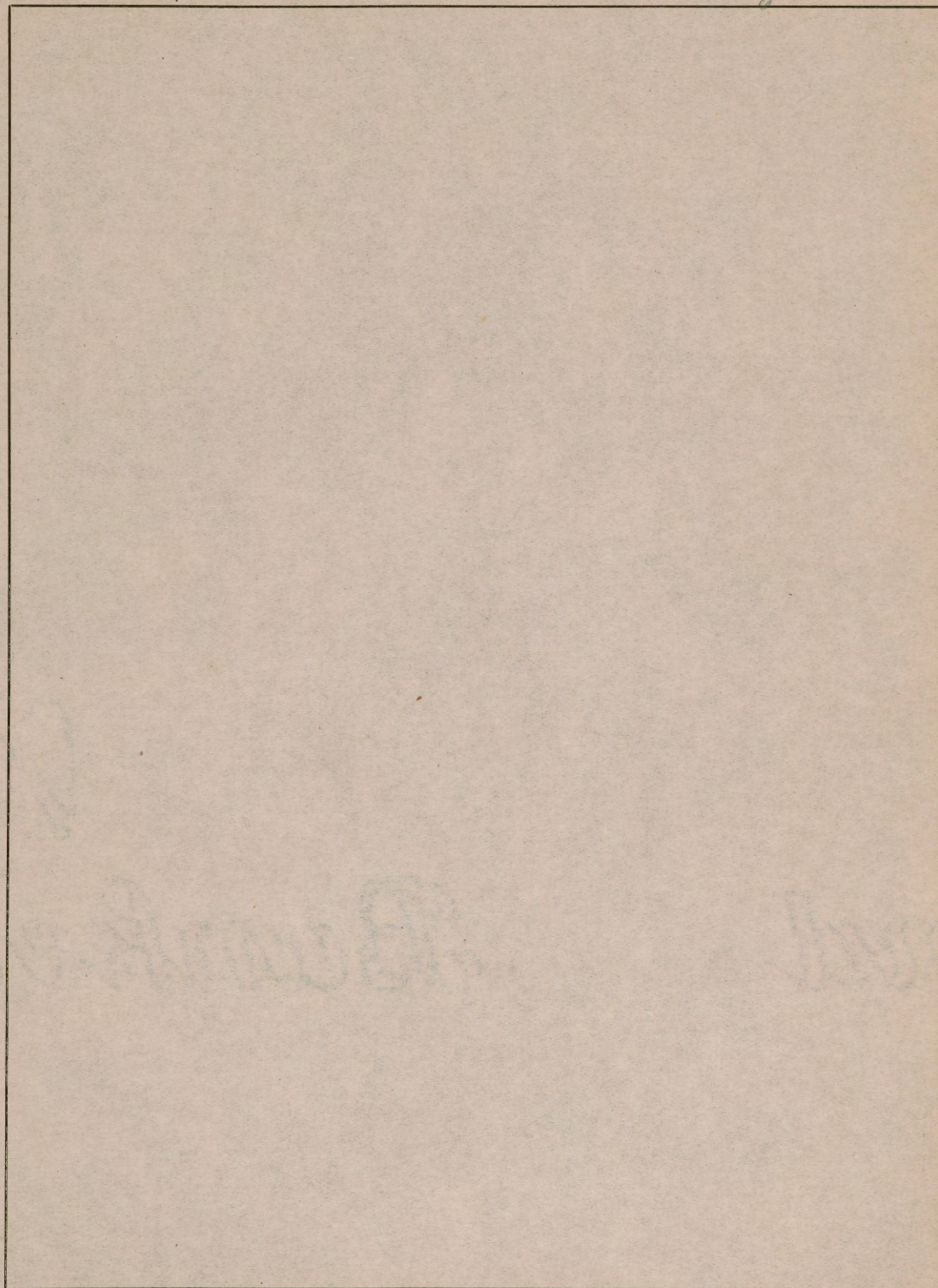


KNOXVILLE GAS COMPANY
KNOXVILLE, TENN.

H. L. Boyd



H. L. D. & CO. No.

NAPHTHALENE IN COAL GAS

BY

HERBERT L. BOYD

A THESIS SUBMITTED FOR
THE DEGREE OF BACHELOR OF SCIENCE
MECHANICAL ENGINEERING COURSE

University of Tennessee

1923

I N D E X

INTRODUCTION	Page 1
HISTORICAL REVIEW.....	Page 2
PURPOSE.....	Page 4
GENERAL THEORY.....	Page 5
APPARATUS AND METHODS.....	Page 10
RESULTS.....	Page 13
CONCLUSIONS.....	Page 17
BIBLIOGRAPHY.....	Page 18
APPENDIX.....	Page 19
APPROVAL.....	Page 23

INTRODUCTION

In the preparation of this thesis, the aim has been to learn something of the nature of naphthalene and its direct application to the coal gas industry; not trying to give a broad general view of the gas industry as a whole.

This work was started upon the request of the superintendent of the Knoxville Gas Company. The object was two-fold, first- To acquire a knowledge of naphthalene and the troubles it causes to coal gas manufacturing; second- to put this knowledge into some logical form from which useful data and references may be taken at a future date.

All the present day literature on the subject of naphthalene was carefully studied and only that part which was clear and logical was considered in this thesis.

PART I
HISTORICAL REVIEW

In the early experiments carried on by Murdock and others (1792-), for the production of coal gas various methods of retort setting were employed, the chief object in arranging the position of the retorts being the removal of the coke and residue. For a number of years after the first coal gas plant was erected the retorts used were made of cast iron.

