15/06/001/005

NOTICE

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SOCONY MOBIL OIL COMPANY, INC.

RESEARCH DEPARTMENT

MONTHLY PROGRESS MEMORANDUM

(Covering September 16 to October 15, 1964)

ANVIL POINTS OIL SHALE RESEARCH CENTER

Rifle, Colorado

October 19, 1964

CONTRIBUTORS:

Mechanical Engineering
Retorting Section
Analytical Laboratory Section
Engineering and Economic Analyses

Signed by:

R. H. Cramer
Program Manager

NOTICE

The primary object of the Anvil Points Oil Shale Research Center MONTHLY PROGRESS MEMORANDUM is to advise authorized personnel employed by the Participating Parties[1] that various activities are in progress or that certain significant data have been obtained within the Research Center.

These MONTHLY PROGRESS MEMORANDA have been prepared to provide rapid, on-the-spot reporting of research currently in progress at Anvil Points. The conclusions drawn by project personnel are tentative and may be subject to change as work progresses. The PROGRESS MEMORANDA have not been edited in detail.

[1] Socony Mobil Oil Company, Inc. and Humble Oil & Refining Company

MONTHLY PROGRESS MEMORANDUM

(Covering September 16 to October 15, 1964)

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MONTHLY PROGRESS MEMORANDUM
Anvil Points Oil Shale Research Center

(Covering September 16 to October 15, 1964)

I. ADMINISTRATION

R. T. Reeder replaced J. M. Petty as the Administrative Manager of the Research Center on October 6, 1964. Mr. Petty resigned from the Research Foundation to accept a position with the Molybdenum Corporation of America. Mr. Reeder was formerly mine production superintendent of the White Pine Copper Mine in White Pine, Michigan.

The transition was effected smoothly, thanks to excellent cooperation on Mr. Petty's part.

II. MECHANICAL ENGINEERING (W. S. Bergen)

The No. 1 Retort has been in operation this last month with mass shale flow rates varying from approximately 250 to 750 lbs/(Hr)(Ft^2). During the latter part of this period emphasis has been placed on the higher shale throughputs.

Summary

1. A new air gas distributor was designed and installed in No. 1 Retort replacing the existing rocket. This distributor was deemed necessary to accommodate higher air and gas rates. The Syntron shale rate controller was installed less the control element. Other changes were made as required to meet operational problems.
2. The design of the No. 2 Retort unit to accommodate shale mass flows to 750 lbs/(Hr)(Ft^2) is complete except for changes dictated by operation of the No. 1 Retort.
3. A PERT diagram outlining the reconstruction of the No. 2 Retort has been completed and transmitted to the Research Foundation supervisory personnel. Demolition of equipment for the No. 2 unit has begun and reconstruction is scheduled to start October 19th.
4. The equipment for the mist formation study has all been received and assembled. The tower, bins, and other equipment needed for the shale flow studies has been fabricated and went into operation October 15th.
5. Rehabilitation of the Research Center as originally planned is now complete. Maintenance problems are being handled as they occur.

Discussion

A. No. 1 Retort

At the conclusion of studies at the lower shale rates, a new air gas distributor was designed and installed. This distributor resembles a space wheel consisting of a 48-inch diameter annular header with 12 distributor tubes from the header to the periphery of the retort. After several tests, an additional distributor tube which discharges 20% of the air and gas mixture into the center of the retort was incorporated into the header.

The Syntron rate of shale feed equipment arrived and was installed. The control element had not arrived but is due very shortly.

Several revisions have been made to the sweeps on the spent shale star-feeder to form a better seal. A shear pin has been incorporated in the drive mechanism to prevent failures of the shaft as have occurred. The shaft has snapped twice in service when large pieces of metal have reached the feeder.

An orifice was installed in the bypass gas line as a final check on total gas flows.

Dusting is a continued problem and means are being designed to minimize its effect.

Operating schedules have continued on a 5-day basis with changes or alterations being made on week ends. A 10-day operating schedule will begin the latter part of October, permitting revisions to be made during the week.

B. Design of the No. 2 Retort

Design work has continued on the No. 2 Retort. The line burner control systems, weigh scales, the brine pump and shale level control systems have been ordered. All shop drawings are ready to be issued to the shops.

C. Construction of the No. 2 Retort

A PERT diagram (attached) scheduling all work for the No. 2 Retort is complete. Discussions have been held with the Research Foundation supervisory personnel concerning the use of the new PERT schedule. Projected completion of the No. 2 Retort is the first week of November, with testing of the unit the second week of November.

Demolition of the liquid and gas piping, and all vessels from the No. 2 Retort is complete. The new equipment and piping will be installed starting October 19th.

D. Mechanical Models and Mist Formation Equipment

The assembly of the equipment ordered to study mist particle size distribution is complete. It was incorporated in a retort program starting the week of October 12th.

The tower and equipment needed to start the shale flow studies program were completed October 15th. Construction of equipment for the gas distributor studies is well underway and should be completed the latter part of this month. A considerable effort has been put into devising a tracer smoke system which will be satisfactory for these studies. A method to contain and release smoke generated fumes has been devised which should do the job of controlling the input of tracer smoke. Its feasibility will be checked after installation. Much of this work has been coordinated by the senior draftsman.

E. Rehabilitation of the Research Center

All work originally scheduled for planned rehabilitation is complete. Other maintenance problems have cropped up, such as replacement of several fire lines in the area, changes in the telephone system, maintenance of transformer and power distribution systems, repairs to the propane distribution system, and repairs to the house air system. These problems are being solved as they occur.

III. RETORTING SECTION (J. E. Lawson)

The primary objectives of the Retorting Section during the past month have been to: (1)ensure a satisfactory raw shale supply; (2)reproduce Bureau of Mines results on Retort No. 1 to ensure that the system was operating properly; (3)improve and evaluate air distributor designs; (4)initiate a mist formation and recovery study; and (5)construct mechanical models for study of shale flow characteristics.

