost of gas production is £17,710. Coke for sale is 1,497 tons and tar 49,000 gallons. The equivalent cost is 64.3d per 1,000 cu.ft. or 0.429d per unit. Labour has been allowed as one additional man per shift for the time required to produce the necessary water gas.

4. Carbonising Liddell Coal and Producing the Additional Gas in a Reforming Plant from Butane.

As in 3 above the additional gas to be produced is 1,670,000 cu.ft. Having in mind the possibility of ultimately producing all gas requirements in a reforming plant, one unit could be installed to operate in conjunction with the carbonising plant until the retorts needed resetting. A decision would then have to be made regarding the economics of installing a second reforming plant or resetting the retorts. With this end in view it would be necessary for the first plant to have sufficient capacity to meet the peak day's send out. Accordingly a 350,000 cu.ft. per day plant was chosen at an estimated capital cost of £37,500. Installation and storage make a total capital cost of £43,900.

The estimated annual cost is £19,110 equivalent to 69.2d per 1,000 cu.ft. or 0.462d. per unit. Coke for sale is 1,520 tons and tar 49,000 gallons. Existing stokers would supply the necessary labour to operate the reforming plant, being paid the award rate of 4/- per shift extra.

5. Producing all Gas Requirements by Catalytic Reforming

Catalytic reforming produces a gas which contains less condensable hydrocarbons and water vapour than coal gas, and unless proper precautions are taken it has a deleterious effect on mains and meters.

The volumetric loss of gas in a distribution system is directly proportional to the pressure, the diameter of the holes and inversely proportional to its viscosity.

In the case of reformed gas, its calorific value is the same as the original coal gas and hence there is no variation in thermal losses. Also there is no reason to increase the distribution pressures since the gas is interchangeable.

The viscosity however is 0.0138 centipoises compared to horizontal retort coal gas of 0.0121 centipoises and this will tend to decrease the volumetric loss by up to 12%.

The diaphragms of meters operating on a gas of lower condensable hydrocarbon content will dry out, crack or become porous and give a slow registration. With the lower water vapour concentration, hemp joints will dry out and the hole area will increase. Rubber rings in joints will lose their softness and flexibility and cause further leakage.

The extent of the effect of these factors on unaccounted for gas is difficult to assess, and will depend on the extent and efficacy of the remedial measures adopted.

There is every indication that the increase could be as high as 60%. The total increased loss to be anticipated would be 50%. The volumetric loss of 9,950,000 cu.ft. would be increased to 14,900,000 cu.ft.

making the equivalent sendout 71,250,000 cu.ft. or 365,000 therms.

If one reforming plant is installed and the coal gas plant worked to the end of its economic life, it would be necessary to install a seoond unit to ensure continuity of supply. The capital cost of the two units is estimated at £71,500 and with 2 - 10 ton storage tanks and installation the total cost would be £82,300.

In this case it is necessary to have one operator in attendance per shift.

It has been assumed that butane would be used as a feedstock at a cost of £28.10.0 per ton. Under these circumstances the annual cost of gas production would be £36,310 per annum equivalent to 122.5d. per 1,000 cu.ft. or 0.816d. per unit.

6. Supplying all Gas Requirements from Tempered Liquefied Petroleum Gas

Unlike the gases produced by the previous methods discussed, tempered liquefied petroleum gas (T.L.P. gas) is not interchangeable with coal gas and it is necessary to modify appliances to burn it.

In the case of those plants already installed a calorific value of 682.4 B.T.U. per cu.ft. equivalent to 200 units per 1,000 cu.ft. has been employed using propane as the feedstock. The specific gravity of this gas is 1.14.

As discussed under the previous section the thermal losses will be increased by 33.5% pressure remaining constant.

The viscosity of the T.L.P. gas is 0.0142 centipoises and this will again account for up to 14% decrease in losses.

Adding the 60% for increased leakage in mains makes the increase in the total leakage some 80%.

As previously stated the sendout of 66,200,000 cu.ft. was based on an unaccounted for loss of 15%, actually a volumetric loss of 9,950,000 cu.ft. This loss will be increased to 17,900,000 cu.ft. making the equivalent sendout 74,250,000 cu.ft. or 380,000 therms.