About 1820 the first clay retorts were introduced in England. The general adoption of clay retorts was very gradual, and it was not until about the year 1860 that their advantages became so apparent as to warrant their common use.

Naphthalene in the days of the cast iron retorts was unknown. It became known and troublesome with the event of the clay and silica retorts where high heats could be employed in the destructive distillation of coal.

With cast iron retorts low heats only were possible and naphthalene as well as stopped standpipes, pitch in hydraulic mains, etc., were unknown. With clay retorts came ambition and competition for increasing yields per pound of coal, heats were raised materially and naphthalene with the other draw backs followed.

The naphthalene question has engaged the attention of the gas manufacturer more constantly than any other one thing and had as much attention been paid to finding methods to prevent its production in excess of the saturation point of the gas as has been devoted to getting rid of it after it has been produced, the work heretofore done in the later case would probably have accomplished the desired results long ago.

Naphthalene is generally removed from gas by a naphthalene scrubber

at the gas works , in which an oil by some mechanical means is brought in-
to intimate contact with the gas. This may be done in a vertical tower
scrubber, in a horizontal rotary scrubber, in a vertical rotary scrubber,
or in a bubble washer, ^t The idea being to bring the oil and gas in inti-
mate contact. The oil will remove the naphthalene. When the oil becomes
saturated with naphthalene it is removed and fresh oil put in its place.

Figure one shows the general layout of a coal gas plant, showing the
position of the oil scrubber in the pipe lines just before the gas holder.
Figure two shows a section of a typical oil scrubber as used in the re-
moval of naphthalene.