The six retort engineers have been separated into two-man teams, each team having been assigned responsibility for some phase of the retorting investigation. The teams are responsible for planning, executing and reporting results from the specific study assigned. The information presented by the teams in this Monthly Progress Memorandum varies in degree of completion. Informal Memoranda will be issued by each team to report the studies in more detail and present conclusions, when all data are complete.

The Research Center experimental work commenced with Run 400 and runs will be numbered consecutively thereafter. This will avoid duplication of earlier Bureau of Mines run numbers. The shakedown runs were given the same run number designation as used by the Bureau for easy identification.

A. Shale Preparation Studies (C. W. Tyson)

A study of the screening operation was made to determine the best set of screens to use in preparing the raw shale for Retort No. 1. Concern about the quality of raw shale feed was generated because of excessive clinkering in the retort from shale produced over 1/4-inch screens and because comparision of particle size distribution between the Bureau of Mines operations and our operations indicated a higher level of fines in our raw shale.

A set of tests was designed to process at least 20 tons of minus 3-inch shale over the following pairs of lower screens. In all cases the upper screens were 1-inch.

Test	Primary Screen Size	Secondary Screen Size
1	3/8 inch	1/4 inch
2	3/8 inch	3/8 inch
3	1/2 inch	1/2 inch

Sampling was done by a cutter bar slicing across the flowing stream of shale at regular intervals during the processing of each batch. Integrated weights of both the product and fines flow were also obtained. Particle size distribution were obtained on the Tylab tester.

It can be seen from the results shown in the table below that the minimum amount of fines in the product is obtained by using 1/2-inch

	Wt. % on Fresh Feed		
Screen size (Primary x Secondary)	3/8" x 1/4"	3/8" x 3/8"	1/2" x 1/2"
1/4-inch minus in product	6.5	2.0	1.5
1/4-inch plus in fines	3.0	4.0	11.0
Yield of product	82.0	79.0	73.5

screens. However, using these screens causes about 11% lower yield of product. Since the supply of raw shale to support the projected research program is of concern, this lower yield could seriously curtail the research effort. Using the 3/8" x 1/4" screen set improves the yield to 82%, however 6.5% fines in the product is too high. The best balance between yield and product quality appears to be with the 3/8" x 3/8" screen set and it has been decided that this combination will be used to produce all future 1/4-inch minus shale.

B. Shakedown of No. 1 Retort System and Duplication of Bureau of Mines Runs (P. H. Gifford)

1. Bureau of Mines Run 222

During the period of initial operation of Retort No. 1, a series of tests labeled Run 222 was conducted. The purpose of these operations was several-fold: (1)to familiarize the operating personnel with the unit, (2)to shakedown data recording and sampling procedures, (3)to discover operating problems with the unit, and (4)to attempt to duplicate the Bureau of Mines Run 222. Some pertinent operating conditions and results are shown in the table below. All of the tests were run at essentially the same shale mass flow rate of about 230 lbs/(Hr)(Ft^2). Bureau of Mines results are shown for comparison.

Test	Air, SCF/Ton	Yield, % FA	Spent Shale FA, gal/ton	Product °API
222D	3960	49.6	7.3	24.0
222C	3870	60.6	2.3	22.6
222G	3900	76.4	0.6	20.8
222B	3930	68.4	2.2	20.7
222H	3970	76.4	0.3	20.1
222F	4050	75.8	0.9	21.6
222F	4460	74.0	0.7	19.1
222E[1]	4710	84.0	0.2	21.4
BM 222	3750	94.0	0.3	20.7

As can be seen from examination of the table, the Bureau of Mines data was never exactly duplicated although the Fischer Assay yield was approached in one test. From the product gravity, it is apparent that "refluxing" occurred in some of the tests; this factor may have been due to uncertainties in the recycle gas rate as described later. Another fact which became apparent is that in order to generate similar temperature profiles and do a similar degree of retorting (as shown by spent shale Fischer Assay), higher air rates were necessary than those used by the Bureau. The reason for this is unknown.

Many minor operating problems and erroneous data recording procedures were encountered and corrected during the series. The most serious problem is that of leakage of gas from the bottom of the retort through the spent shale star feeder. The leakage rate appears to be variable and, therefore, causes uncertainties in the amount of recycle gas actually going up the bed as well as contributing to material balance losses. Attempts are continuing to measure the gas leakage and minimize it so as to eliminate the problem. Another problem is the possibility of low efficiencies in the mist recovery system as evidenced by appearance of oil in some of the vent gas samples which may have contributed to calculation of low yields in some tests. A program to evaluate the mist recovery system is now in progress. Heavy "clinkering" was also observed in some of the tests, possibly due to the temperature pattern created by the rocket air-gas distributor in the combustion zone. Attempts to improve air distribution are reported elsewhere in this Memorandum.

2. Bureau of Mines Run 334

The purpose of this series of tests was to reproduce the Bureau of Mines Run 334F, a run in which a 10% brine solution was used at a rate of 1.92 gallons per ton of raw shale.

The most significant results are given below:

	Bureau of Mines	Research Center		
	334F	334FA	334FB	334FC
Raw Shale Rate lb/(hr)(Ft^2)	299	272	283	278
Raw Shale Fischer Assay, % Vol.	26.7	28.6	27.8	28.8
Recycle SCF/ton Raw Shale	13,400	13,220	12,170	12,450
Air SCF/ton Raw Shale	4,270	4,580	4,400	4,480
Brine gal/ton Raw Shale	1.92	0.46	0.0	3.6
Yield, Vol. % FA	91.8	87.9	91.2	89.1
API Gravity	19.1	19.6	19.4	19.6
Overall Material Balance, % Wt.	98	101.7	97.9	98.1

As can be seen from the above data, the attempt to reproduce the Bureau of Mines Run 334F was successful concerning yield and gravity. It is also quite evident that at this level of operation, brine addition had little effect on these variables. However, later studies, which are currently planned, may show that brine is necessary to achieve satisfactory operation and yields under other operating conditions.

