THE COMBUSTION OF PYRITES
IN A HERRESHOFF FURNACE

A THESIS
SUBMITTED TO THE FACAULTY
OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE
DEGREE OF BACHELOR OF SCIENCE

Submitted by:

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Approved by:

May 24, 1929

Cambridge, Mass.
May 24, 1929.

Professor A. L. Merrill
Secretary of the Facaulty
Mass. Institute of Technology
Cambridge, Mass.

Dear Sir:

As required by the regulations of the Facaulty, we take pleasure in submitting this thesis in partial fulfillment of the requirements for the degree of Bachelor of Science.

Very truly yours,

Eugene C. Koo

Suresh C. Bose

In appreciation to Charles M. Gilmour of the Institute, under whose direction this thesis was done; to Professor F. W. Adams of the Institute and to Mr. C. Dean of the Merrimac Chemical Company for their kind assistance.

CONTENTS

167005

Thesis

SUBJECT:

The Combustion of Pyrites in a Herreshoff Furnace.

OBJECT:

A study of the present operating conditions of C set Herreshoff Furnace with special reference to the mechanism of combustion and hearth study at different shelves.

ABSTRACT:

The mechanism of combustion of pyrites follows these reactions:

$FeS_2 = FeS + S$ --------------(1)

$FeS + 3O = FeO + SO_2$ --------------(2)

$S + O_2 = SO_2$ --------------(3)

$2FeO + O = Fe_2O_3$ --------------(4)

(2) and (3) reactions follow the first one immediately. Sulfur as sulfides has beem found in shelves 3,4,5,6. Sulfur as sulfate decreases at top 7 shelves, increases gradually, maximum being in cinder. The average combustion efficiency is 95%, 70% of combustion is completed in top five shelves.

Introduction.

General Discussion :

The contact plant of the Merrimac Chemical Company, South Wilmington, Mass. manufactures its SO_2 by roasting pyrites in Herreshoff Burners. The pyrites is obtained from Eustis Copper Co, Canada. This type of burner is the largest size built by Nichols Herreshoff Company, having twelve shelves for each burner~~s~~. These two burners were recently installed by the plant, a rotary sulfur burner having been previously employed.

Last year, a thesis was run on one of the burners, heat and material balances were made, and some hearth study was carried out. However, the operating conditions are quite different at present, and they have been improved a great deal during this year.

Purpose of investigation :-

The chief difficulty in operation is the temperature control at different shelves. The big variation in temperature is due to local combustion, that is, most of pyrites is burnt off on a few shelves only. This local combustion causes the following difficulties :-

(1) Slagging of the ore and cinder on rabble arms and causing them to break off.

(2) Increase of repairing and depreciation cost of the equipment due to high temperature.

(3) Less complete combustion.

There are two extra cooling arms on each of the top six shelves, but due to air leakage (it is said that 30% of the cooling air is leaked into the burner) the shelves can not be very well cooled. At present the only temperature control method is to open some of the doors of the shelf especially of fifth one which has temperature around 850°C. But this air admitted supports the combustion, thus its cooling effect is counter balanced.

The object of this thesis, therefore, is to find some means of temperature control for the burner. It is also the aim of this investigation to obtain the present operating conditions with special reference to hearth study at different shelves.

Scope of thesis :-

Since it has been found that C set burner has less air leakage, the whole thesis is run on this set only.

The following are the methods of attack :-

a. Feed and cinder analysis for sulfur in different forms and iron.

b. Distribution of combustion at different shelves, by analysis both inlet and outlet pyrites samples at each shelf, for sulfur in different forms and iron content.

c. Gas analysis at different shelves.

d. Temperature study at different hearths.

e. Time requirement for pyrites travel from shelf to shelf.

f. Amount of air for combustion.

g. Leakage of cooling air to the burner.

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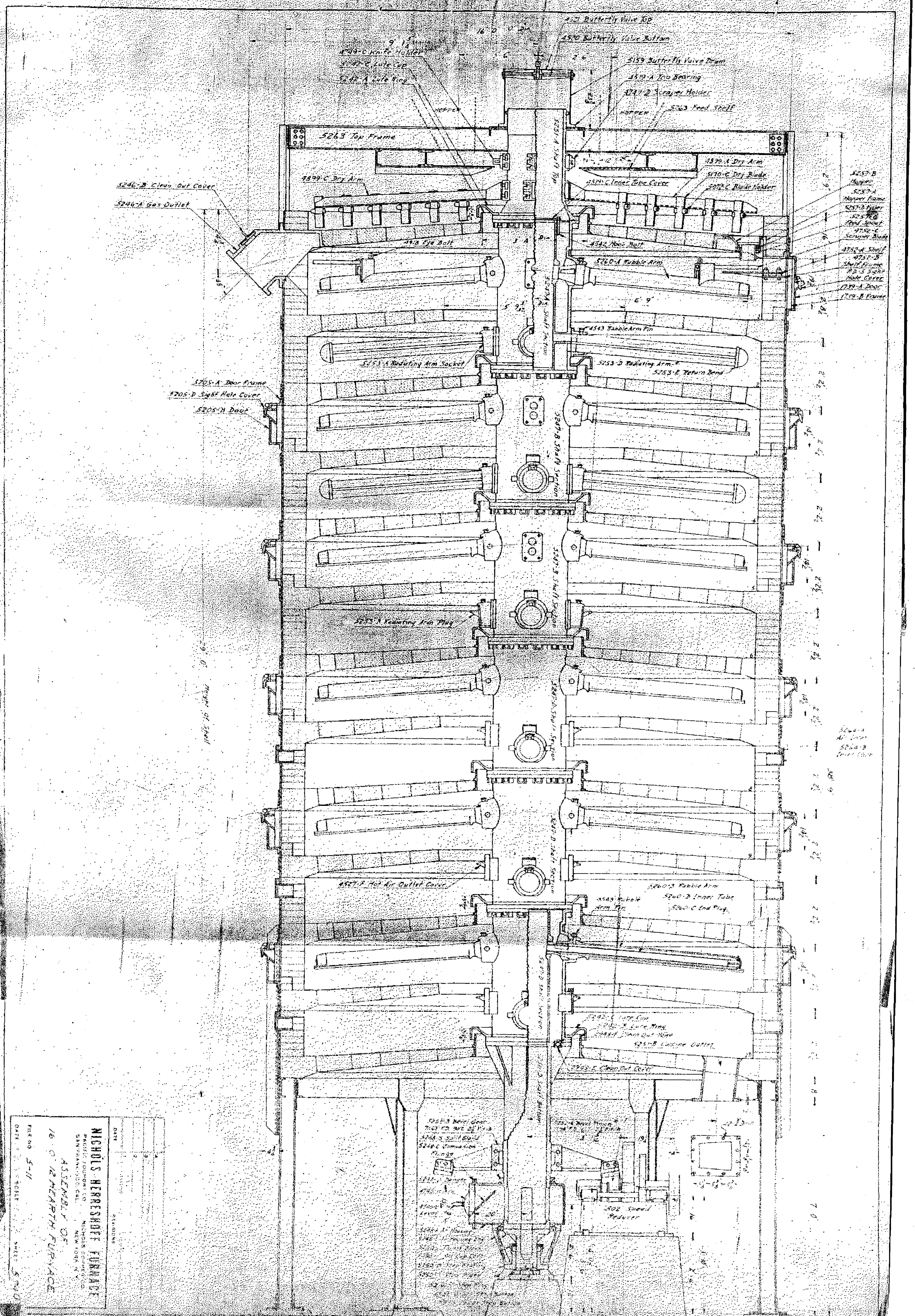

NICHOLS HERRESHOFF FURNACE
PACIFIC FOUNDRY CO
SAN FRANCISCO, CAL.
NICHOLS COPPER CO
NEW YORK N.Y.
ASSEMBLY OF
16' 0" 12 HEARTH FURNACE
FILE NO 5-11
DATE
SCALE
SHEET
No. 5
REVISIONS
DATE

Operation of Herreshoff Burner.

Pyrites is conveyed into two bins by means of a bucket conveyor which is being fed continuously by a rotating arm attached to the central shaft. The ore is rabbled from the centre to the side gradually on the top of the burner, during which time considerable drying takes place, finally drops thru luted feed hole on the first shelf. In the first shelf the feed is rabbled from side to centre and falls on the next one, and this process continues till the ore reaches the twelfth shelf.

The rabble arms to which ploughs are attached are hollow cast iron, ~~xxxx~~ having cooling air circulating thru them. Besides these, there are two extra cooling arms on each of the first six shelves. The central shaft is ~~x~~ double jacketed ~~xxxx~~, cooling air following one path and the hot air ~~thru~~ another. The ploughs on the first six shelves have a bigger angle of inclination so that the feed is pushed faster from shelf to shelf.

The air for combustion is introduced at the last shelf, and the cooling air is forced thru the central shaft by means of a fan and led out thru a pipe. The air for combustion gains heat in the lower shelves whereas it looses heat on upper shelves. Combustion of feed is entirely self supporting due to the fact that most of the reactions taking place are exothermic.

The burner gas is taken by suction from the top of the last shelf and goes thru a process of purification, cooling and dehumidification.

The cinder is collected from the last shelf and it goes to a bin by gravity. From this bin it is carried to the top floor by the same mechanism as is used for the feed, flows by gravity thru pipes and is dumped into cars outside.

Theoretical Discussion

The mechanism of roasting pyrites is quite different from that of combustion of coal and burning of sulfur. Increasing the rate of flow of air will not appreciably accelerate the rate of roasting, while in the case of coal or sulfur this has a big effect. Sulfur in rotary burners volatilizes first before it combines with O_2, while pyrites breaks down and then is oxidized. Consequently the maximum exposed area for roasting pyrites is desirable.

The dissociation or decomposition of pyrites has been studied by some authorities and may have the following possibilities.

A. Pyrites breaks down into FeS and S, and then is oxidized.

$$Fes_2 = FeS + S - 18{,}611 \quad (1)$$

$$S + O_2 = SO_2$$

$$2\ FeS + 7\ O = Fe_2O_3 + 2\ SO_2$$

B. Pyrites is partially oxidized first. (2)

$$FeS_2 + O_2 = FeS + SO_2$$

$$FeS + 3\ O = FeO + SO_2$$

$$2FeO + O = Fe_2O_3$$

C. Pyrites gives sulfur and pyrrhotite upon heating, the latter is a solid solution of S in ferrous sulfide. (3)

$$7\ FeS_2 = Fe_7S_8 + 3\ S_2 - 8{,}910$$

D.

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(1) Ref. 7

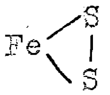
(2) Ref. 9

(3) Ref. 6

D. It has been found that in vacuo decomposition of pyrites into FeS and S becomes evident at 550°C. At 670-680°C, decomposition into FeS and S ~~iss~~ complete in 8 hours. Heating in a current of N_2 at 850°C for 1 hour gives complete decomposition into FeS and pure crystalline sulfur. (1)

E. Pyrites is directly oxidized to SO_2 and Fe_2O_3.

$$2\ FeS_2 + 11O = Fe_2O_3 + 4\ SO_2$$

G. W. Plummer (2) has definitely shown the structural formula of pyrites as  , i. e. the atomsofof sulfur in the FeS_2 molecule are symmetrical with respect to the iron atom. As soon as one sulfur has broken away from the molecule,  will be very active, either to break down further or to combine with other element. Since the breaking down of pyrites into combined sulfur and free S have been proved by many authorities, reaction E seems not to be possible, although the equation does represent the net result of roasting of pyrites.

The amount of air for combustion is important. Too much excess will favor the secondary reaction,

$$FeS_2 + 7\ O = FeSO_4 + SO_3$$

(3)
Theoretically, if pyrites were burned to ' normal condition' $2FeS_2 + 11O = Fe_2O_3 + 4\ SO_2$, and if the reaction could proceed to complete exhaustion of O in the air used, gas in the furnace

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(1) Ref. 8
(2) Ref. 2
(3) Ref. 18

would contain 16.1 % SO_2 and 83.9 % N_2 Thus the ratio of O absorbed to form Fe_2O_3 to SO_2 will be 0.375. The common practice one can never approach such a high percentage of SO_2 in burner gas due to the secondary reactions and formation of sulfates and SO_3.