DOHERTY
WASHER COOLER

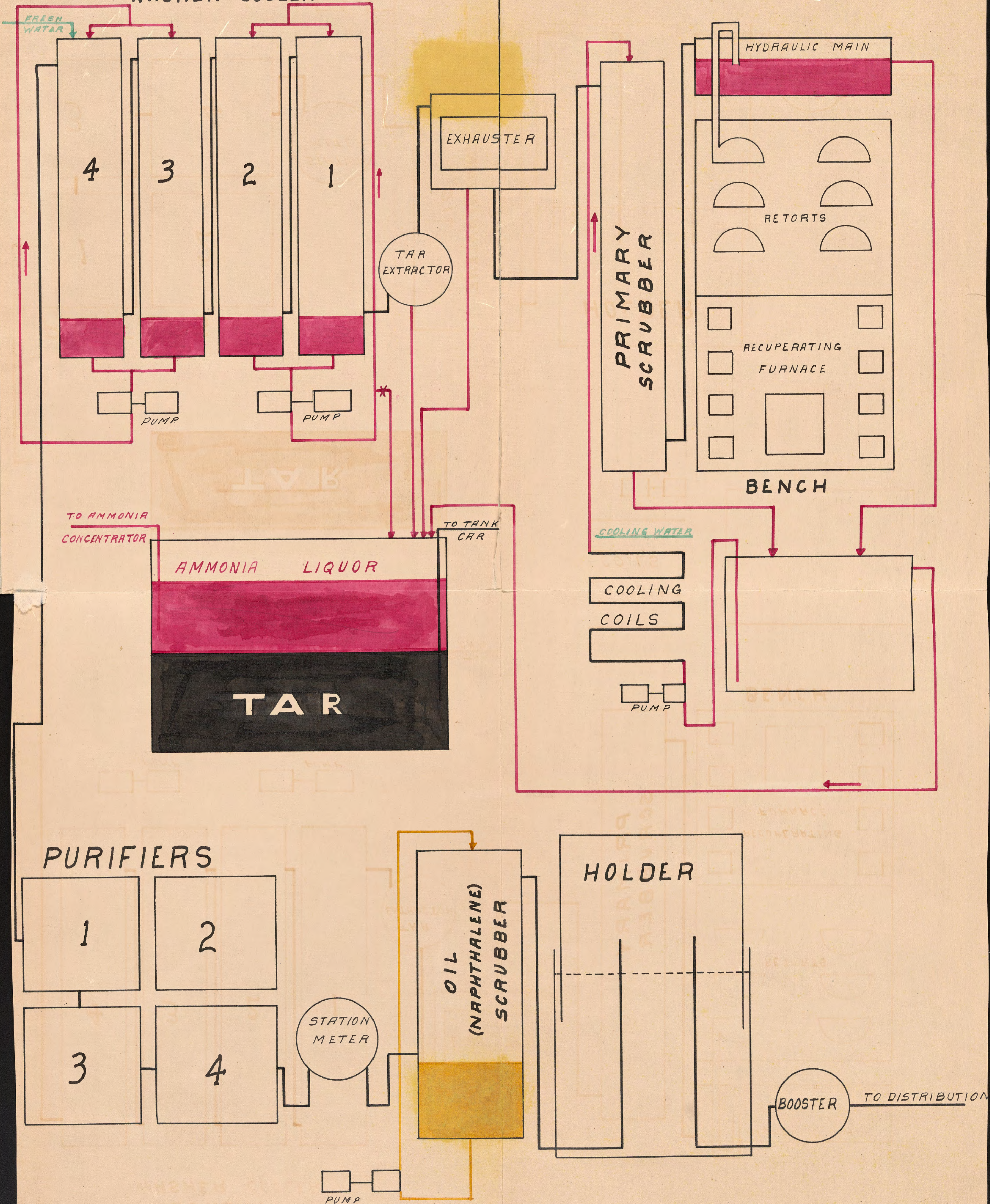
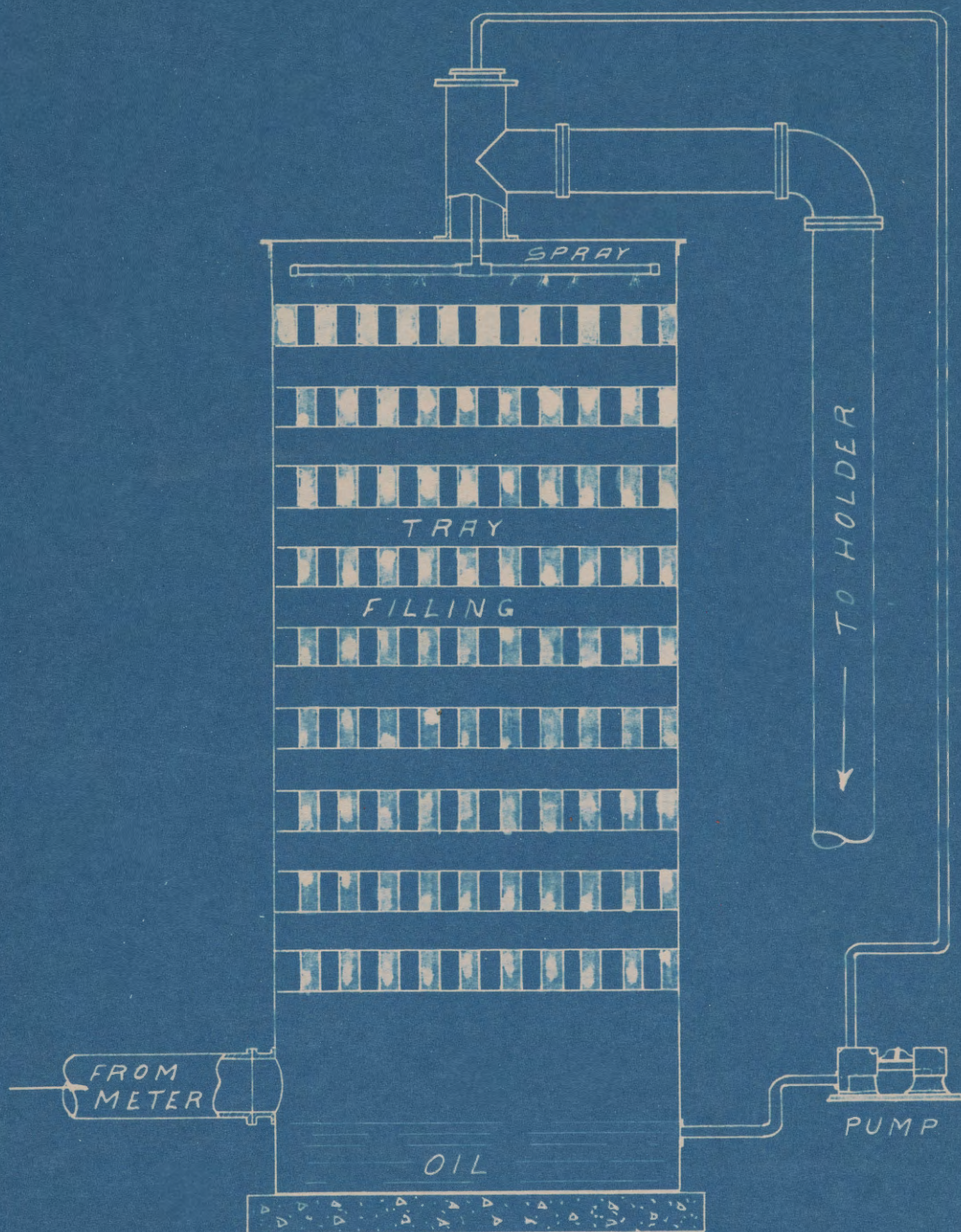


FIGURE 1

LAYOUT OF A COAL GAS
MANUFACTURING PLANT

FIGURE 1



OIL SCRUBBER FOR THE REMOVAL
OF NAPHTHALENE FROM COAL GAS
FIGURE 2

PART II

PURPOSE

This thesis is for the purpose of studying the naphthalene problems as met in the manufacture of coal gas and from conclusions based on actual experiments formulate a method of getting rid of naphthalene either by use of a solvent or dissociation.

This thesie will deal only with the idea of dissociation, i.e., the breaking up of naphthalene into another form such as CH_4 , C_2H_6 , etc.

PART III

GENERAL THEORY

Naphthalene ($C_{10}H_8$) is a hydrocarbon and has a melting point 174° F., a boiling point 424° F., and it sublimes at lower temperatures. The deposition of naphthalene in a solid state in the mains of apparatus causes many operating difficulties, as it decreases the cross-sectional area of the gas conduits and thus produces considerable back pressure on the works.

Naphthalene originates in the retort by the exposure of the nascent gas to a high temperature long enough to have it assume it, breaking up some of the heavy vapors. It is worth noting that the production of naphthalene is not directly a function of the degree of heat employed in the bench, but rather a function of the temperature the gas has to assume before leaving the retort. It is the direct result of superheating the gas after it has been generated, there by breaking down the hydrocarbon to a rearrangement producing naphthalene.