C. Performance of Peripheral Air Distributor (I. A. Jefcoat)

Purpose: This study was undertaken in order to evaluate the effectiveness of the new air distribution system installed in Retort No. 1 to give a more even temperature profile than that achieved with the Bureau of Mines rocket-type air distributor.

Description of Experiments: The capability of the retort to give satisfactory operation was investigated over a wide range of six variables. These included raw shale, air, recycle, and dilution gas rates, brine addition, and preheating of the inlet air stream. The range of each variable studied was: Raw shale, 260 to 780 lbs/(Hr)(Ft^2); Air, 4,000 to 6,000 SCF/T; Recycle, 9,000 to 21,000 SCF/T; Dilution Gas, 1,000 to 4,000 SCF/T; Brine, 1.03 to 1.89 gal/ton; and air-preheat, 1,480 to 1,695° F. Eight experiments were planned for the evaluation of the performance of the new air distribution system shown in Figure 1.

Discussion: A temperature profile was constructed for each experiment performed. Figure 2 shows a comparison between Bureau of Mines Run 331-A using the rocket type air distributor and the current Runs 401 and 408 using the peripheral air distributor shown in Figure 1. Runs 331-A and 401 were at mass shale rates of approximately 250 lbs/(Hr)(Ft^2) while Run 408 was at a shale rate of 500 lbs/(Hr)(Ft^2).

Inspection and comparison of the three temperature profiles shows that higher retorting temperatures were attained across the retort with the peripheral air distributor than with the rocket. These profiles demonstrate the effectiveness of the new air distribution system over the old.

Run 401 was conducted with all air ports open. Run 408 was conducted with ports 1, 3, 4, 6, 7, 9, 10, and 12 closed (See Figure 1).

The approximate recovery for 401 was 95% vol. Fischer Assay; 408 was 80% vol. Fischer Assay; and BM 331-A was 88.7% vol. Fischer Assay.

Recommendations: The following recommendations for operation with the new air distribution system are made based on visual observation of the performance of the retort and an analysis of the data obtained during test conditions.

1. The air rate should be 4,500 - 5,500 standard cubic feet per ton of raw shale.

2. The recycle gas rate should be 14,000 - 19,000 standard cubic feet per ton of raw shale.

3. The dilution gas rate should be 1,200 - 4,000 standard cubic feet per ton of raw shale.

Figure 1

POSITION OF AIR ENTRY PORTS FOR NEW AIR DISTRIBUTION SYSTEM

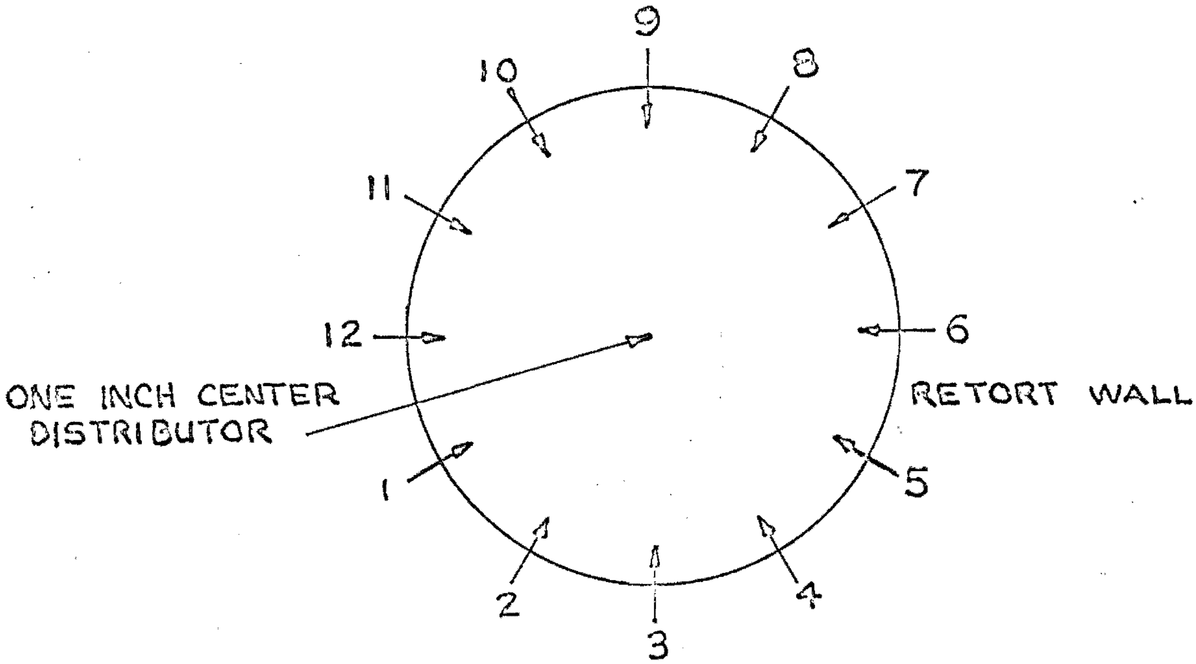
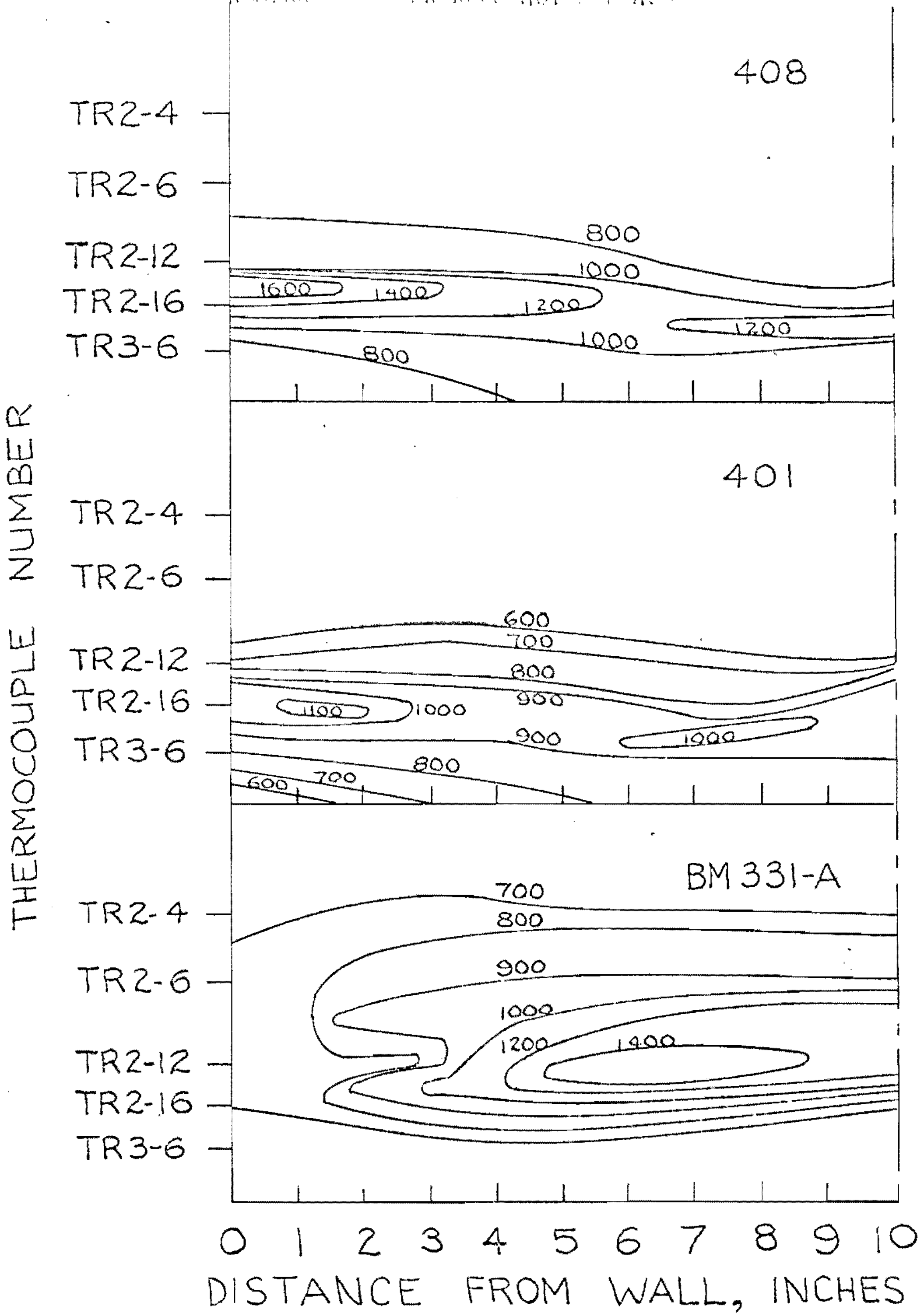