Previous Work

Some laboratory work on roasting of pyrites have been done by G. F. Huttig (1) and P. Lurmann in Germany and M. G. Marchal (2) in France. L. T. Wright (3) have carried on the experiment of varying the oxy gen content of the gases from roasting pyrites. P. Parrish (4) gives some valuable data in the combustion of sulfur-content materials in hand and mechanical burners.

On this particular set of Herreshoff Furnace a thesis (5) was run last year by J. A. Jamison, B. F. Miller and E. L. Welcyng. They had heat and material balances on the furnace with a little hearth study. The assumption in getting theoretical Fe for a given percentage of S seems to be incorrect. Moreover, a method of expressing the sulfur content on each shelf to the same basis is lacking, thus the curve of pounds of sulfur per 100 pounds of theoretical iron against number of shelf cannot show the rate of combustion of pyrites.

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(1) Ref. 10
(2) Ref. 8
(3) Ref. 18
(4) Ref. 5
(5) Ref. 17

Summarized Method of Procedure.

The work of this thesis mainly consists of hearth and mechanism of combustion of pyrites. This can be divided into (1) extent of combustion on different shelves, (2) Temperature on different shelves, (3) amount of air for combustion, (4) amount of air for cooling and its leakage.

1. Extent of combustion was found by analysing solid samples coming from shelf to shelf for iron and sulfur in different forms.

2. Temperature was found by observing the recording pyrometers and millivoltmeter.

3. Amount of air for combustion was determined by pitot tube measurement.

4. Amount of air for cooling was determined by pitot tube and leakage found by determining the amount of exit air.

Two runs of 5 hrs and 8 hrs respectively were conducted to determine the above results.

RESULTS

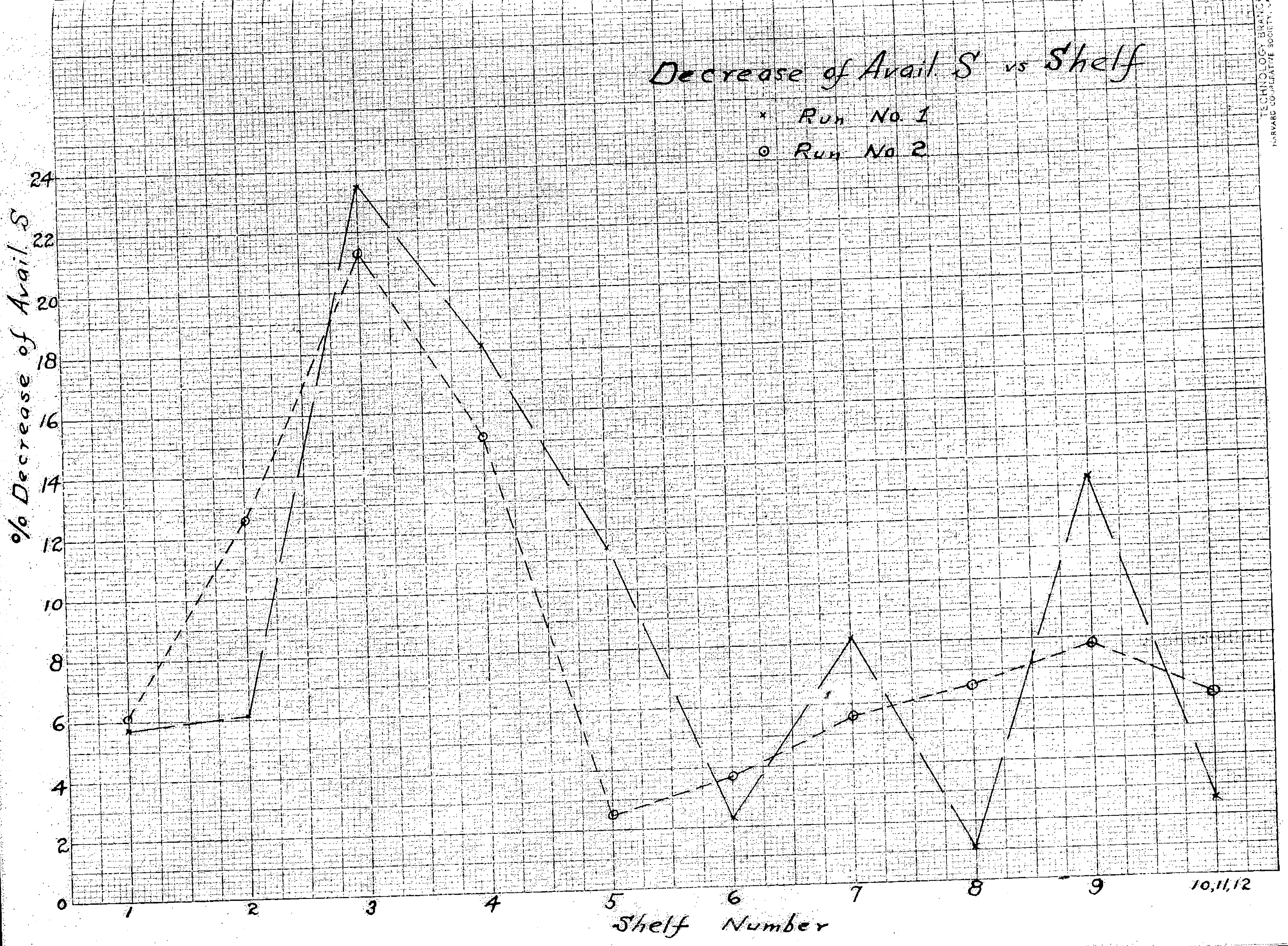
Tabulated Results

Shelf No.	% Decrease of Avail. S	
	Run No.1	Run No.2
1	5.75	6.10
2	6.15	12.60
3	23.50	21.30
4	18.20	15.20
5	11.40	2.50
6	2.30	3.70
7	8.20	5.60
8	1.10	6.50
9	13.35	7.80
10,11,12	2.63	6.10
	Eff. of Comb. 92.58	Eff. of Comb 97.40

Free Sulfur (Run #1)

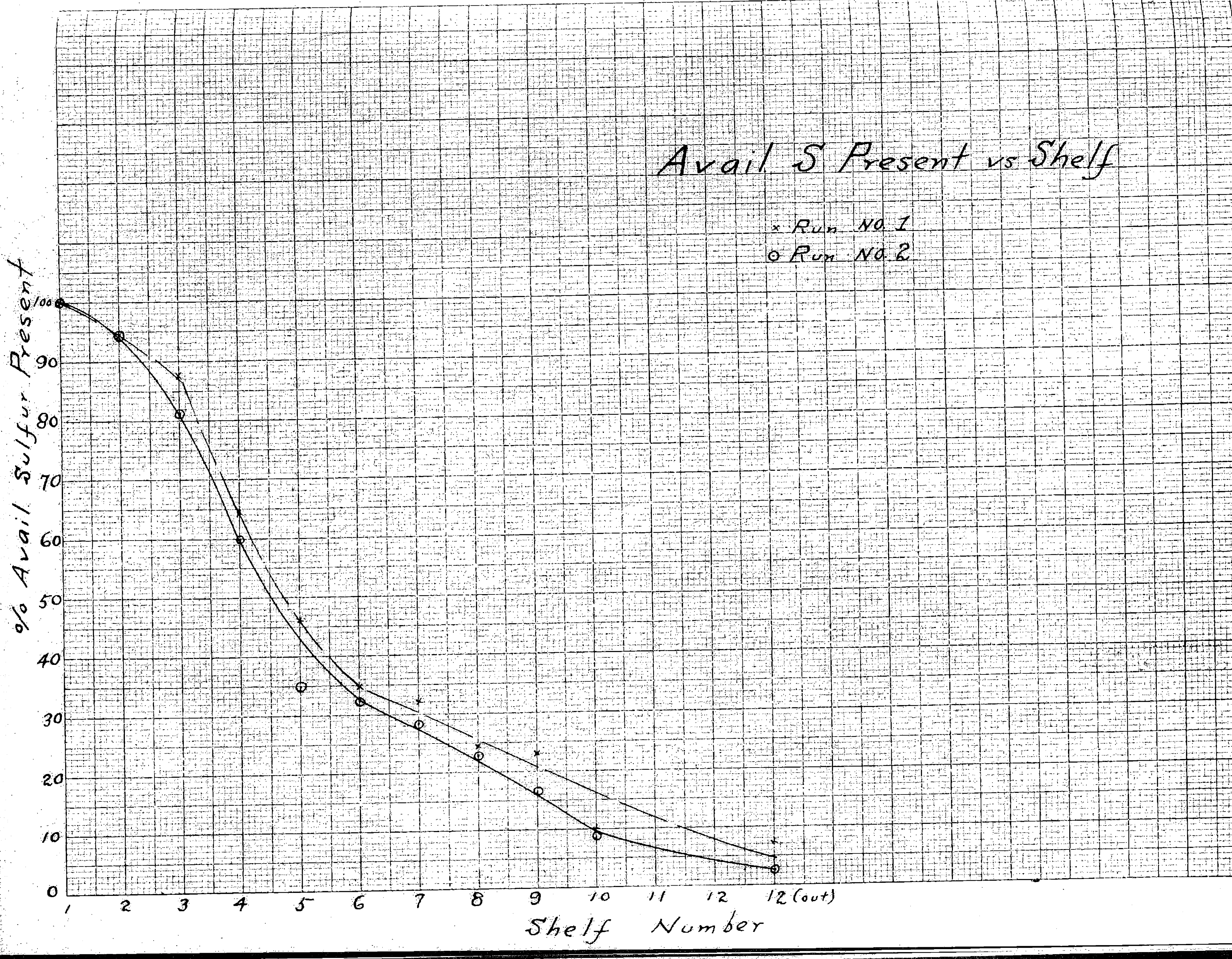
Feed = 0.232%

2 = 0.268%.


Decrease of Avail S vs Shelf
× Run No. 1
⊙ Run No 2
% Decrease of Avail. S
0
2
4
6
8
10
12
14
16
18
20
22
24
Shelf Number
1
2
3
4
5
6
7
8
9
10,11,12

Run # 1.