Since naphthalene is a result of the cracking of the less complex hydrocarbons, then the greater proportion of naphthalene should be formed in coal gas practice during the earlier period of carbonization when the production of the rich gases is greatest and during the period before the body of the coal has become an incandescent mass. The final cracking of the gas occurs as it passes along the space at the top of the retort when in contact with the hot top. At that particular time the top of the retort is the hottest part of it, as the heat of the sides and bottom is being absorbed by the coal, the top remains at a higher temperature throughout the period and attains the maximum temperature of the retort.

The cracking effect of various temperatures seems to be in inverse ratio to the time of exposure, i.e., gas exposed to a low temperature

for a certain period will have the same effect as if exposed to a higher temperature for a shorter period.

Carbonization at low temperatures can be so conducted that there will be a practical absence of naphthalene.

The desirability of carbonizing at higher temperatures being apparent, the conclusion is obvious. In order that the gas may be taken from the carbonizing chamber without undue superheating, the conveying space for the passage of the gas should be reduced as the temperature is increased in order to secure an increased velocity of the gas in its passage to the off-take pipe. The enforced increase in the carbonizing period will not reduce the production of the setting but on the contrary, will increase it through higher yield obtained, while the heavy charges improve the quality of the coke and the decrease in production of lamp-black improves the quality of the tar.

Some pyrogenic reactions quoted from various authorities are as follows:

1. $5\text{C}_2\text{H}_4 = \text{C}_{10}\text{H}_8 \text{ plus } 6 \text{ H}_2$
2. $2 \text{ CH}_4 = \text{C}_2\text{H}_2 \text{ plus } 3 \text{ H}_2$
 $3 \text{ C}_2\text{H}_2 = \text{C}_6\text{H}_6$
 $2 \text{ C}_6\text{H}_6 = \text{C}_{10}\text{H}_8 \text{ plus } \text{C}_2 \text{ plus } 2 \text{ H}_2$
3. $2 \text{ C}_6\text{H}_6 = \text{C}_{12}\text{H}_{10} \text{ (Diphenyl) plus } \text{H}_2$
 $\text{C}_{12}\text{H}_{10} \text{ plus } \text{C}_2\text{H}_4 = \text{C}_{14}\text{H}_{10} \text{ plus } 2 \text{ H}_2$
4. $3 \text{ C}_6\text{H}_6 = \text{C}_{14}\text{H}_{10} \text{ plus } 2 \text{ C}_2 \text{ plus } 4 \text{ H}_2$
5. $\text{C}_6\text{H}_6 \text{ plus } \text{C}_2\text{H}_4 = \text{C}_6\text{H}_5 \text{ C}_2\text{H}_3 \text{ plus } \text{H}_2$
 $\text{C}_6\text{H}_5 \text{ C}_2\text{H}_3 \text{ plus } \text{C}_2\text{H}_4 = \text{C}_{10}\text{H}_8 \text{ plus } 2 \text{ H}_2$

Under the effect of heat, all compounds containing carbon and hydrogen tend to form naphthalene, but it seems that the higher the percent of carbon in the compound the greater its tendency to form naphthalene.

The order of decomposition in making coal gas hydrocarbons seems to be as follows:

COAL					
PARAFFINS			OLEFINS		
PARAFFINS	OLEFINS		AROMATICS (BENZENE)		HYDROGEN
PARAFFIN	OLEFINS	AROMATICS	HYDROGEN	NAPHTHALENE	CARBON

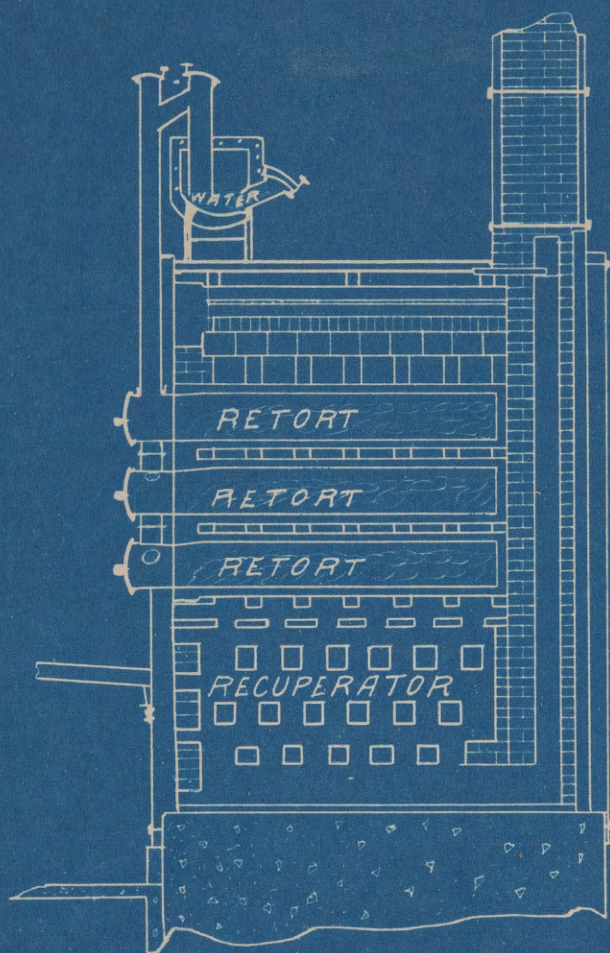
The decomposition is continuous and both time and temperature have their effect, but there seems to be a point at which a good yield of good quality gas, containing little naphthalene, is made. The problem is how to remove it at the moment it is formed.

If it were possible to remove the gas from the retort the instant it was liberated from the body of the coal there would be no naphthalene formed. As this is not a practicable thing, the nearest approach possible to it will reduce the amount of naphthalene formed.