Figure 2

COMPARISON OF TEMPERATURE PROFILES AMONG BUREAU OF MINES RUN 331-A AND RESEARCH CENTER RUN 401 AND 408



4. The pressure drop across the air distributor should be approximately 15 inches of water.

5. The combustion zone should be approximately one foot above the air inlet or the bed height shortened by a foot.

A more detailed report is to be issued at a later date.

D. Mist Formation and Recovery (K. I. Jagel, Jr. and C. W. Tyson, Jr.)

Nucleation Study - The Bureau of Mines has concluded that brine addition does significantly improve oil yields and process operability in the gas combustion retorting process. An exploratory experimental program has been designed which is intended to either substantiate or refute this conclusion in a range of operating variables which are of current interest. The combination of variables chosen for the planned 16 run program is arranged as an interrelated group of factorial and fractional factorial experiments from which it will be possible to decide whether water or an aqueous salt solution has an effect on retorting yields. It will also be possible to evaluate the effect of shale mass velocity, total recycle rate and air rate on retorting yields within the range of operating variables chosen. As a part of this study the recently purchased jet-impactor will be used to evaluate the effect of these variables on mist size and mist recovery efficiency. The study is summarized below.

Nucleation Study

Run	Shale Rate lb/(Hr)(Ft^2)	Recycle Rate SCF/T	Air Rate SCF/T	Brine or Water Addition(1)
B1	500	18,000	6,000	B
B2	500	18,000	5,000	O
B3	500	16,000	6,000	O
B4	500	16,000	5,000	B
B5	300	18,000	6,000	O
B6	300	18,000	5,000	B
B7	300	16,000	6,000	B
B8	300	16,000	5,000	O
W1	500	18,000	6,000	O
W2	500	18,000	5,000	W
W3	500	16,000	6,000	W
W4	500	16,000	5,000	O
W5	300	18,000	6,000	W
W6	300	18,000	5,000	O
W7	300	16,000	6,000	O
W8	300	16,000	5,000	W

(1) B = 26.7 lb/T of 9.75% NaCl
W = 24.1 lb/T of H_2O
O = Brine

Raw Shale Properties
Fischer Assay 27 gal/ton
Mesh Size 1/4 - 1 inch

Dilution Gas Rate 0.4 SCF/SCF Air
Air Inlet Temperature 800 - 850° F
Bed Height Above Air Inlet 6 Feet

The above test series is currently in progress.

E. Mechanical Model Studies (T. C. Lyons and L. J. Skowronek)

The construction of the shale flow model is nearing completion and studies will begin shortly. The model consists of a plywood box (4 ft. wide x $1\frac{1}{2}$ ft. deep x 6 ft. high) with a plexiglass face to facilitate visual observation of the shale flow. It also includes a surge bin, several receiving hoppers, and a hoist for the batch circulation of shale. The initial efforts will be directed toward obtaining some basic data concerning the flow characteristics of raw and spent shale. This will include determining flow angles, coning heights, and bridging tendencies of various particle sizes in moving beds. One of the earliest objectives will be to develop a simple baffle system to improve the uniformity of shale flow in Retort No. 2 which is currently undergoing reconstruction.