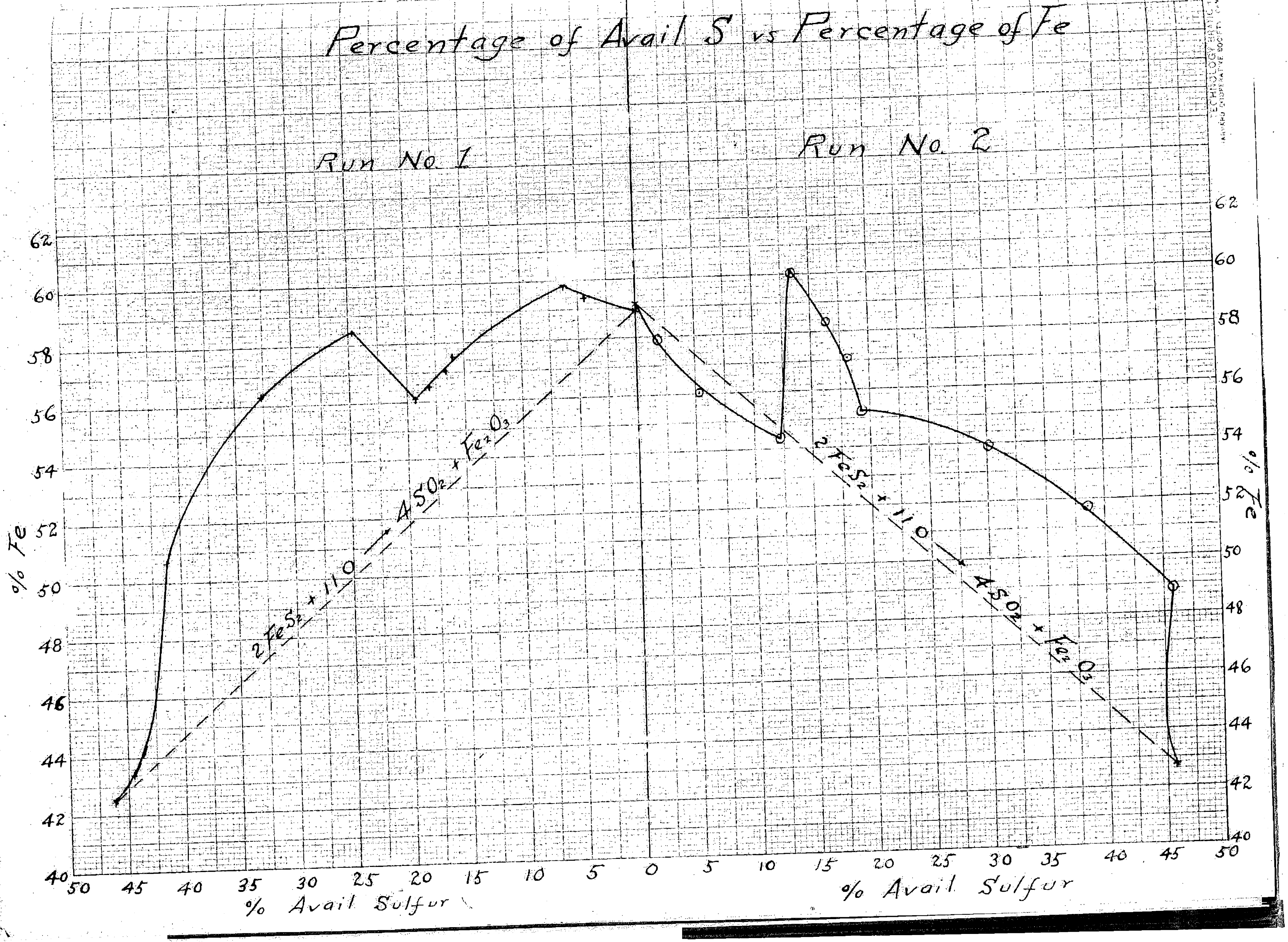
Sample No	# avail S / 100# feed	% avail S present.	% avail S burnt off.
Feed	45.25	100.0	0.0
2	42.65	94.25	5.75
3	39.90	88.10	11.90
4	29.25	64.60	35.40
5	21.00	46.40	53.60
6	15.86	35.00	65.00
7	14.80	32.70	67.30
8	11.10	24.50	75.50
9	10.59	23.40	76.60
10	4.55	10.05	89.95
Cinder	3.36	7.42	92.58
	Run No 2.		
Feed	45.16	100.00	0.0
2	42.40	93.90	6.1
3	36.70	81.30	18.7
4	27.10	60.00	40.0
5	15.70	34.80	65.2
6	14.60	32.30	67.7
7	12.90	28.60	71.4
8	8.30	23.00	77.0
9	6.10	16.50	83.5
10	3.91	8.65	91.3
Cinder	1.18	2.61	97.4



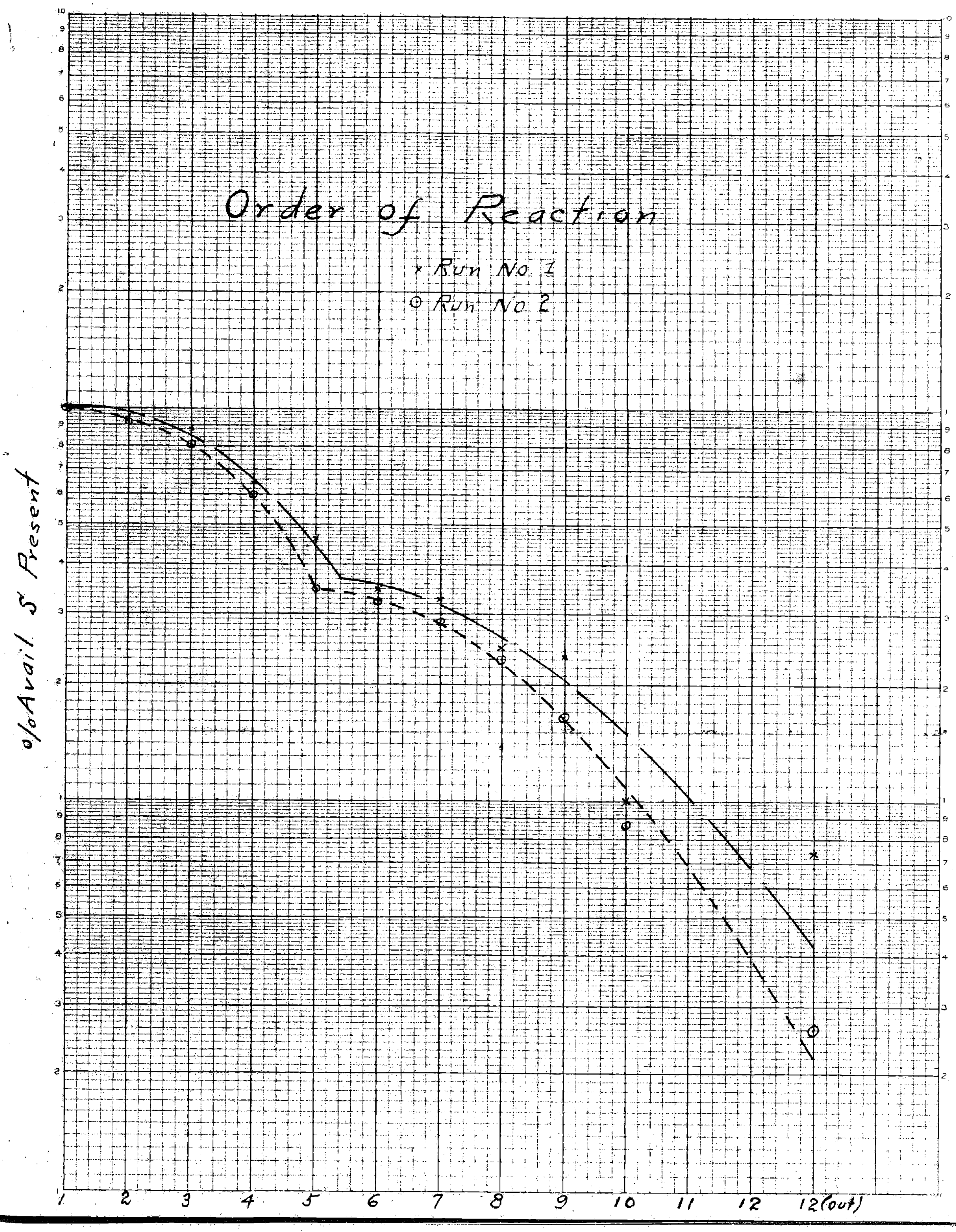
Avail S Present vs Shelf

Percentage of Avail. Sulfur
against Percentage of Iron

	RUN NO. I		RUN NO. II	
Shelf	% Fe	% Avail S	% Fe	% Avail.S
Feed	42.61	45.26	42.85	45.16
#2	44.90	43.40	48.95	43.12
#3	50.70	41.27	51.70	38.61
#4	56.38	32.55	53.90	30.48
#5	58.40	24.75	55.30	19.05
#6	56.10	19.43	57.10	18.04
#7	56.50	18.31	58.35	16.17
#8	57.05	14.10	60.35	13.30
#9	57.65	13.52	54.40	9.76
#10	59.90	6.11	56.10	5.27
Cinder	59.40	4.55	57.95	1.63



Percentage of Avail S vs Percentage of Fe


Order of Reaction
× Run No. 1
⊙ Run No. 2
o/o Avail. S Present
1
2
3
4
5
6
7
8
9
10
11
12
12(out)

Sulfur in Different Forms - Run #1

Sample	% Total Sulfur	% Sulfur as Sulfate	% of Tot. Sulfur (1)	% Sulfur as Sulfide	% Avail. Sulfur
Feed	46.08	0.815	1.51		45.26
#2	43.70	0.307	0.70		43.40
#3	41.50	0.232	0.56	0.11	41.27
#4	32.95	0.396	1.04	0.56	32.55
#5	25.15	0.403	1.35	0.59	24.75
#6	19.82	0.388	1.68	0.36	19.43
#7	18.73	0.416	1.90		18.31
#8	14.48	0.375	2.22		14.10
#9	14.19	0.672	4.75		13.52
#10	6.85	0.738	10.80		6.11
Cinder	6.59	2.040	31.00		4.55

Sample Calculation

% Avail. Sulfur = % Total Sulfur - % Sulfur as Sulfate

#10 6.85 -0.738 = 6.11

$$\% \text{ of Total Sulfur} = \frac{0.738}{6.85}(100) = 10.80$$

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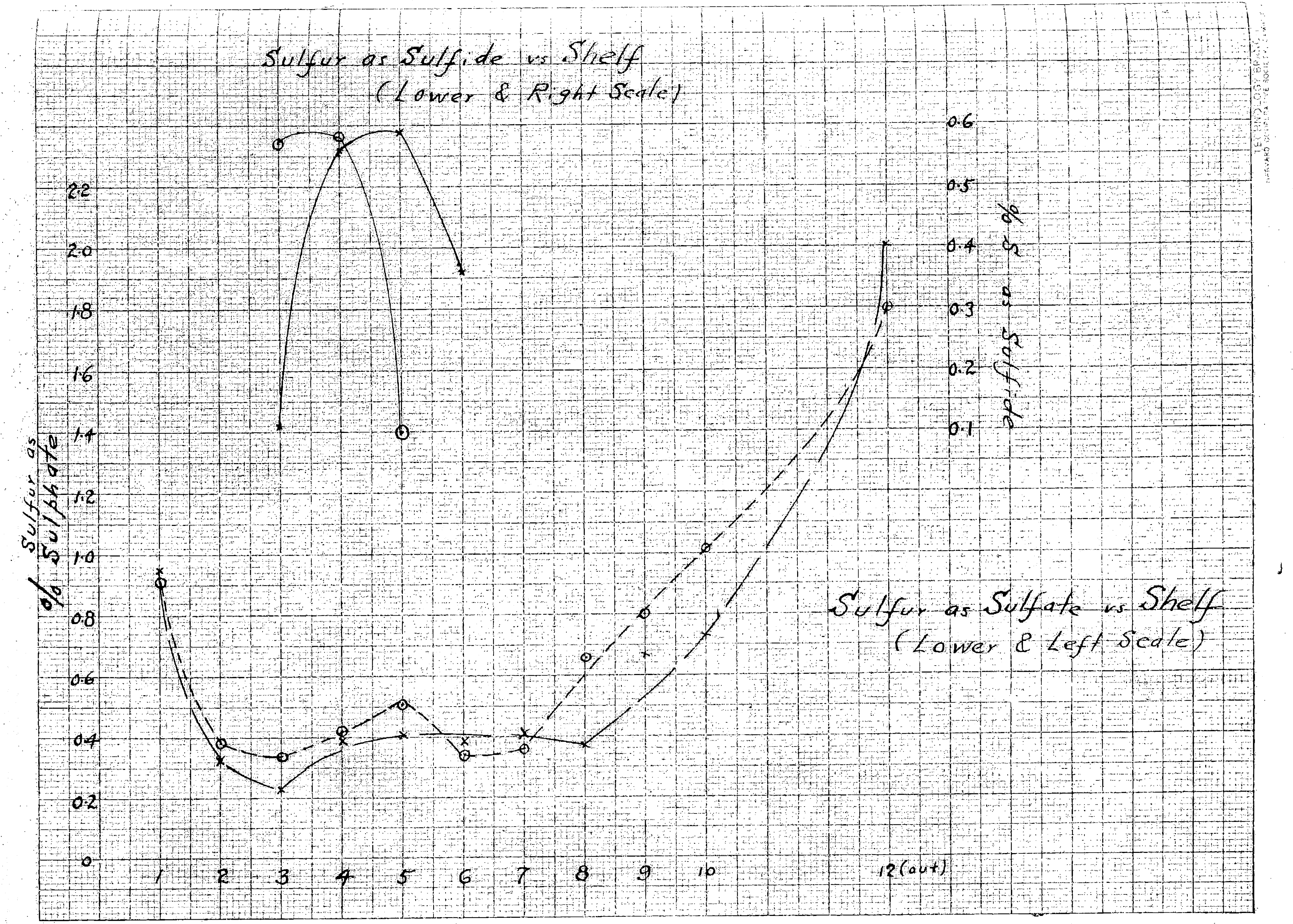
(1) % of Total Sulfur = Sulfur as Sulfate/ Total Sulfur