The ideal condition can be approached in carbonization of coal in horizontal retorts by increasing the size of the charges to the limit of the capacity of the retorts leaving barely space enough over the coal for the insertion of a narrow drawing rake. Under such conditions temperatures may be increased to 2100° F., or even 2200° F., without being accompanied with the usual naphthalene and standpipe troubles at the same time the yield of gas, per pound of coal will be increased and the carbonization of coal per 24 hours will not have been reduced with the enforced lengthening of the burning time and the yield of gas per retort will have been increased.

Generally naphthalene does not appear to be formed in important amounts below 1300° F. (700° C.).

Figure three shows a section of a modern gas bench, with its retorts, recuperators, etc.,



SECTION THROUGH A SHIP-BELLY FURNACE
 of a SHIP-BELLY FURNACE
 FIGURE 2

Table I (appendix) shows the production of naphthalene per ton of coal and oil in different methods of manufacture and from different coals. These indicate that the nature of the coal and the method of manufacture are important factors.

The greater portion of the naphthalene produced, especially with high distillation or carbonization temperatures, goes over into the tar, the gas containing only a portion of the naphthalene vapor, its maximum content being dependent upon saturation at various temperatures, but outside of the temperature of carbonization the amount of naphthalene present in the gas is also due to the character of the coal used, and upon the time of contact between the gas and hot coke and hot retort walls.

The amount of naphthalene required to saturate a gas varies according to different investigators, none of them agreeing with each other. In Table II (appendix), the results are shown as the amount of naphthalene in grains per 100 cubic feet of gas. It was formerly held that the other vapors in the gas had no effect on naphthalene, but Thomas apparently shows there is some effect due to water vapor.

The natural method of removing naphthalene is by condensation. Experiments indicate that the condensation of naphthalene does not always follow theoretical considerations.

It is believed that the reason condensation does not remove more of the naphthalene is due to the fact that in our existing apparatus the naphthalene does not come into equilibrium with the condensate and that unless the gas is brought into intimate contact with the condensate it will continue to carry higher amounts of naphthalene than would be expected.

Since condensation in general does not remove as much naphthalene as is desired, it appears to be necessary that the gas should be scrubbed

with some form of absorbing material.

The theory of scrubbing has been worked out and has been shown to be very similar to the flow of heat and in its general form is proportional to the diffusion constant times the difference in the vapor pressure of the material in the scrubbing liquid.

The difficulty in working out the theoretical equations is the fact that the observed results with gas do not always accord with the theory.

Table III (Appendix) shows some calculations on the equilibrium between gas and oil. Here it is shown that where air was used the results are very closely in accordance with the theory but where gas was used, there was more naphthalene than called for by the theory.

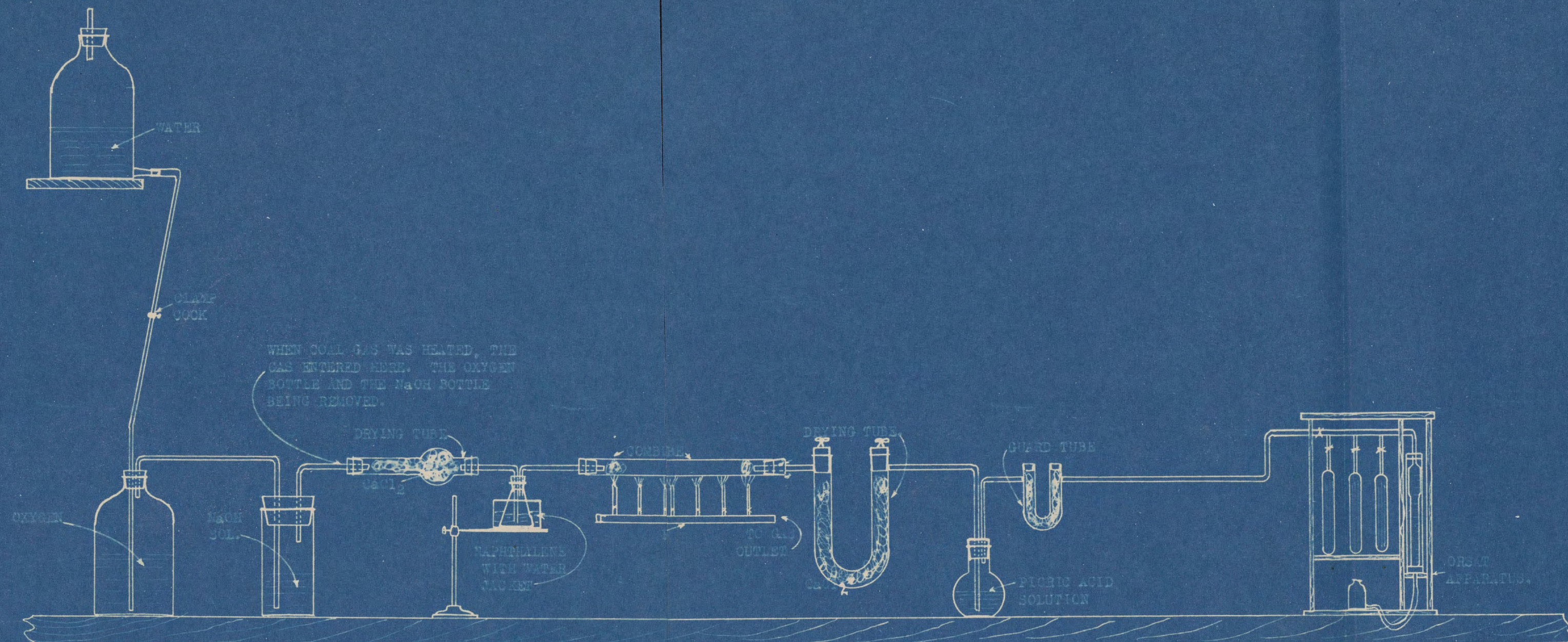
A study of the theoretical considerations, however, has shown that the velocity of the gas is very important, that the velocity of the scrubbing oil is not so important.