A second model - for studying air and recycle gas mixing in shale beds - has been designed and is being fabricated. This model will be used to evaluate different distributor schemes in an effort to obtain uniform gas distribution throughout the shale bed. The first scheme planned for study will be the injection of air from orifices located in a horizontal run of pipe. The model will simulate a two-pipe section and will be constructed of plywood and plexiglass. Pipe to pipe spacing, orifice spacing, injection velocity (orifice size), and angle of injection into the bed will be studied. Smoke will be used as a tracer to determine the effectiveness of mixing (air with simulated recycle gas) and the uniformity of distribution (air throughout shale bed). In order to simplify the equipment required in the early studies, a static shale bed will be used.

Concerning the use of smoke, candles which produce a non-toxic, no-residue smoke are being considered. However, it will be necessary to make some preliminary studies to determine the most effective means of accumulating the smoke and controlling its flow to the model. Several candles of various colors have been ordered for this preliminary work.

In all of the model work, visual observation will be stressed. To assist in the analysis and to provide a record of our studies, movies will be taken wherever applicable. Therefore, a 16 mm. camera (capable of speeds up to 64 frames/second) and the necessary accessories such as lights, tripods, projector, etc. have been purchased.

IV. ANALYTICAL LABORATORY SECTION (B. L. Beck)

All of the currently required laboratory tests are now in operation. During the past month two carbon-hydrogen units were set up as well as a second apparatus for the determination of mineral carbon dioxide. Equipment for the laboratory distillation analysis of the crude shale oil is being assembled and ordered. Since the water-in-gas test appears to be more reasonably performed at the retort, the primary responsibility for this test has been transferred to the retort engineers.

Our efforts continue to go towards analyzing samples from the No. 1 Retort. A large portion of our time the past two weeks has been spent in reducing the back log of carbon-hydrogen analyses to practically zero.

A quality control program has been initiated. Samples for all of the tests involved have been prepared, and some initial data have been obtained.

We continue to write procedures for the tests as they are put into operation, and to revise earlier ones when required.

Starting approximately the first of October the graveyard shift for the laboratory technicians was eliminated, presently they are working in pairs Monday through Friday on the day and swing shifts.

V. ENGINEERING AND ECONOMIC ANALYSES

A. Engineering Analyses (P. W. Snyder)

1. Changes to Program

The combustion zone has been somewhat arbitrarily defined as the zone between the air inlet and where 90% of the oxygen is consumed. Several math model runs have resulted in 80 - 90% of the oxygen consumed at the top of the retort; therefore the top of the combustion zone is being redefined as where the rate of combustion becomes relatively small. C. W. Tyson suggested the following definition to achieve this based on his experience with defining breakout concentrations:
Top of combustion zone is where:

$$\frac{Fou_t - Fou}{Fou} = 0.1$$

Fou_t = Fraction of oxygen consumed from the air inlet to the top of the retort.
Fou = Fraction of oxygen consumed at any point in the retort.
This new definition has been programmed into the model.

A mass transfer mechanism is being studied and developed to simulate the refluxing of water in the top of the retort.

2. Comparison of Experimental Profiles With Those Calculated By The Math Model

a. Run 334F-C

The Bureau of Mines run number 334F was duplicated in the No. 1 Retort to verify our modification of the No. 1 Retort. This run has also been used as the standard for our math model development. As shown in Figure 3, the model appears to calculate a temperature profile which is a reasonable representative of the experimental temperatures. However, the experimental radial temperature distribution was very poor. The temperature varied 600° F radially in the combustion zone; therefore, it is difficult to draw any quantitative conclusions from the comparison of the temperature profiles.

b. Run 400B

A peripheral distributor was installed in place of the rocket distributor in order to improve radial temperature distribution after completing the demonstration runs. Although satisfactory radial temperature distribution was not obtained with this new distributor, a high yield period was obtained while attempting to improve radial temperatures at unusually high air and recycle gas rates. An attempt was made to duplicate these conditions with the math model. In order to achieve solution with the math model it was necessary to reflux 150 lbs. of water per ton and use 1-inch particles. No water was used in the experimental run and the effective particle size was 0.39-inches. In spite of these differences and the still uneven radial temperature distribution in the retort, the profile calculated by the math model shown in Figure 4 is reasonably similar to the experimental temperatures. The major differences are:

(1) The higher experimental offgas temperature. This difference will be reduced and perhaps eliminated when we get the program to converge without water addition.
(2) The higher experimental temperatures below the air inlet which are probably the result of consuming the 0.7 vol. % oxygen in the recycle gas below the air inlet - a zone where combustion is not programmed in the math model.

The reason for the math model not being able to converge on a solution for very small particle size and without water is being studied. The program will be corrected as soon as this reason can be established.