Sulfur in different forms (Run#2)

Sample	%total sulfur	%sulfur as sulfate	%oftotal sulfur	%sulfur as sulfide	% avail sulfur
Feed	45.87	0.71	1.55		45.16
#2	43.50	0.38	0.87		43.12
#3	38.95	0.34	0.87	0.57	38.61
#4	30.90	0.42	1.36	0.58	30.48
#5	19.55	0.502	2.57	0.10	19.05
#6	18.38	0.34	1.85		18.04
#7	16.53	0.36	2.18		16.17
#8	13.96	0.66	4.73		13.30
#9	10.56	0.80	7.60		9.76
#10	6.46	1.19	18.40		5.27
Cinder	3.43	1.80	52.50		1.63


Sulfur as Sulfide vs Shelf
(Lower & Right Scale)
Sulfur as Sulfate vs Shelf
(Lower & Left Scale)
% Sulfur as Sulphate
% S as Sulfide
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
0.1
0.2
0.3
0.4
0.5
0.6
1
2
3
4
5
6
7
8
9
10
12 (out)

Average Gas Analysis

	Run No.1	Run No. 2
SO_2	8.65	9.56
O_2	7.85	6.81
N_2	83.50	83.63

Total Air For Combustion

Run No.1	Run No.2
74,100 Ft^3/Hour	74,000 Ft^3/Hour

Cooling Air leakage to Shelves

Run No. 1	Run No. 2
15.2% Cooling Air	6.1% Cooling Air

Shelves having air leakage

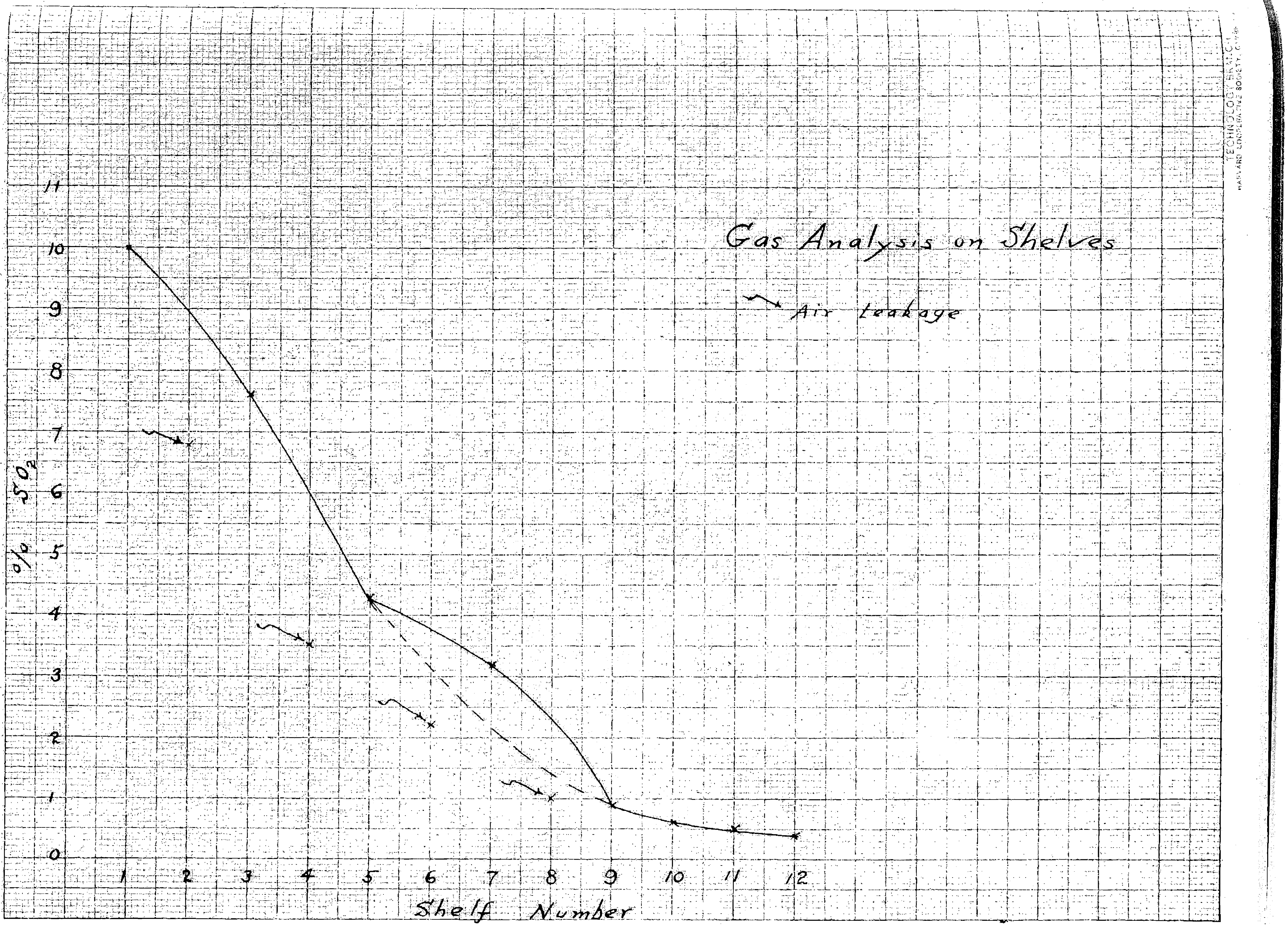
No. 2, 4, 6

Gas Analysis on different shelves.

Shelf No	SO_2	$SO_2 + O_2$	O_2
1.	10.0	16.8	6.8
2.	6.8	16.6	9.8
3.	7.6	16.6	8.6
4.	3.5	16.2	12.7
5.	4.3	16.1	11.8
6.	2.2	16.1	13.9
7.	3.2	15.8	12.6
8.	1.0	15.4	14.4
9.	0.9	16.6	15.7
10.	0.6	18.6	18.0
11.	0.5	20.4	19.9
12.	0.4	20.6	20.2

Exit gas analysis :-

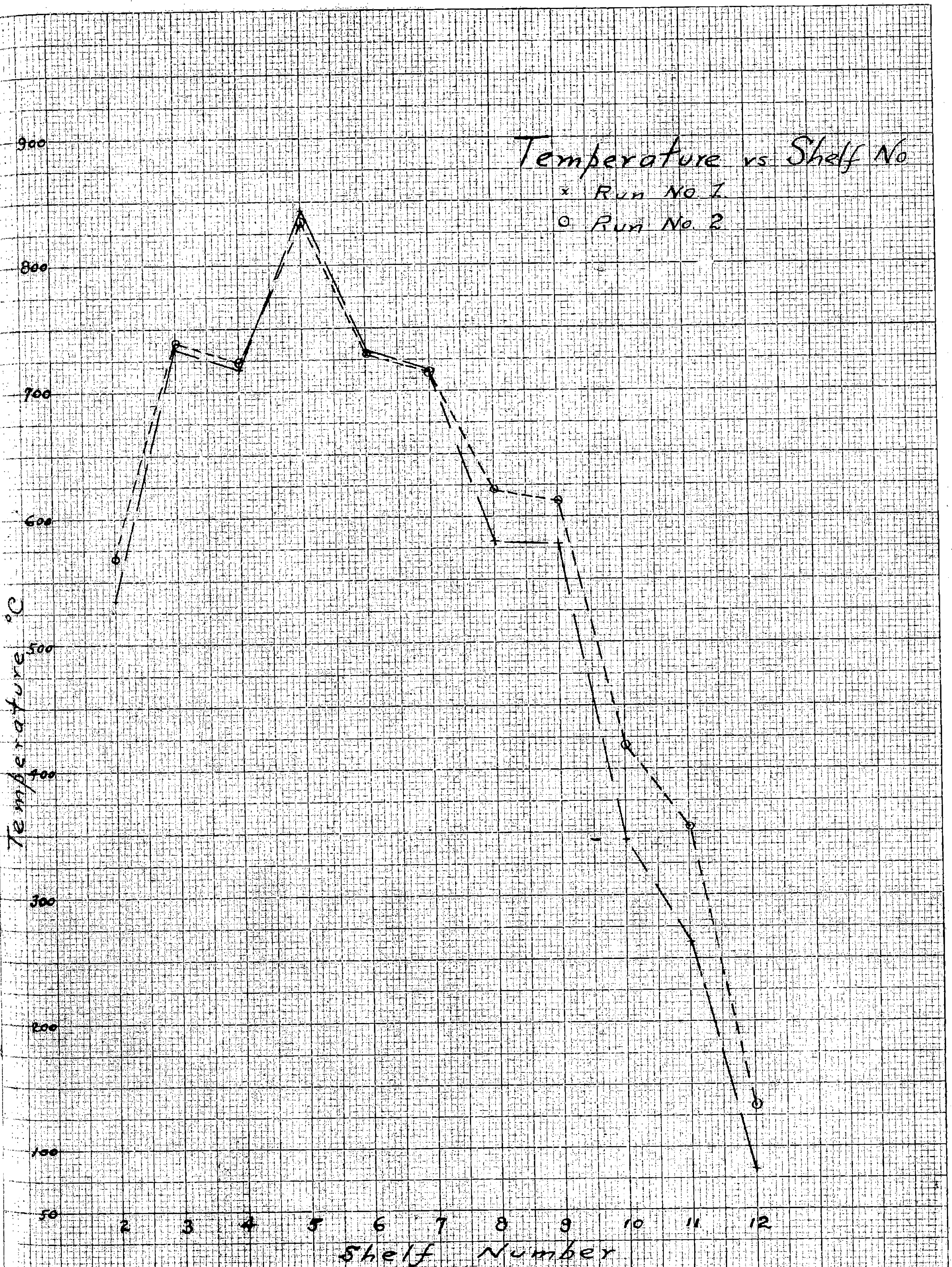
10.8	16.3	5.5
10.9	16.2	5.3


Gas Analysis on Shelves

Average Temperature on shelf.

Temperature in °C.

Shelf No	Run #1	Run#2	Run #3
2.	535	568	590
3.	734	739	730
4.	717	724	680
5.	844	834	685
6.	732	729	640
7.	715	717	665
8.	580	622	685
9.	577	612	680
10.	344	418	335
11.	263	354	270
12.	82	133	95
Outlet gas	662	750	----
Outlet air	285	289	----


Temperature vs Shelf No
× Run No 1
○ Run No 2
900
800
700
600
500
400
300
200
100
50
Temperature °C
2
3
4
5
6
7
8
9
10
11
12
Shelf Number

Discussion of Results

A. Mechanism of Combustion: From the complete analysis of different forms of S in each solid sample it is found that S as sulfate varies from 0.3 to 2.0 %, available S varies from 1.6 to 45.3 %, while S as sulfide only exists between 3 to 6th. shelfs . Since the % of S as sulfide is so low (0.10 to 0.59%), FeS as soon as it breaks down from FeS_2 is oxidized further to FeO or Fe_2O_3 and SO_2 instantaneously. The reactions are as follows:

$$FeS_2 = Fes + S \quad \text{--------------} \quad (1)$$

$$FeS + 3O = FeO + SO_2 \quad \text{--------------} \quad (2)$$

$$S + O_2 = SO_2 \quad \text{--------------} \quad (3)$$

$$2FeO + O = Fe_2O_3 \quad \text{--------------} \quad (4)$$

The reactions (2) and (3) have been shown by the result of two runs on the Herreshoff Furnace to be instantaneous after the first reaction. After No. 5th. shelf the iron content of the samples is decreasing sometimes will prove the reaction (4) is going on. From a plot of % S against % Fe it has been found that pyrites is not oxidized directly to SO_2 and Fe_2O_3. However, no way of expressing % S against % Fe has been obtained from above 4 reactions. The graph developed by J. A. Jamison(1), E. F. Miller, and E. L. Welcyng is obviously wrong, since according to their graph pyrites is completely decomposed to FeS and S in the top five shelves which cannot be true according to their results as well as the results obtained by the writers.