These theoretical studies have also shown that coke filled scrubbers have a very high efficiency and that the viscosity of the scrubbing medium has an important bearing on its efficiency.

Anthracene oil is very efficient as a scrubbing agent but is expensive. Gas oil has given very good results, but water-gas tar or any material containing considerable quantities of naphthalene cannot be expected to entirely eliminate naphthalene when the gas tends to come into equilibrium.

Table IV (appendix) shows the quantities of naphthalene which different oils will absorb.

The presence of water in the scrubbing material is to be avoided as it greatly reduces the scrubbing efficiency.



SKETCH SHOWING THE APPARATUS WHICH IN THE EXPERIMENTS ON THE DISSOCIATION OF NAPHTHALENE.

FIGURE FOUR.

APPARATUS AS USED IN THE EXPERIMENTS
ON THE DISSOCIATION OF NAPHTHALENE.

PART IV

APPARATUS AND METHODS

Figure four shows the general arrangement of the apparatus which was used in the experiments to determine if naphthalene could be dissociated into some other compound which would remain a gas and not solidify at ordinary temperatures.

This apparatus consisted of a purifying train, a combustion furnace and an absorption train.

The purifying train consisted of the following purifying reagents arranged in order of passage of oxygen through them: Sodium hydroxide solution, and granular calcium chloride. Between the combustion tube and the purifying train was placed a bottle of pure naphthalene through which the oxygen was bubbled.

The combustion tube was a piece of hard glass tubing. An asbestos plug was placed at each end of the tube. A cork was inserted at each end for connections to the purifying and absorption trains.

The absorption train consisted of; first, a Marchand tube filled with granular calcium chloride to absorb moisture. The Marchand tube was followed by a bottle containing a saturated solution of picric in alcohol and water. A guard tube of granular calcium chloride was attached to the bottle to absorb any water evaporating from the picric acid solution. After this was placed an Orsat apparatus (or Morehead gas apparatus) for the analyzing of the gases passing the picric acid solution.

The naphthalene was first melted either by using a water jacket or by direct heating, then the oxygen was forced through by pressure caused by water. This gas was then passed through the combustion tube which was kept at a red heat. After passing through the combustion tube and absorbing train, the test was stopped by cutting off the oxygen supply and removing the burner which was used to keep the naphthalene in a melted condition.

Then by weighing the absorption tubes and bottles and the naphthalene bottle the amounts of these could be found and from these amounts calculations made as to what effect the heating of naphthalene and oxygen was.

All joints were carefully shellaced to prevent leaking.

The greatest difficulty, and in fact the only one, was the fact that a vacuum seemed to be produced in the combustion tube and hence pulled the picric acid solution into the drying tube, thus ruining the weighing value of the absorption reagents. The only way in which this could be remedied was by heating the naphthalene so that the pressure was enough to carry over the tube.

Another source of trouble was the explosion or combustion of the oxygen and naphthalene in the combustion tube, when the naphthalene was heated direct and the temperature of the combustion tube was around 1300° F.

When first noted the oxygen and naphthalene were going through the apparatus at the rate of about four bubbles per second. The combustion tube seemed to be filled with a series of long yellow flames. This kept up for a few minutes until the naphthalene bottle itself burst and the naphthalene caught on fire. This last explosion entirely destroyed the value of the experiment, but an analysis of the gases showed some results.

When coal gas was passed through the tube, using the same apparatus, excepting the sodium hydroxide solution, no results at all were obtained at first. Later it was noticed as the heats were raised that the gas only burned and all that could be obtained were the products of combustion of the coal gas.

It was the writer's intention to run a series of tests of gases taken from different points of the plant of the Knoxville Gas Companies plant. These tests were to include a test of the gas before and after it was heated. The apparatus was assembled and the ^{temperature} raised to about 1350° F., to 1400° F. When a rubber tube was attached to the Morehead gas analyzing apparatus the short neck of the capillary tube snapped off at the top of the gas

burette and hence this part of the work had to be discontinued.

An attempt was made to find a better indicator for naphthalene than the picric acid solution now in use. When naphthalene comes into contact with picric acid a precipitate of white crystals is formed which is naphthalene picrate. This method of indicating is not very accurate as sometimes it works and some times it does not. Various chemicals were mixed together and naphthalene brought in contact with it. Results as obtained are in the following part.

PART V
RESULTS

1

Substance	weight before heating	weight after
Naphthalene	15.809 grams	Exploded
Drying tube (CaCl_2)	17.925 grams	18.045 grams
Picric acid	28.022 grams	Blew over
Pyro-gallic $\text{Na}(\text{OH})$ solution	27.000 grams	Blew over.

The explosion of the naphthalene tube blew the picric acid over into the pyro-gallic sodium solution which in turn blew out the end of the tube.

This explosion destroyed the value of this experiment. The heat carried on the combustion tube was 1250°F .

2 - 3 - 4

The apparatus was again set up and three experiments made but each time the naphthalene exploded ruining the experiment.