3. Process Variable Study

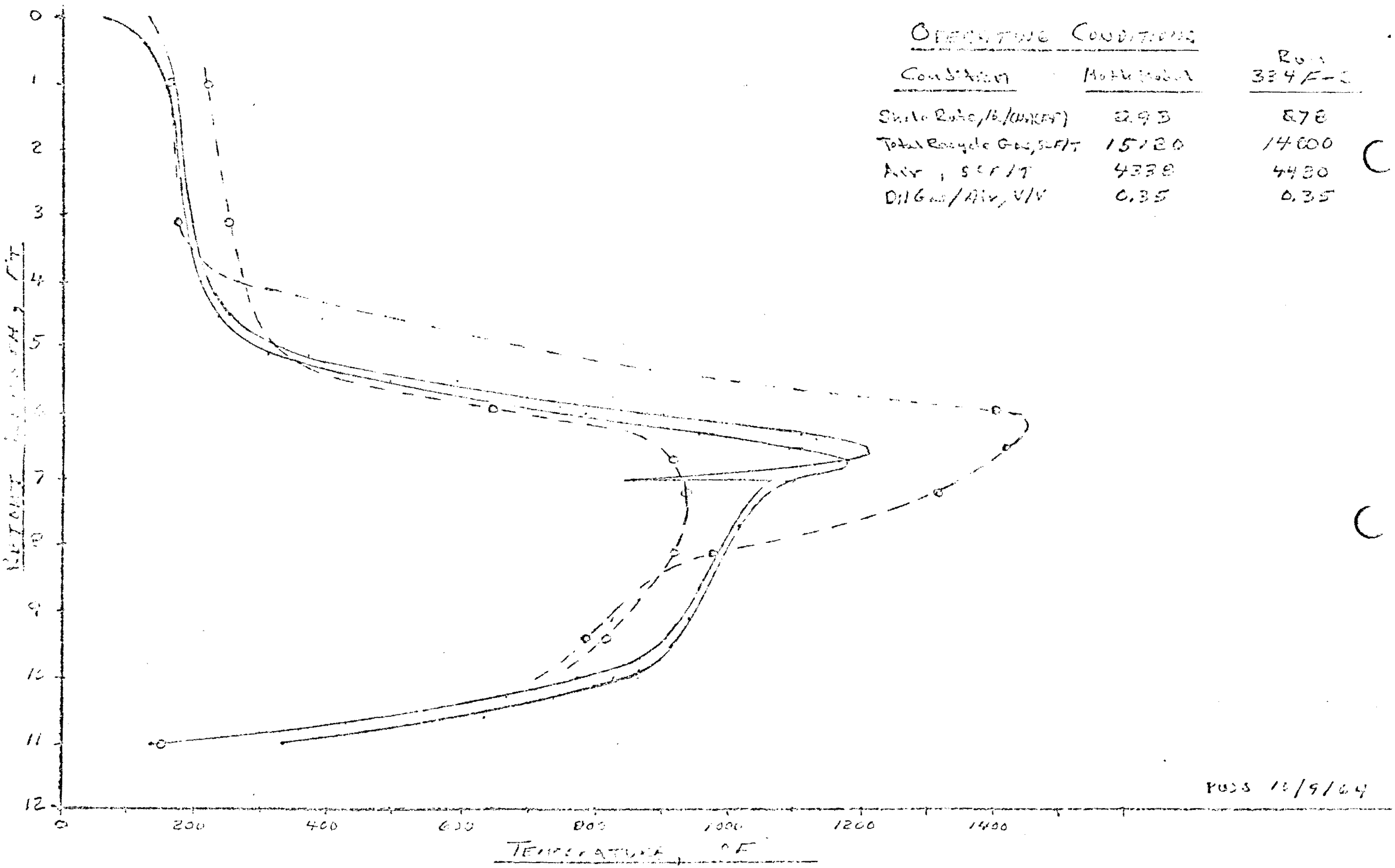
The effect of air rate and recycle rate on retort condition when operation at 500 lbs/(Hr)(Ft^2) have been calculated with the math model. These results are shown in Figures 5 through 7. The main observations are:

(1) Air rate and recycle rate do not significantly affect offgas temperature - it appears to be controlled primarily by the water dew point.
(2) Increasing recycle gas rate slightly reduced gas cooling rate while increasing air rate increased it.
(3) The fraction of oxygen used to burn coke increases with increasing air and recycle gas rates.
(4) Peak shale temperatures were relatively unaffected by air and gas recycle rates.
(5) Peak gas temperatures decreased with increasing air and recycle rates. This was probably due to the increase in the length of the combustion zone with increasing air and gas recycle rate.
(6) Spent shale temperature is controlled primarily by the gas recycle rate.

Figure 3

MATH MODEL TEMPERATURE PROFILE VS MEASURED PROFILE FOR RUN 334F-C

——— Mathematical Model
O – Measured Temperature for 334F-C at 3-inches in from wall
⊙ – Measured Temperature for 335F-C at 6-inches in from wall