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(1) K-B Thesis 1928

B. Air for Combustion: At present air for combustion is admitted from the bottom shelf, and in addition 10 % cooling air leaked thru. The theoretical amount of air for combustion calculated from gas analysis and feed analysis is much higher than the actual amount measured. This will explain the fact that Fe in cinder has not been totally oxidized to Fe_2O_3. Some magnetic oxide, Fe_3O_4, may be present along with FeO and Fe_2O_3; this magnetic oxide is objectional because it will form a coating on the ore particles thus preventing further oxidation of enclosed sulfur as pyrites. Perhaps this will explain why in the cinder there is still some unburned pyrites. (1.63 % in Run No. 2 and 4.55 in Run No. 1) However, if more air for combustion is admitted it may bring up the efficiency of combustion, but will reduce the SO_2 content of the gas which is not desirable for sulfuric acid manufacture in the contact plant.

C. Temperature Control on Shelves: From the recording pyrometers and thermocouples , temperature readings on two runs show that the fifth shelf has the highest temperature, while the fourth shelf has even a little lower temperature than the third one. The change of temperature on these shelves can be explained thermochemically from the following reactions:

$FeS_2 = FeS + S - 18,611$ (1)

$S + SO_2 = SO_2 + 69,260$ (2)

$Fe + 1.5O = 1/2\ Fe_2O_3 + 97,800$ (3)

The decomposition of pyrites is an endothermic reaction. A. C. Halferdahl (4) stated that the heat of decomposition of pyrites is -10,000 Cal./ mol S. As shown from tabulation of % decrease of available sulfur, combustion occurs mostly in No. 3 and 4 shelves, so the temperatures do not rise rapidly and No. 4 shelf even shows a little lower temperature than No. 3 shelf. It is believed that in No. 5 shelf Fe is oxidized to Fe_2O_3, resulting in highest temperature.

D. Order of Reaction of Roasting Pyrites: From the complex series of reactions and other secondary reactions, the order of reaction is not easy to determine. A plot of % available S present vs number of shelves is done on a semi-log paper, the general shape of curve shows some definite shape but not of a straight line. This shows the order of reaction cannot be primary. Most likely it belongs to consecutive reactions or simultaneous reactions.

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(1) Ref. 7
(2) Ref. 4
(3) Ref. 4
(4) Ref. 6

CONCLUSIONS

I. That pyrites breaks down to FeS and S, followed by secondary reactions immediately.

II. That the first top five shelves do 70% of the combustion, while the lower five shelves complete the combustion to 95 %. About 10% of combustion is done by the ninth shelf, while the bottom three shelves help to cool down the cin- ~~der~~ der.

III. That the highest temperature is in fifth shelf; this does not indicate most combustion is taken up in that shelf but rather shows Fe is oxidized to Fe_2O_3.

IV. Sulfates decreases at top few shelves, increases gradually, until to 50% of S is present as sulfate in cinder.

V. That 74,000 Ft^3 air / hour is admitted into the furnace for combustion, which includes about 10% of cooling air leaked in.

VI. That the order of reaction of roasting pyrites is not primary.

VII. That a plot of available sulfur present against different shelves is worked out using 100# feed basis. The two curves show clearly the change of rate of combustion.

VIII. That the average combustion efficiency of 95% shows the satisfactory operating condition of the burner in general.

Recommendations

I. That further study of the mechanism of combustion of pyrites can be done in laboratory by passing known amount of air over heated pyrites.

II. That the order of reaction may be worked out by another ~~two~~ runs on the furnace with the present available data.

III. That studying temperature control may be helped by modifying the present operating conditions:

  A. Increase speed of central shaft

  B. Vary the quantity of air for combustion within certain limits.

  C. Change the angle of plough of top six shelves to increase the rate of flow further.

IV. That the rate of flow of material through different shelves should be studied by mixing some quartz in the feed.

V. That more gas samples should be taken on each individual shelf in order to find the exact leakage shelves.

VI. That analysis for free sulfur be done on shelves 3,4,5, since the two free sulfur analysis of feed and shelf 2 does show the increasing of amount of free sulfur.

APPENDIX

Method of Procedure.

a. Solid samples :-

All solid samples were taken as they fell from shelf to shelf. In case where they fell near the central shaft a shovel with a long handle was used. The samples were immediately put into tin cans, covered and dipped in water to stop any further combustion.

b. Gas samples :-

Gas samples on shelves were taken by using a quartz tube about three feet long and samples taken by covering peep holes.

The exit gas samples were taken from the main line thru which gas is sucked.

c. Cooling air :-

A galvanized iron duct about 21 inches diameter and 3 ft long was made. A portion of it was cut longitudally to fit the front of the fan. A hole was made about 1 ft away from the fan where pitot tube was inserted and readings observed on a multiplying gauge.

d. Air for combustion :-

The passage of the air for combustion are squares holes of 4.5 inces and ducts of the same size were made. These were inserted right inside holes where they fit perfectedly. These ducts were

5 ft long and hole for inserting pitot tube was made 1 ft away from the burner and readings observed on multiplying gauge.

During the second run some peep holes were opened and the amount of air entering was measured by inserting a long glass inside the burner and recording the pressure drop by an alcohol manometer.

e. Exit hot air :-

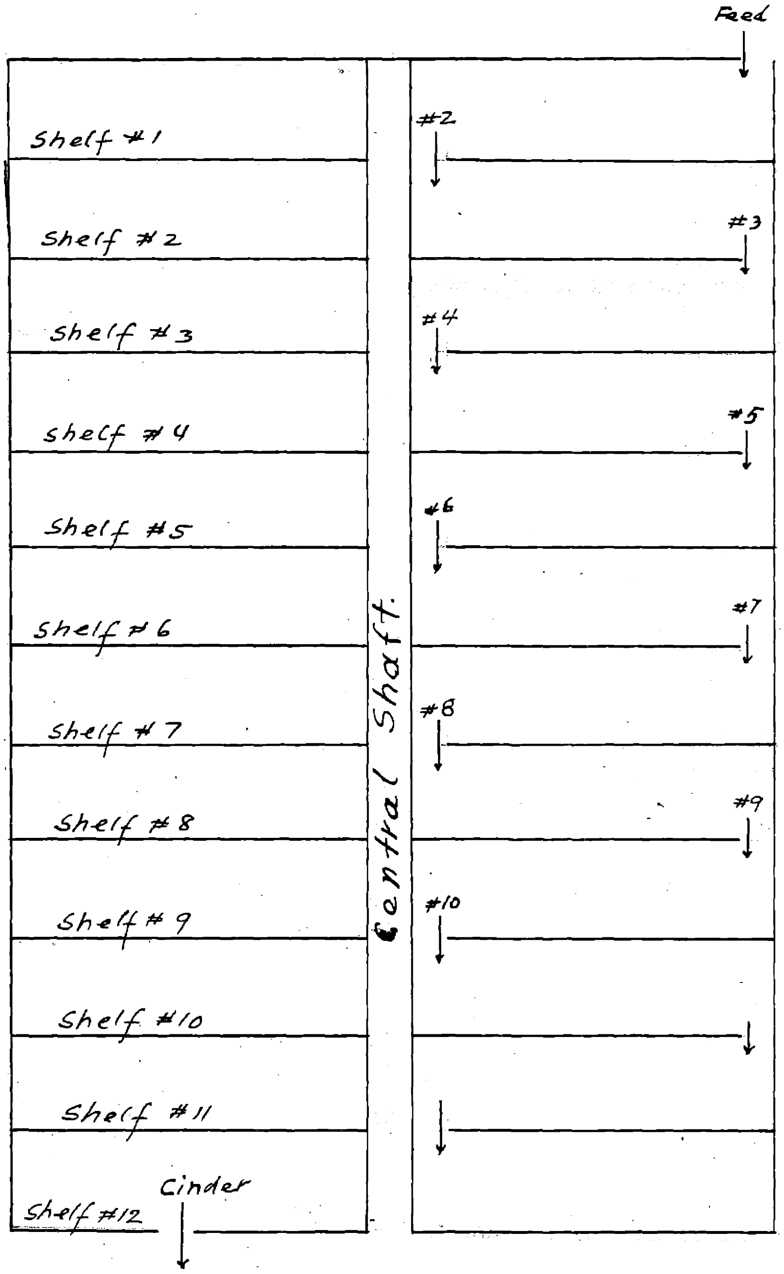
Hot air was measured directly by inserting the pitot tube inside the exit pipe and the temperature from the recorder.

f. Temperature :-

Temperatures were taken from plant [illegible] pyrometers. [illegible]

Location of Sampling Points in Burner

Figure 8



Method of procedure for the determination of iron and sulfur :-

A 0.5 grm of dry sample was mixed with fusion mixture of 10 grms of Sodium Peroxide and 0.4 grm of sugar carbon. Part of the fusion mixture was used to line the nickel crucible. The sample mixed with the fusion mixture was then placed into the properly lined crucible and the mass set off by a glowing string thru a hole in the nickel cover. The crucible was rested in a bath of cold water.

The contents of the crucible was dissolved upon cooling in 150 c.c. hot water. To this solution was added 5 c.c. HCl(sp gr 1.12) saturated with bromine. The solution was boiled and the precipitate of Ferric Hydroxide filtered, which was saved for the determination of iron. The filtrate was acidified with HCl(Sp gr 1.12) and evaporated to dryness to dehydrate the silica. The mass was then taken with 2 c.c. HCl (Sp gr 1.12). 100 c.c. hot water was added and the solution filtered and the silica was washed free from sulfate.

The solution was then heated until it began to boil, when 100 c.c. of boiling hot 0.2N $BaCl_2$ solution added and stirred vigorously. The $BaSO_4$ precipitate was washed three times by decantation with boiling water, then transfered to a filter and washed free from chloride. The precipitate is burnt and weighed as $BaSO_4$.

Iron was determined by dissolving the ferric hydroxide precipitate from the above determination with 15 c.c. of 6N HCl. This solution was combined with filtrate from $BaSO_4$ precipitation. The iron was determined volumetrically by the method of Zimmerman-Renhardt. All the samples were analysed for sulfur and iron by the above methods.

Determination of Sulfide :-

2.5 Grms sample were put into a 250 c.c. flask and stoppered with a two-holed rubber stopper carrying a dropping funnel and an exit tube leading to three 150 c.c. flasks in series. The stem of the dropping funnel was extended nearly to the bottom of the flask. Each piece of tubing started just below the bottom of the stopper in one flask and lead nearly to the bottom of the next one. In the first of the small flask 50 c.c. of water was placed to collect HCl that distill-ed over. In each of the other of the other two small flasks 40 c.c. ammoniacal $CdCl_2$ solution was placed. (20 grms $CdCl_2$ was dissolved in 400 c.c. of water and 600 c.c. of 6 N NH_4OH added to make the $CdCl_2$ solution).

The precipitate was filtered and washed twice with water. The filter and precipitate were placed in a flask containg 20 c.c. 3% KI solution, 25 ml of 9 N H_2SO_4 added. To this solution was added the content of the first small flask containg acid solution of H_2S. To this mixture was added 10ml of standard $KMnO_4$ soltion and excess of iodine was titrated with standard sodium thiosulfate solution.