5

In this experiment a water jacket was placed around the naphthalene bottle and the naphthalene was heated to 210°F .

Substance	Wt. before	Wt. after	Difference
Naphthalene	50.000 grams	49.851 grams	0.149 grams
Drying tube (CaCl_2)	67.740 grams	67.760 grams	0.020 grams
Picric acid	117.240 grams	117.118 grams	Blew over
Guard tube (CaCl_2)	29.160 grams	29.164 grams	0.004 grams

Gas analysis

	a	b
CO_2	0.60 %	0.00 %
O_2	32.40 %	51.00 %
CO	3.80 %	4.00 %

The heat employed was 1320° F. The heating of the naphthalene was not sufficient by means of the water jacket, to keep the products under pressure. Though there was a difference in weight of the naphthalene this could be accounted for by that which either was absorbed by the rubber stopper or clung to it. The gas analysis showed no reaction at all, excepting the presence of the carbon monoxide which was probably due to the high percentage of oxygen escaping over to the cuprous chloride solution.

6

The apparatus was disconnected at the sodium hydroxide bottle and a connection made to the city gas. No weights were ^{used} only a gas analysis being made as follows:

	a	b
CO ₂	0.50 %	0.40 %
O ₂	19.20 %	19.50 %
CO	0.00 %	0.00 %

This analysis was so much like that of ordinary air that all the joints were carefully shellaced and the experiment again made with the results as shown in b, which compares very closely with a. From the analysis of the city gas as given in the appendix it can be seen that the CO₂ content runs 4.40 % to 3.80 %, while oxygen runs 3.30% to 3.20 %. This makes this experiment look as though there was a leak some where in the apparatus which refused to be stopped.

7

The city gas was disconnected and oxygen bubbled through the naphthalene in this experiment.

Realizing the difficulty in melting the naphthalene with a water jacket, the water was removed and the naphthalene container heated direct by means of a Bunsen burner. All the reagents and absorbents were carefully weighed;

Substance

Naphthalene	67.820 grams
Drying tube (CaCl_2)	68.120 grams
Picric acid	119.110 grams
Guard tube (CaCl_2)	30.105 grams

This experiment was started with a heat of 1340°F . All was going along nicely when a slight sucking sound was heard and upon looking, the writer observed long yellow flames playing about in the combustion tube. No effect was noticed and a sample of the gas was led into the gas burette. The gas sample was hardly determined when an explosion, (the most violent of the experiments), occurred. The explosion destroyed the naphthalene bottle, breaking it into little pieces and scattering them. Also the explosion must have produced a vacuum as the picric acid solution was drawn back through the drying tube into the combustion tube.

For results there can only be said that the presence of drops of water were noted at the end of the combustion tube before the explosion and the analysis of the gas as taken is given below;

CO_2	14.70 %
O_2	29.60 %
CO	0.00 %

The presence of the carbon dioxide in such a large percentage denotes combustion of the naphthalene.

NAPHTHALENE INDICATOR

1

Methyl orange was added to a hot solution of picric acid and naphthalene vapor bubbled through the solution. A white precipitate was the only result, no better than if picric alone had been used.

2

A mixture of the following chemicals was then made: 10 % solution hydrobromic acid plus picric acid plus alizarine sodium sulfonate. This

solution was heated and filtered. Naphthalene vapor was passed through the filtrate. A heavy yellow precipitate was noticed. Seemingly this would be a good indicator. A test tube of this solution was placed near the meter at the gas plant and gas allowed to bubble through. After two weeks the only result was a dark purple stain on the tube which could have been caused by tars in the gas.

3

A 10 % hydrobromic acid solution was saturated with picric acid and filtered. Naphthalene was passed through while hot. This solution was of no value as the naphthalene would only solidify and remain floating on top of the solution.

PART VI

CONCLUSIONS

The conclusions of this thesis are based on two things - first, the results of actual experiments made and - second, from reading and studying the works of others on this subject.

1

The removal of naphthalene by heating seems to be an impossibility. Naphthalene seems to have so great stability that when once formed it resists any effort again to decompose it by heat.

The above statement is made from results as found by heating naphthalene in the presence of oxygen.

Further experiments could be made, heating naphthalene in the presence of other gases, chemicals or compounds.

2

It is difficult to remove naphthalene effectively by condensation alone.

Some form of scrubbing appears to be essential for the removal of it.

The addition of low tension oil such as kerosene in the form of fog appears to be effective.

The amount of naphthalene that may be safely sent into the distribution system depends on many conditions, fundamentally the amount of vapor in the gas, and that probably careful study of the concentration in the street drips is as effective as any thing in predicting possible trouble.

Naphthalene may exist in the gas in amounts exceeding those calculated on theoretical grounds.

PART VII
BIBLIOGRAPHY

American Gas Institute Proceedings:

Volume 2 - page 83, 252, 686.

Volume 3 - page 209, 800, 1029.

Volume 4 - page 727.

Volume 5 - page 119.

Volume 6 - Part II - page 151.

Volume 8 -Part I - page 624, 651, 662.

Volume 9 - page 186, 348.

Production and Prevention of Naphthalene. by T. D. Miller.

Removal of Naphthalene from Gas. by W. H. Fulweiler.

Gas Chemists' Handbook (1922) The American Gas Association.

Richards' Metallurgical Calculations. Volume I.