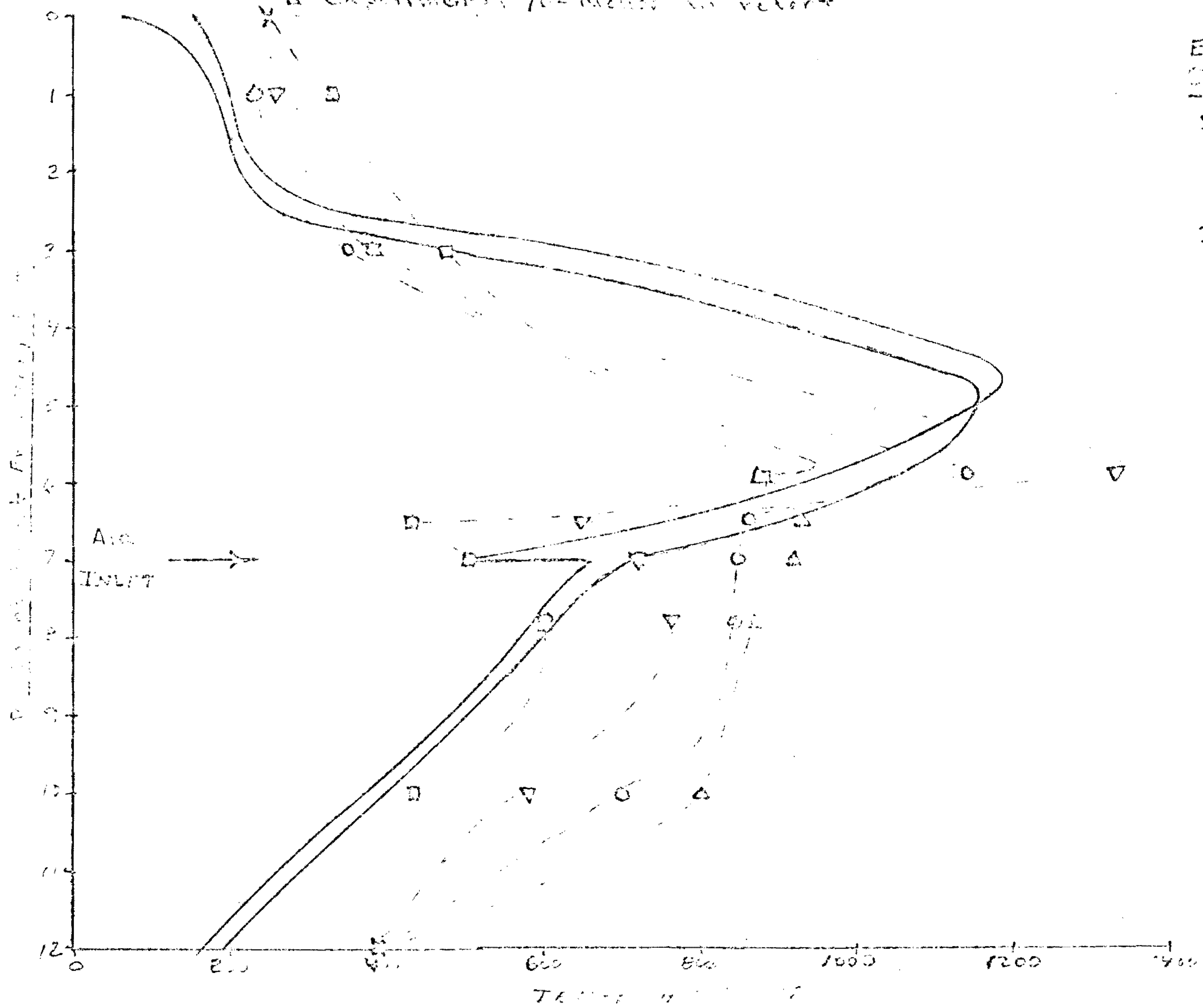
OPERATING CONDITIONS

Condition	Math Model	Run 334F-C
Shale Rate, lb/(Hr)(Ft²)	293	278
Total Recycle Gas, SCF/T	15120	14600
Air, SCF/T	4338	4480
Dil Gas/Air, V/V	0.35	0.35

Figure 4

MATH MODEL TEMPERATURE PROFILE VS MEASURED PROFILE FOR RUN 400B

—— Math Model calculations; X - experimental outlet temperature
O - experimental 6-inches in retort   ∇ - experimental 4½-inches in retort
□ - experimental 1½-inches in retort
Δ - experimental 10-inches in retort



Experimental Operating Conditions

Shale Rate : 522 lb/(hr)(ft²)
Recycle Gas : 19,700 SCF/T
Air : 5950 SCF/T
Diluting Gas : 4000 SCF/T