Method of procedure for determination of free sulfur :-

Samples of about 12 grms were taken and extracted in Soxlet apparatus for 12 hrs with carbon bisulfide. The residue ~~is~~ was evaporated to dryness and carbon tetrachloride saturated with brome. 10 ml of strong nitric acid added and boiled for a while. The solution ~~is~~ was then diluted and barium chloride solution added and the precipitate is burnt and weighed as barium sulfate.

Method of procedure for Sulfate :-

In every case a 10 grms sample was taken and boiled with about 200 c.c. water for 20 Minutes and filtered. The filtrate was treated with Bromine and then 10 c.c. fairly strong NaOH added. The solution is then boiled till all bromine is driven off and filtered. Unless bromine is totally expelled the indicator shows no colour. A few drops of phenolphthalein was added to the filtrate and neutralized by HCl. To this neutral solution a known volume of standard Barium Chloride solution added and excess titrated with standard Sodium Carbonate solution to pink colour.

The end point is not quite distinct due to white precipitate formed. So when it nears end point a few drops were at a time and let the precipitate settle so that the liquid will show the true colour.

Method for Gas Analysis.

The gas was analysed by an Orsat apparatus by first absorbing SO_2 in chromic acid solution, and then passing the remainder of the gas into pyrogallic acid which absorbed the O_2. The unabsorbed gas was assumed to be N_2. A trap was made of glass wool that was inserted between the Orsat and the main to take off the dust that happen to come with the gas. Mercury was used to draw the gases from the main and shelves. In orderto prevent the dry gas from taking up any moisture while being passed thru the solution for absorbtion, the mercury was covered with a very thin layer of water. Thus the gases were saturated before entering the absorbtion tubes. The gas burette was water jacketed and kept at constant pressure.

The chromic acid solution was made by dissolving 165 grm of sod dichromate in 125 mil water and adding 40 ml of 66°Be H_2SO_4.

The pyro solution was made equal weight of pyrogallic acid and sod hydroxide. 25 % solution of caustic was made and same weight of pyrogallic acid as caustic was placed on some glass wool in a funnel and caustic solution poured thru which dissolved the pyro without oxidizing to a great extent.

TABULATED DATA

Tabulated Data

Run No. 1

Shelf	%Fe	% Total S	$\frac{\# \text{ Total S}}{100 \ \# \text{Fe}}$	% Avail. S	$\frac{\# \text{Avail.S}}{100 \ \# \text{ Fe}}$
Feed	42.61	46.08	108.0	45.26	106.2
#2	44.90	43.70	97.4	43.40	96.5
#3	50.70	41.50	81.9	41.27	81.3
#4	56.38	32.95	58.5	32.55	57.7
#5	58.40	25.15	43.1	24.75	42.4
#6	56.10	19.82	35.3	19.43	34.6
#7	56.50	18.73	33.2	18.31	32.4
#8	57.05	14.48	25.4	14.10	24.7
#9	57.65	14.19	24.6	13.52	23.4
#10	59.90	6.85	11.4	6.11	10.2
Cinder	59.40	6.59	11.1	4.55	7.6

Sample Calculations

#10 Shelf

$$\frac{\# \text{ Total S}}{100 \ \# \text{ Fe}} = \frac{6.85}{59.90}(100) = 11.4$$

$$\frac{\# \text{ Avail.S}}{100 \ \# \text{Fe}} = \frac{6.11}{59.90}(100) = 10.2$$

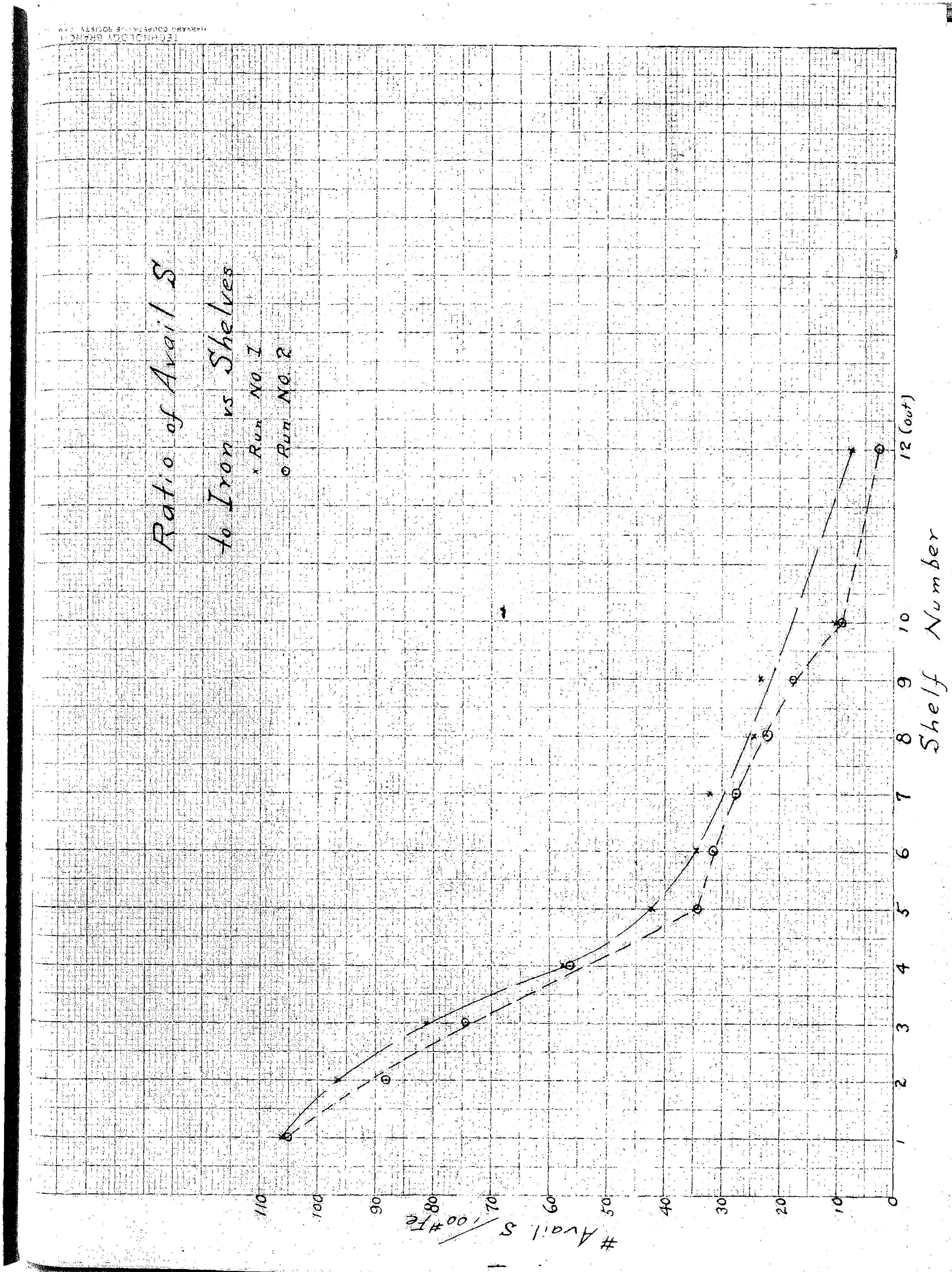
Tabulated Data

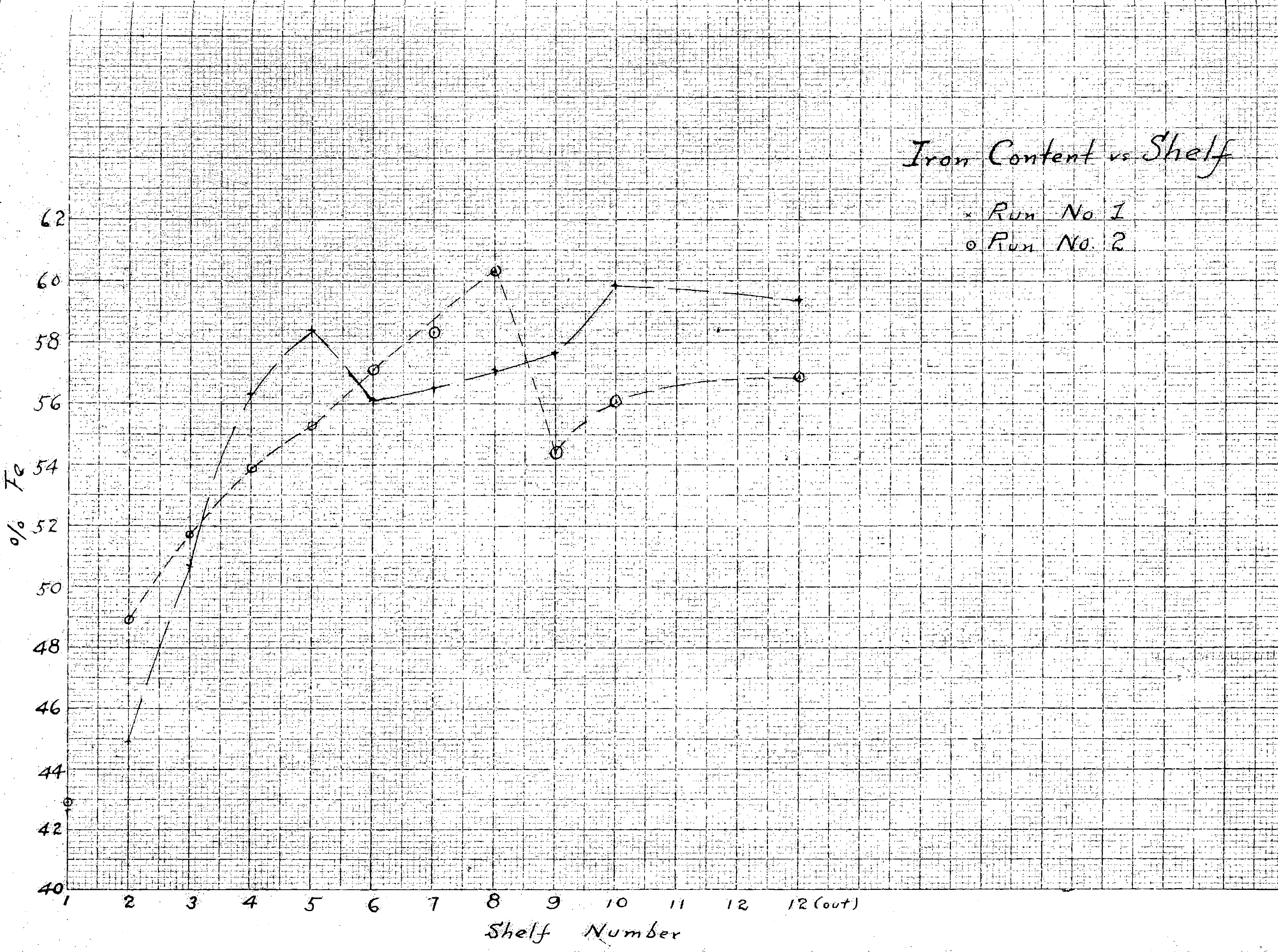
Run No. 2

Shelf	% Fe	% Total S	#Total S / 100 #Fe	% Avail. S	# Avail. S / 100 # Fe
Feed	42.85	45.87	107.0	45.16	105.2
#2	48.95	43.50	89.0	43.12	88.2
#3	51.70	38.95	75.4	38.61	74.7
#4	53.90	30.90	57.4	30.48	56.5
#5	55.30	19.55	35.4	19.05	34.4
#6	57.10	18.38	32.2	18.04	31.6
#7	58.35	16.53	28.4	16.17	27.7
#8	60.35	13.96	23.2	13.30	22.0
#9	54.40	10.56	19.4	9.76	17.9
#10	56.10	6.46	11.5	5.27	9.4
Cinder	57.95	3.43	5.9	1.63	2.8

Copper and iron as sulfate in cinder.