The peak hour's sendout for a peak day of 273,000 cu.ft. would be approximately 24,000 cu.ft. of 511.8 B.T.U. per cu.ft. gas. This is equivalent to 18,000 cu.ft. for 682.4 B.T.U. T.L.P. gas.

It has been assumed that two mixing units of the "Algas" type would be installed having a capacity of 15,000 cu.ft. per hour, one operating and one a standby.

A T.L.P. plant is completely automatic in its operation, gas making being started and stopped instantaneously by upper and lower limit switches on a holder. Accordingly no labour in the form of operators is required.

After allowing £20 per consumer for the conversion of appliances at 1,140 consumers' premises, the total capital expenditure including 2 - 10 ton storage tanks, 2 mixing units and 2 vapourisers is £42,000. The annual costs of production amount to £28,300 equivalent to 91,7d. per 1,000 cu.ft. or 0.610d. per unit.

7. Supplying Portion of the Area with T.L.P. Gas and the Remainder with Coal Gas from Liddell Coal

It may be that the area of supply in some towns is divided by a river or a railway line into two distinct areas. In this case it would be possible to supply coal gas from the existing plant to one section and T.L.P. gas to the other.

It has been assumed that the area to be supplied with T.L.P. gas requires a sendout of 30,200,000 cu.ft. per annum leaving 36,000,000 to be supplied by coal gas.

The T.L.P. gas area will have a peak day requirement of 130,000 cu.ft. of 511.8 B.T.U. per cu.ft. gas. This is equivalent to a peak hour of 8,500 cu.ft. of 682.4 B.T.U. gas. With the conditions of supply postulated above, the whole area would most probably be changed to T.L.P. gas at the end of the economic life of the coal carbonising plant. Accordingly two 15,000 cu.ft. per hour mixers have been installed.

The coal gas plant would be required to supply a peak day's sendout of 150,000 cu.ft. which is well within the capacity of the 32,950,000 per annum or 168,500 therms.

After making allowance for converting 320 consumers' appliances in the T.L.P. area of supply, the capital expenditure would be £26,000. The annual costs of production amount to £27,280 equivalent to 95.0d. per 1000 cu.ft. or 0.634d. per unit.

8. Natural Gas

And what of natural gas? Natural gas will come to the larger cities and it is anticipated that prices will be right for Companies purchasing thousands of million cubic feet per annum. But what of smaller undertakings distributing a few hundred million cubic feet per annum? If they are some distance from the trunk main feeding Capital cities will it be profitable to lay a spur main to supply them? Unfortunately there is no crystal ball into which we may gaze to ascertain the answer to these questions.

It is understood that natural gas has been offered to the Brisbane Gas Companies at 72d. per 1,000 cu.ft. equivalent to 0.217d. per unit of 1,000 B.T.U. per cu.ft. gas. Hetherington says that Companies would desire to purchase at 40d. per 1,000 cu.ft. or 0.121d. per unit. These prices are for the first thousand million cubic feet per annum and would reduce with larger quantities.

The same difficulties would be encountered in the distribution system as with T.L.P. and reformed gas if natural gas is distributed.

It is necessary to dehydrate the gas before compressed to prevent the formation of hydrates and consequent possibility of blockages in the transmission main.

Losses due to mains and services could as before increase by 60%. Since the viscosity of natural gas is approximately equal to that of coal gas, losses will not be affected by this characteristic. The thermal loss will increase in the ratio of 1,000 B.T.U. per cu.ft. to 511.8 B.T.U. or 96%.

Depending on the method of conversion of appliances adopted it will be necessary to increase pressures at their inlet 2 to 3 times, resulting in a similar increase in volumetric loss.

The combined loss could amount to 4 times that experienced with coal gas. In the example the volumetric losses would be increased to 9,950,000 x 4 = 39,800,000 cu.ft. making the total sendout required 96,150,000 cu.ft. per annum equivalent to 493,000 therms.

If natural gas can be purchased at 0.25d. per unit, the annual cost would be £15,050.