PART VIII

APPENDIX

TABLE I

NAPHTHALENE FORMED IN GASIFICATION

Process	Coal gas- Verticals;	Horizontal;	Coke Ovens.	Water Gas.
Lbs. per gal. Tar	0.04 -0.32	0.26 - 0.73	0.35-0.83	0.16-0.60
Lbs . per ton	0.05 -4.30	3.20 -11.40	3.01-8.50	8.60-27.00

NAPHTHALENE FROM VARIOUS COALS

(See White, Wyman, Dunkley and Barker.)

Coal	Carb. Temp.	Gals. Tar/ ton	Naphthalene in Tar
Illinois	1360 ° F.	17.2	4.51
Michigan	1140	16.5	5.54
Kentucky	1550	18.3	5.69
Pennsylvania	1400	21.2	8.14
Alabama	1345	19.2	10.65
West Virginia	1725	14.6	11.42

TABLE II

GRAINS OF NAPHTHALENE PER 100 CU. FT. OF GAS

Authority	Allen	White	Schlumberger	Thomas (dry)	Thomas (wet)
00- 32° F.	6.0	6.8	2.0	1.9	0.6
5 - 41	9.8	3.7	3.2	3.3	1.1
10 - 50	14.0	7.0	6.7	5.6	2.0
15 - 59	19.0	12.0	11.0	9.4	4.0
20 - 68	25.0	21.0	17.0	16.0	7.9
25 - 77	31.0	36.0	25.0	25.0	14.0
30 - 86	40.0	58.0	39.0	40.0	35.0
35 - 95	58.0	91.0	61.0	64.0	65.0
40 - 104	84.0	140.0	92.0	99.0	102.0
45 - 113	132.0	206.0	147.0	150.0	150.0
50 - 122	208.0	300.0	226.0	227.0	252.0
55 - 131	317.0	407.0		336.0	370.0
60 - 140	482.0	630.0		497.0	552.0

TABLE III

CALCULATED AND OBSERVED EQUILIBRIUM -

GRAINS PER 100 CU. FT.

(C₁₀H₈ in Gas and C₁₀H₈ in Solvents)

Showing That Constituents of gas Apparently Affect the Equilibrium

Pannertz Results With Anthracene Oil @ 64° F.

Pounds C ₁₀ H ₈ per gallon	0.01	0.48	0.95	1.33	1.90	2.38	2.85
Observed Equilibrium Gas	0.22	2.40	3.80	5.80	6.30	9.10	9.50
Observed Equilibrium Air	0.00	2.30	2.60	3.20	4.00	6.00	7.50
Calculated Air	0.29	1.30	2.80	3.40	4.90	6.00	7.50

MISCELLANEOUS TESTS ON VARIOUS TARS.

Content C ₁₀ H ₈ Percent.	Temperature	Observed Equilibrium	Calculated Equilibrium
15.1	142° F.	165	42
10.8	129	208	49
10.8	128	131	47
4.2	125	69	17
5.1	120	45	25
8.0	124	71	19
10.8	90	65	9
12.4	87	9	8
7.9	70	8	2
12.5	70	12	4
1.0	69	2	1
10.8	73	25	4

TABLE IV

NAPHTHALENE ABSORPTENTS

Substance	Grains of	Will absorb grains of Naph.
Anthracene Oil	100 grains	10 - 25
Creosote Oil	100 grains	100
Water-gas Tar	100 grains	18 - 20

TABLE V
PROPERTIES OF NAPHTHALENE

Formula	$C_{10}H_8$	C_{10}
Molecular weight	128.06	
Specific gravity gas or vapor at 60° F. (Air = 1)		4.4230
Specific gravity liquid at 60° F. (Water = 1)		1.1508
Boiling point	424.7° F.	
Melting point	174.0° F.	
Cubic feet per pound	2.952	
Weight one cubic foot in pounds	0.3387	

HEAT OF COMBUSTION

Calories per molecular weight in grams	1,230,657
B. T. U. per cubic foot	5,859.0
B. T. U. per pound	17,298.0

HEAT OF FORMATION (LIQUID)

Per formula weight	plus	9,100
Per unit weight of carbon	plus	76
Per unit weight of hydrogen	plus	1,138
Per unit weight of compound	plus	71

PRODUCTS OF COMBUSTION

Cubic feet per cubic feet of gas or vapor.	Required for combustion;			
Air 57.42 ;	Oxygen 12.0 ;	CO ₂ 10.0 ;	H ₂ O 4.0 ;	N ₂ 45.42.
Pounds per pound of gas or vapor.	Required for combustion;			
Air 12.984 ;	O ₂ 3.00 ;	CO ₂ 3.437 ;	H ₂ O 0.563 ;	N ₂ 9.984.

TABLE VI
ANALYSIS OF COAL GAS

CO ₂	4.4 %	3.8 %
Ill.	3.7 %	3.4 %
O ₂	3.3 %	3.2 %
CO	7.6 %	7.4 %
CH ₄	18.6 %	23.1 %
H ₂	33.4 %	32.88 %
N ₂	29.0 %	26.22 %
Specific gravity (Air = 1)	0.520	

TABLE VII
CONDENSING TESTS ON MIXED GAS

	60° Coil	50° Coil	40° Coil	70° Coil
Condensate Gallons per M	0.0072	0.0082	0.0093	0.0036
Saturation Point	31° F.	-10° F.	-10° F.	56° F.
C ₁₀ H ₈ Pound per Gallon	0.93			1.58

Table VII shows the results of condensing mixed gas to various temperatures, together with the saturation point of the condensate. It is believed that if this saturation point is more than 10 degree below the temperature of the gas that no trouble may be expected.

PART IX

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name Charles E. Ferris

Title Professor Mech. Eng.