Run #1.	Run #2.
Fe = 1.10%	Fe = 0.316%
Cu = 0.254%	Cu = 0.651%


Ratio of Avail S to Iron vs Shelves


Iron Content vs Shelf
× Run No 1
○ Run No. 2
% Fe
62
60
58
56
54
52
50
48
46
44
42
40
1
2
3
4
5
6
7
8
9
10
11
12
12 (out)
Shelf Number

Qualitative test for Sulfide.

Sample	Run #1	Run #2
Feed	No	No
#2	No	No
#3	Yes	Yes
#4	Yes	Yes
#5	Yes	Yes
#6	Little	No
#7	Little	Little
#8	No	Little
#9	No	No
#10	No	No
Cinder	No	No

Free Sulfur (RUN #1)

	Feed	#2
Wt of sample	12.2482	12.9252 Grms.
Wt of $BaSO_4$	0.2190	0.2388 Grms.

Copper and iron as sulfate in cinder.

	Run #1	Run #2
Wt of sample	10.000	10.000 Grms
Wt of CuO	0.0318	0.0703 Grms
Ml $KMnO_4$	19.2	5.5 ml.

Sulfur as Sulfate.(Run #1)

Sample	% sulfur as sulfate	Average
Feed	0.795 0.835	0.815
#2	0.329 0.284	0.307
#3	0.224 0.239	0.232
#4	0.406 0.386	0.396
#5	0.401 0.406	0.403
#6	0.367 0.410	0.388
#7	0.416	0.416
#8	0.376 0.374	0.375
#9	0.664 0.680	0.672
#10	0.750 0.727	0.738
Cinder	2.040	2.040

Sulfur as Sulfate. (Run #2).

Sample	% sulfur as sulfate	Average
Feed	0.764 0.650	0.707
#2	0.403 0.364	0.382
#3	0.353 0.334	0.343
#4	0.431 0.410	0.420
#5	0.505 0.500	0.502
#6	0.342 0.347	0.345
#7	0.370 0.352	0.361
#8	0.628 0.690	0.659
#9	0.746 0.855	0.800
#10	0.474 0.500	0.487
Cinder	1.840 1.770	1.800

ORIGINAL DATA

Original Data.

Temperature on dif. Shelf (Run #1)

Temperature in °C.

Shelf No	10.00	11.00	12.00	1.00 (time)	Ave
2.	520	523	545	550	535
3.	715	730	745	745	734
4,	716	715	722	715	717
5.	850	830	830	865	844
6.	740	730	730	730	732
7.	726	715	715	705	715
8.	575	580	585	580	580
9.	570	580	580	580	577
10.	360	375	320	320	344
11.	295	298	240	220	263
12.	85	82	80	82	82
Outlet gas	655	660	670	665	662
Outlet air	275	276	290	300	285

(Pressure drop = 4.4)

Original Data Sheet.

Temperature on dif. shelf (Run #2)

Shelf No	9.00	10.00	11.00	12.00	1.00	2.00	3.00	4.00	Ave
2.	560	545	5565	562	575	568	566	585	568
3.	720	713	715	740	750	720	738	740	739
4.	727	713	710	735	740	716	735	720	724
5.	846	835	815	8852	840	816	842	825	834
6.	780	755	720	755	725	740	680	675	729
7.	772	740	705	730	720	670	665	650	717
8.	660	640	630	615	640	638	585	570	622
9.	660	640	630	605	640	630	570	520	612
10.	450	450	450	450	430	462	345	305	418
11.	380	420	380	392	360	395	270	235	354
12.	120	150	160	145	120	140	120	105	133
Outletgas	726	730	760	756	760	746	766	764	750
Outletair	282	285	285	290	295	275	290	285	289

(Pressure drop = 4.2)

Temperature on dif. shelf when gas samples were analysed on each shelf.

Temperature in °C.

Shelf No	8.00	9.00 (time)	Aver.
2	590	590	590
3	730	730	730
4	680	680	680
5	680	690	685
6	640	640	640
7	670	660	665
8	690	680	685
9	680	680	680
10	340	330	335
11	270	270	270
12	100	90	95

Original Data Sheet.

Exit Gas Analysis.

Run #1.

Time	SO_2	O_2	SO_2+O_2
10 A.M.	9.1	7.7	16.8
11	8.4	8.0	16.4
12	8.0	8.4	16.4
1 P.M.	9.1	7.3	16.4
Average	8.65	7.85	16.5

∴ $N_2 = 83.5$

Run #2.

10 A.M.	9.5	7.3	16.3
11	11.0	4.4	15.4
12	10.2	6.0	16.2
1 P.M.	10.0	6.4	16.4
2	8.0	8.2	16.2
3	10.1	7.1	17.2
4	8.8	7.6	16.4
Average	9.56	6.81	16.37

∴ $N_2 = 83.63$.

Original Data Sheet.

Air for combustion.

Pitot tube Readings. (Run #1)

Inlet No	Dif. in Rdg. of Multiplying Manometer.			
	10.00	11.00	12.00(Time)	Aver.
1.	3.3	2.4	2.2	2.63
2.	---	5.6	2.2	3.90
3.	3.8	2.6	2.6	3.00
4.	----	2.4	2.4	2.40
5.	----	2.2	1.8	2.00
6.	3.4	2.6	3.0	3.00
7.	2.1	2.2	2.0	2.10
8.	---	2.0	2.0	2.00
			Average	2.63

Temperature of inlet air = 60°F.

Multiplying factor = 47.6

Original Data Sheet.

Air for Combustion (Run#2).

Pitot tube Readings.

Inlet No	Dif in Rdg. of multiplying manometer.				
	11.00	12.00	1.00	2.00 (time)	Ave.
1.	1.0		1.4		1.2
2.		3.2		2.4	2.8
3.	2.0		2.4		2.2
4.		1.4		1.0	1.2
5.	3.0		2.0		2.5
6.		3.2		2.2	2.7
7.	0.8		1.2		1.0
8.		2.6		1.6	2.1
				Average	1.96

Average air temp = 67°F.

Manometer rdg in peep holes.

Inlet No	Dif. in Rdg. of alcohol Manometer.
1.	0.30 inch
2.	0.25
3.	0.25
4.	0.30
5.	0.30
Average	0.28

Original Data Sheet.

Cooling air measurement.

(Run #1)

	Inlet	Outlet.
Time	Dif in manometer Rdg.	Dif in manomtr Rdg.
10.00	1.2	2.0
11.00	0.8	1.0
12.00	1.6	1.4
1.00	1.4	1.6
Temp (ave)	60°F	285°C.
Average	1.25	1.35

(Run #2)

12.00	1.8	2.0
1.00	1.4	1.6
2.00	1.2	2.4
3.00	1.0	1.2
Average	1.35	1.8
Temp(ave)	60°F	289°C

Pipe Factor Determination
of Inlet Cooling Air Pipe

Point No.	Distance from Circumference	Dif. in Rdg.
1	21.0 ''	0.8
2	19.8	1.6
3	18.4	2.6
4	16.6	3.2
5	10.7	3.6
6	4.9	3.2
7	3.1	3.0
8	1.7	0.4
9	0.6	0.8

Diameter of Pipe = 21.5 ''

Rdg. at center point = 3.6

Average Reading = 2.28

$$\therefore \text{Pipe Factor} = \frac{2.28}{3.60}(100) = 63.4\% = 0.634$$

Pipe Factor Determination
of Outlet Cooling Air

Point No.	Distance from Circumference	Dif. in Rdg.
1	17.5''	2.0
2	16.5	2.2
3	15.3	2.6
4	13.8	2.8
5	9.0	3.0
6	4.2	2.6
7	2.7	2.6
8	1.5	2.2
9	0.5	2.2

Diamwter of Pipe = 18''

Rdg. at Center Point = 3.0

Average Rdg. = 2.52

$$\therefore \text{Pipe Factor} = \frac{2.52}{3.00} = 0.84$$

ANALYTICAL DATA

Analytical Data

Iron Determination (Run #1)

Shelf	Wt. of Sample	CC. Kmno$_4$ 0.1087 N.	% Fe	% Fe Average
Feed	0.5177 g.	34.8	40.75	42.61
	0.5193	38.1	44.48	
2	0.5174	38.3	44.90	44.90
3	0.5114	42.8	50.70	50.70
4	0.5163	48.0	56.38	56.38
5	0.5044	48.5	58.40	58.40
6	0.4982	46.1	56.10	56.10
7	0.4895	45.6	56.50	56.50
8	0.4991	47.0	57.05	57.05
9	0.4988	47.4	57.65	57.65
10	0.5156	51.0	59.90	59.90
Cinder	0.5317	53.5	61.00	59.40
	0.5157	48.9	57.80	

Sample Calculation

#10

$$\frac{(51.0)(0.1087)(.05584)}{0.5156}(100) = 59.90$$

Analytical Data

Total Sulfur Determination (Run #1)

Shelf	Wt. of Sample	Wt. of $BaSO_4$	% S	% S Average
Feed	0.5179 g. 0.5193	1.7106 g. 1.7644	45.40 46.76	46.08
2	0.5171	1.6451	43.70	43.70
3	0.5150	1.5566	41.50	41.50
4	0.5188	1.2425	32.95	32.95
5	0.5099	0.9326	25.15	25.15
6	0.5192	0.7487	19.82	19.82
7	0.5132	0.6998	18.73	18.73
8	0.5132	0.5401	14.48	14.48
9	0.5362	0.5542	14.19	14.19
10	0.5119	0.2549	6.85	6.85
Cinder	0.5221 0.5317	0.2394 0.2668	6.29 6.89	6.59

Sample Calculation

#10

$$\frac{0.2549(S/BaSO_4)}{0.5119}(100) = 6.85$$

Original Data.

Sulfur as sulfate (Run No 1.)

(Weight of Each Sample = 10 g.)

Sample	c.c. $BaCl_2$ N=0.1309	c.c. $BaCl_2$ N= 0.441	c.c.Na_2CO_3 N= 0.1235
Feed		20.0	31.3
		20.0	32.9
#2	50.0		36.5
	50.0		38.7
#3	50.0		41.6
	50.0		40.9
#4		10.0	14.8
		10.0	16.2
#5		10.0	15.4
		10.0	14.9
#6		10.0	17.1
		10.0	16.3
#7 #7		10.0	16.0
#8		10.0	16.7
		10.0	16.7
		10.0	16.9
#9		20.0	37.0
		20.0	36.9
#10		20.0	33.4
		20.0	34.7
Cinder		40.0	37.1

Sulfur as Sulfide.

All samples are 2.500 Grms.

(Run #1)

Sample No	#3	#4	#5	#6
c.c $KMnO_4$ (2nd Soln)	100.0	210.0	140	100.0
c.c Thio	80.5	31.5	14.8	44.2
% sulfur as sulfide	0.109	0.555	0.585	0.356

(Run #2)

Sample No	#3	#4	#5
c.c $KMnO_4$ (2nd Soln)	110.0	160.0	100.0
c.c Thio	14.0	18.0	81.35
% Sulfur as Sulfide	0.570	0.581	0.104

Analytical Data

Iron Determination (Run #2)

Shelf	Wt. of Sample	cc.KMno$_4$ 0.1087 N	% Fe	% Fe Average
Feed	0.5173 g. 0.5390	37.0 37.6	43.35) 42.35	42.85
2	0.5150	41.6	48.95	48.95
3	0.4988	42.5	51.70	51.70
4	0.5189	46.1	53.90	53.90
5	0.5153	47.0	55.30	55.30
6	0.5143	48.5	57.10	57.10
7	0.5136	49.4	58.35	58.35
8	0.5145	51.2	60.35	60.35
9	0.5176	46.5	54.40	54.40
10	0.5085	47.0	56.10	56.10
Cinder	0.5185 0.5158	49.7 49.1	58.20) 57.70	57.95

Analytical Data

Total Sulfur Determination (Run #2)

Shelf	Wt. of Sample	Wt. of $BaSO_4$	% S	% S Average
Feed	0.5173 g. 0.5390	1.7346 g. 1.7892	46.10 45.65	45.87
2	0.5150	1.6305	43.50	43.50
3	0.4988	1.4113	38.95	38.95
4	0.5189	1.1688	30.90	30.90
5	0.5153	0.7337	19.55	19.55
6	0.5143	0.6862	18.38	18.38
7	0.5136	0.6179	16.53	16.53
8	0.5145	0.5222	13.96	13.96
9	0.5176	0.3978	10.56	10.56
10	0.5085	0.2393	6.46	6.46
Cinder	0.5158 0.5334	0.1287 0.1334	3.43 3.44	3.43

Sample Calculation

Shelf #10

$$\% \; S = \frac{.2393 \; (S/BaSO_4)}{0.5085} (100) = 6.46$$

Original Data.