The conversion of appliances would be greater than in the case of T.L.P. gas since white flame burners would need to be replaced by bunsen type burners. The cost has been estimated at £30 per consumer The capital to be expended would be £34,110 and the annual repayment £2,590. The annual cost would amount to £17,640 and this is considered to be a minimum.

Natural gas could be used as feedstock in a catalytic reforming plant. After allowing an efficiency of conversion of 92% instead of 88% in the case of butane and assuming the gas could be purchased for 0.25d. per unit, the cost of feedstock would be reduced from £22,885 to £11,480, a reduction in annual cost of £11,405. Since all other costs would remain the same, the annual cost of supplying all the Undertakings' requirements for gas by reforming natural gas would be £23,125.

DISCUSSION OF ECONOMICS

The economics of the various methods discussed has been summarised in the attached Table together with the maximum capacity of plant and the capital to be expended.

It will be seen that the highest cost of gas production and capital expenditure occurs in the case of producing all the Undertaking's requirements of gas in a catalytic reforming plant.

The combination of coal carbonisation and blue water gas production with L.P.G. enrichment is the cheapest method of supplying the sendout. The total daily capacity of 460,000 cu.ft. is sufficient to meet the peak day's requirements for a number of years.

The cost of resetting the two benches would be of the order of

£10,000 for each bench when it becomes due in 5 and 6 years time. The annual repayments on this capital over 8 years would be at the rate of 15.7% per annum or £3,140. Even when this sum is added to the production costs the coal gas-blue gas combination is still the cheapest.

If the by-product or labour position becomes so acute that coal carbonisation has to be abandoned, the next cheapest method is to convert to T.L.P. gas, supplying a restricted area if possible, until the coal plant requires resetting and then making the change for the remainder of the area. In this way capital expenditure of some £16,000 would be deferred for 5 - 6 years.

Butane at £28.10.0 per ton is equivalent to 0.55d. per unit when used as a feedstock for supplying all requirements of gas in a catalytic reforming plant. It is extremely doubtful if natural gas will be available to a Country Undertaking at 0.25d. per unit. However, if it can be purchased at any price below 0.55d. per unit it will compete with butane as a feedstock at £28.10.0 per ton.

The unknown factor in the use of straight natural gas is the cost of converting appliances. At the rate of 0.25d. per unit its use compares favourably with coal gas-water gas-propane production.

PRECAUTIONS TO BE TAKEN WHEN CHANGING FROM COAL GAS

Coincident with a change to a drier gas containing no condensable hydrocarbons, it is necessary to take all precautions to reduce unaccounted for gas to a minimum.

Meter leathers and exposed rubber ring joints have adsorbed hydrocarbons from coal gas and these are liable to be re-evaporated into the new gas. It is essential therefore that the new gas be treated with similar hydrocarbons to such a concentration that equilibrium is maintained and no re-evaporation occurs. In some cases benzol has been employed but its use has not proved satisfactory.

A naphtha with a boiling range of 115° - 200°C is more nearly akin in composition to the hydrocarbons in the leathers. The action of the naphtha can be assisted by oil fogging the gas.

R.J. Holloway described the equipment in use at Geelong, in his paper to the Australian Gas Association in 1962. The naphtha passes through a heat exchanger, steam heated, together with gas under pressure. The hot gas and naphtha pass through an injector into the main gas stream at the inlet to the holder. It was found that some 16 gallons per million cu.ft. of naphtha were required.

A hot oil fogger was installed at the outlet of the Works holder. The oil was allowed to drip over Raschig rings in a tower externally heated by steam, up which flowed heated town's gas. The mixture then passed into the main gas stream out of the Works.

A parafinic oil having a distillation range of 265^{o} - 350^{o}C was used at the rate of 2 - 3 gallons per million cu.ft.

It has been the practice to inject a light "Diesoleum" oil under pressure into the gas stream at outlet of the Works in a number of cases where a change has been made to T.L.P. gas. This has been done several months before the changeover. In at least one case this does not appear to have been efficacious. Meters are going slow and stopping, rust is being carried forward into them, and unaccounted for has risen to 35%.

In the Netherlands when a change was made to straight natural gas, it was humidified to a relative humidity of 80% to 90%. Where it was suspected that joints containing hemp were already dry, water with a surface tension reducing chemical such at T-pol, was injected into the mains.

It would appear that where rust in a main is wet the addition of an oil would not "wet" it and hold it in place.

A programme of leak detection and repair is essential in any undertaking whatever type of gas is distributed. This programme must be prosecuted with the utmost vigour both as regards leakage from mains and services and from service cocks.

When meters are repaired or new meters purchased, the leather dressing on the diaphragms must be one suitable for use with the particular gas being distributed. In repairing an older type of meter it is an advantage to replace the meter valve with a plastic one.

The truth of my opening remarks should now be evident.

Whichever one of the various methods is selected to produce a gas to replace coal gas, the Engineer will be faced with many more problems which will have to be solved to suit each individual undertaking.

One fact stands out above all others. It is more than ever necessary for the Engineer to pursue a vigorous policy of detecting and repairing leaking mains and services and above all to so adjust the pressure of gas in his distribution system that its average over 24 hours is a minimum compatible with giving his consumers an adequate supply at all times. The cleaning of blocked mains and services and the replacement of small mains with larger ones is a necessary pre-requisite to attaining the optimum in pressure control.

COMPARISON OF THE COST OF PRODUCING AN UNDERTAKING'S REQUIREMENTS OF GAS BY VARIOUS MEANS

Method of Gas Production	Maximum Capacity of Plant cubic ft. per day	Cost of Producing 66,200,000 cu.ft. of 511.8 B.T.U. per cu.ft. gas	Plant Installed and Capital Expended
1. Existing coal carbonising plant, Aberdare coal and Propane for 4 months, Liddell coal for remaining 8 months.	273,000	£19,200 69.7d. per 1000 cu.ft. 0.465d. per unit	Nil
2. Producing the additional gas in a water gas plant, cold enriching with propane, coal gas from Liddell coal.	Coal gas 210,000 Water gas 250,000 Total 460,000 No standby	£17,710 64.3d. per 1000 cu.ft. 0.429d. per unit	1 - 250,000 cu.ft. per day water gas plant. 1 - 7½ ton storage tank £28,500
3. Producing the additional gas in a reforming plant from butane, coal gas from Liddell coal.	Coal gas 210,000 Reformed gas 350,000 Total 560,000 No standby	£19,110 69.2d. per 1000 cu.ft. 0.462d. per unit	1 - 350,000 cu.ft. per day reforming plant 1 - 10 ton storage tank £43,900
4. Producing all gas requirements by catalytic reforming of butane	Reformed gas 350,000 from 1 unit with 350,000 standby	£36,310 122.5d. per 1000 cu.ft. 0.816d. per unit	2 - 350,000 cu.ft. per day reforming plants 2 - 10 ton storage tanks £82,300

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5. Producing all gas requirements in a tempered liquefied petroleum gas plant from propane.	T.L.P. Gas 360,000 from 1 unit with 360,000 standby	£28,300 91.7d. per 1000 cu.ft. 0.610d. per unit	2 - 360,000 cu.ft. per day mixing units 2 - vapourisers 2 - 10 ton tanks £19,000 Conversion of appliances £23,000 Total £42,000
6. Supplying portion of the area with T.L.P. Gas and the remainder with coal gas from Liddell coal.	Coal gas 210,000 T.L.P. gas 360,000 from one unit 570,000 T.L.P. gas 360,000 as standby	£27,280 95.0d. per 1000 cu.ft. 0.634d. per unit	2 - 360,000 cu.ft. per day mixing units 2 - vapourisers 2 - 10 ton tanks £19,000 Conversion of appliances £ 7,000 £26,000
7. Distributing natural gas for all requirements.	Unlimited	£17,640 minimum 44.0d. per 1000 cu.ft. 0.294d. per unit	Conversion of appliances £34,110
8. Producing all gas requirements by catalytic reforming of natural gas	Reformed gas 350,000 from one unit with 350,000 standby	£23,125 minimum 78.2d. per 1000 cu.ft. 0.521 per unit	As for (4) £82,300