Sulfur as Sulfate (Run #2).

(Weight of Each Sample = 10g.)

Sample	c.c. $BaCl_2$ N=0.441	c.c. Na_2CO_3 n=0.116	c.c.Na_2CO_3 N=0.1235
Feed	20.0		32.9
	20.0	41.2	
#2	10.0	16.4	
		18.3	
#3	10.0	19.0	
	10.0	19.9	
#4	10.0	14.8	
	10.0	15.9	
#5	10.0		10.2
	10.0		10.3
#6	10.0	19.6	
	10.0	19.3	
#7	10.0	18.1	
	10.0	19.1	
#8	20.0	42.5	
#9	20.0	36.0	
	20.0	30.1	
#10	20.0		11.7
	20.0		10.7
Cinder	40.0		49.7
	40.0		46.0

Standardization of Barium Chloride as $BaSO_4$:-

(First Soln)

	#1	#2	
c.c $BaCl_2$ taken	100	100	
Wt of $BaSO_4$	1.5329	1.5154	Grm.

$$N_1 = \frac{1.5329 \times 10 \times 2}{233.44} = 0.1316$$

$$N_2 = \frac{1.5154 \times 10 \times 2}{233.44} = 0.1302$$

Ave N = 0.1309.

(Second Soln)

	#1	#2	
c.c $BaCl_2$ taken	50	50	
Wt of $BaSO_4$	2.5770	2.5749	Grm.

$$N_1 = \frac{2.5770 \times 20 \times 2}{233.44} = 0.442$$

$$N_2 = \frac{2.5749 \times 20 \times 2}{233.44} = 0.441$$

Ave N = 0.4415.

Standardization of Pot Permanganate Vs $Na_2C_2O_4$:

<u>(First Soln)</u>	# 1	# 2
Wt of $Na_2C_2O_4$	0.2618	0.2585 Grm
c.c. $KMnO_4$ used	35.90	35.55

$$N_1 = \frac{26.18}{35.9 \times 6.701} = 0.1086$$

$$N_2 = \frac{25.85}{35.55 \times 6.701} = 0.1088$$

Ave N = 0.1087.

$\therefore$ 1 c.c $KMNO_4$ = =,1.087 x .005584

= .00606 grm Fe.

(<u>Second Soln</u>)	#1	#2
Wt of $Na_2C_2O_4$ =	0.2555	0.2622 Grm.
c.c $KMnO_4$ used =	37.2	38.3

N_1 = 0.1026

N_2 = 0.1024

Ave N = 0. 1025

1 c.c $KMnO_4$ = = 1.025 x .005584

= :00573 grm Fe.

Stan~~d~~dardization of Sod Carbonate Vs Benzoic Acid :-

(First Soln)

	#1	#2	
Wt of HBz	0.7114	0.6993	Grm.
c.c Na_2CO_3 used	48.95	50.4	

$$N_1 = \frac{1000 \times 0.7114}{48.9 \times 122.2} = .119$$

$$N_2 = \frac{1000 \times 0.6993}{50.3 \times 122.2} = .114$$

Ave nN = 0.116.

(Second Soln)

	#1	#2	
Wt of HBz	0.5000	0.5000	Grm.
C.c. Na_2CO_3	33.4	33.1	

$$N_1 = \frac{1000 \times 0.5000}{33.4 \times 122.2} = 0.1229$$

$$N_2 = \frac{1000 \times 0.5000}{33.1 \times 122.2} = 0.1240$$

Ave N = 0. 1235.

$KMno_4$ vs $Na_2S_2O_3$

	A	B
cc. $KMno_4$	25.00	25.00
cc. $Na_2S_2O_3$	24.15	24.15

N of $KMno_4$ = 0.1025

I_2 vs $Na_2S_2O_3$

	A	B
cc. I_2	25.00	25.00
cc. $Na_2S_2O_3$	26.05	26.00

CALCULATIONS

Calculation of Air for Combustion

Run No. 1

$$\Delta h = \frac{2.63 \times 62.5}{47.6 \times 12 \times .0765} = 3.765$$

$U = \sqrt{2 g h} = 15.58$ ft/sec

Total Area of 8 Air Ports = 1.00 ft^2.

$\therefore$ Ft^3 Air / Hour = 56,000 from measurement

Air Leakage = 18,100 Ft^3/hr.

Total Air for Combustion = 74,100 Ft^3/ hr.

Run No. 2

$$\Delta h = \frac{1.96 \times 62.5}{47.6 \times 12 \times .0765} = 2.81$$

$U = \sqrt{2 g h} = 13.43$ ft./sec

$\therefore$ Ft^3 Air/ Hour = 48,400

Air Leakage = 7,600

Air thru Peep Holes (1) = 18,000 Ft^3/hr.

Total Air for Combustion 74,000 Ft^3/ hour

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(1) $h = 0.338''$ H_2O = 23 ft of air

Cooling Air Measurement

Multiplying Factor of Manometer = 10.05

Inlet: Pipe Cross-sectional Area = 268.4 in^2

Pipe Factor = 0.634

Run No.	h in ft. of air	u in ft/sec	$Ft^3/Hr.$
1 (59°F)	4.94	17.8	119,300
2 (60°F)	5.34	18.5	124,000

Outlet: Pipe Cross-sectional area = 255 in^2

Pipe Factor = 0.84

Run No.	h in ft. of air	u in ft./sec.	$Ft^3/Hr.$
1 (285°C)	14.85	30.8	196,200
2 (289°C)	19.90	35.7	227,000

Air Leakage Calculation

Run No.	Inlet Air $Ft^3/hr.$	Outlet Air Ft^3/hr
1 (59°F)	119,300	101,200
2 (60°F)	124,000	116,400

∴ % air Leakage = 15.2 --------Run No.1

∴ % Air Leakage = 6.1 ------ Run No.2

Sample Calculation for Sulfate.

Wt of sample = 10 grms.

c.c. $BaCl_2$ added = 20, N = .441.

c.c. Na_2CO_3 used to tirate back

= 31.3 , N=.1235.

c.c. $BaCl_2$ used to form $BaSO_4$

$$= 20 - \left(31.3 \times \frac{.1235}{.4410} \right)$$

$$= 11.24.$$

grm $BaCl_2$ | c.c.
grms $BaCl_2$ | total
grms $BaSO_4$ | total
grms of $BaSO_4$ | grm sample
grm of S | grm sample

$$.1042 \times .441 \left| 11.24 \right| \frac{116.7}{104.0} \left| \frac{1}{10} \right| \frac{32}{233} \left| 100 = 0.79\ \%. \right.$$

Calculation of # S/ 100# feed.

X = #S/100# feed.

a = % available S in feed.

b = % Fe in feed.

c = % inert in feer.

d = % s in analytical data of any shelf.

$$d = \frac{100\ x}{b + (a - x)\ 0.375 + c + x}$$

$$\therefore x = \frac{(b + 0.375a + c)\ d}{100 - 0.625\ d}$$

Calculation for iron and sulfur assuming complete combustion of sulfur and iron oxidising to Fe_2O_3.

Basis 100# ore.

	Run #1.	Run #2.
Feed :-		
	Fe = 42.61	Fe = 42.80
	S = 46.08	S = 45.87
	Inert = 11.31	Inert = 11.35
	42.61 Fe= $\frac{159x42.6}{111.6}$	42.8 Fe = 159.6 x42.8/111.6
	= 61.0 Fe_2O_3	= 61.2 Fe_2O_3
	Fe = 42.6 = 85.9%	Fe = 42.8 = 59.1 %
	O_2 = 18.1	O_2 = 18.4
	Inert = 11.3	Inert = 11.3
	72.3	72.5

Calculation of theoretical air for Combustion.

Assumption :- 30 tons pyrites/day.

Run #1.

ton Pyr/hr — ton Fe — # Fe — # O_2 in Fe_2O_3

$$\frac{30 \,\big|\, 0.4261 \,\big|\, 2000 \,\big|\, 48 \,\big|\,}{24 \,\big|\, \quad \big|\, \quad \big|\, 55.8 \times 2 \,\big|\, 32} = 14.3$$ mols of O_2 for formation of Fe_2O_3.

Tons ore/hr — ton S/hr — # S/hr — mols S = mols O_2 for SO_2

$$\frac{30 \,\big|\, (.4608 - .0659) \,\big|\, 2000 \,\big|\,}{24 \,\big|\, \quad \big|\, \quad \big|\, 32} = 30.8$$ mols of O_2 for SO_2.

$$\frac{30.8 \times 7.85}{8.65} = 38.0$$ mols of excess O_2 in exit gas.

Total mols of O_2 = 14.3 + 30.8 + 38.0 = 73.1

mols O_2/hr — mols air/hr — ft^3/air at S.T.P/hr

$$\frac{73.1 \,\big|\, 100 \,\big|\, 359 \,\big|\, (460 + 60)}{\quad \big|\, 21 \,\big|\, \quad \big|\, 493} = 132{,}000 \ ft^3 / hr.$$

Theoretical air for combustion (Run #2).

Assumption :- 30 tons of pyrites/day.

$$\frac{30}{24}\overset{\text{Ton ore/hr}}{\Bigg|}\frac{.4285}{}\overset{\text{Ton Fe/hr}}{\Bigg|}\frac{2000}{}\overset{\text{\# Fe/hr}}{\Bigg|}\frac{\qquad 48}{55.8 \times 2}\overset{\text{\#}O_2\text{ in }Fe_2O_3}{\Bigg|}\frac{}{32} = 14.4 \text{ mols of } O_2 \text{ for } Fe_2O_3.$$

$$\frac{30}{24}\overset{\text{Tons ore/hr}}{\Bigg|}\frac{(.4587 - .0343)}{}\overset{\text{Ton S/hr}}{\Bigg|}\frac{2000}{}\overset{\text{\# S/hr}}{\Bigg|}\frac{}{32}\overset{\text{mols S in }O_2\text{ for }SO_2}{\Bigg|} = 33.2 \text{ mols of } O_2 \text{ for } SO_2.$$

$$\frac{33.2 \times 6.81}{9.56} = 23.6 \text{ mols of } O_2 \text{ excess in exit gas.}$$

Tot mols of O_2 = 14.4 + 33.2 + 23.6 = 71.2

$$71.2\overset{\text{mols }O_2}{\Bigg|}\frac{100}{21}\overset{\text{mols air}}{\Bigg|}359\overset{\text{ft}^3\text{/air}}{\Bigg|}\frac{(460 + 67)}{492} = 131{,}000 \text{ ft}^3 \text{ air/hr.}$$

Calculations

Dividing equal areas of a circle used in pipe factor determination

let:

R = radius of the circle

m = no. of equal areas

n = order of circle counting from inner circle

r = radius of any circle

General Equation,(1)

$$r_n = \sqrt{n/m}\ R$$

If m = 5,

$$r_1 = \sqrt{1/5}\ R$$

$$r_2 = \sqrt{2/5}\ R = \sqrt{2}\ r_1$$

$$r_3 = \sqrt{3/5}\ R = \sqrt{3}\ r_1$$

$$r_4 = \sqrt{4/5}\ R = \sqrt{4}\ r_1$$

$$r_5 = \sqrt{5/5}\ R = R$$

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(1) This general equation also applies to squares, substituting side for radius

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