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Figure 5

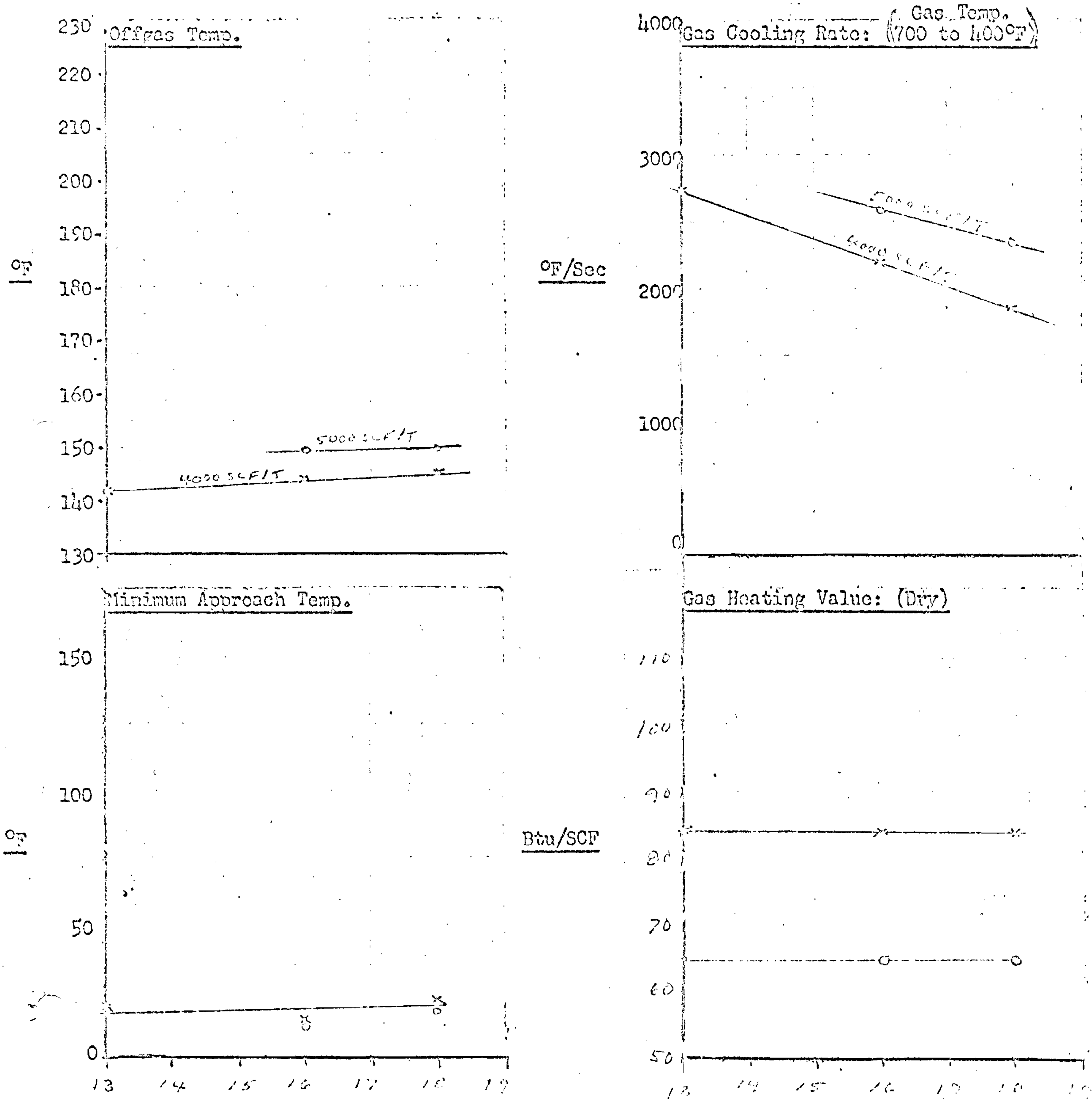
MATHEMATICAL SIMULATION

EFFECTS OF PROCESS VARIABLES ON CONDITIONS IN THE MIST FORMING ZONE

etort Height – 13 ft | Shale Part. Size – 1-inch | Tot Recycle Gas 13 – 18,000 SCF/T
ir Inlet to Top – 6 ft | Shale Rate 500 lbs/(Hr)(Ft²) | Air Rate 4000 & 5000 SCF/T
nter Rd. & Reflux – 45 lbs/T | Raw Shale Temp. 60 | Dil. Gas/Air 0.4 V/V
 | Air-Dilution Gas Temp. ambient |

EFFECT OF GAS RECYCLE RATE

(Runs 31, 32, 33, 34 & 35)



TOTAL RECYCLE GAS M SCF/T

RWS 10/7/68

Figure

MATHEMATICAL SIMULATION
EFFECT OF PROCESS VARIABLES ON CONDITIONS IN COMBUSTION ZONE

...tort Height - 12 ft	Shale Part. Size - 7-inch	Tot Recycle Gas
...ir Inlet to Top - 6 ft	Shale Rate - 500 lb/(hr)(ft²)	Air Rate
...ter Rd. _ Reflux. - 45 lb/ft	Raw Shale Temp, 60°F	Dil. Gas/Air
	Air-Dilution Gas Temp, ambient	

EFFECT OF GAS RECYCLE RATE
(Runs ...)

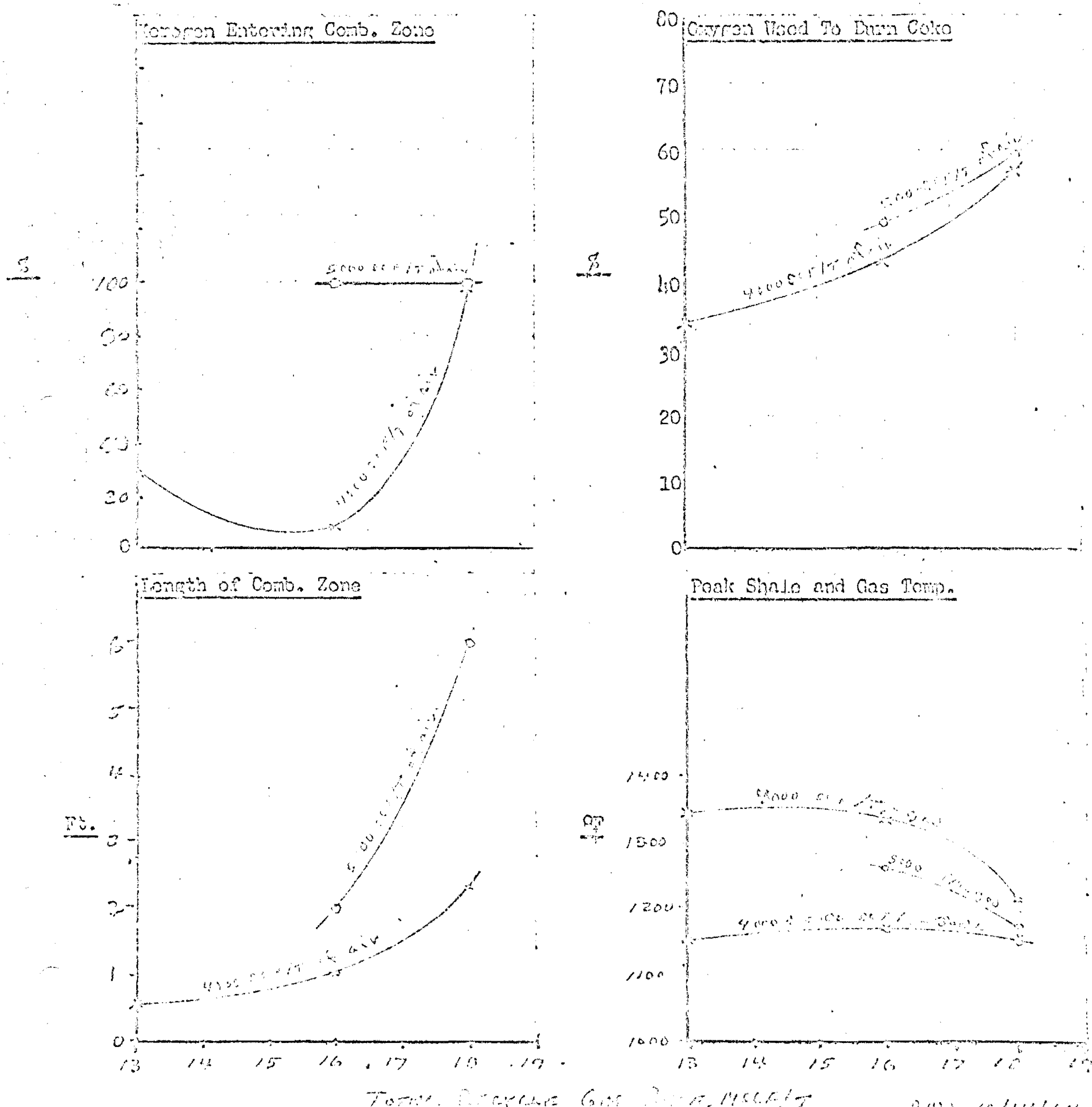


Figure 7

MATHEMATICAL SIMULATION

EFFECTS OF PROCESS VARIABLES ON CONDITIONS IN THE SHALE COOLING ZONE

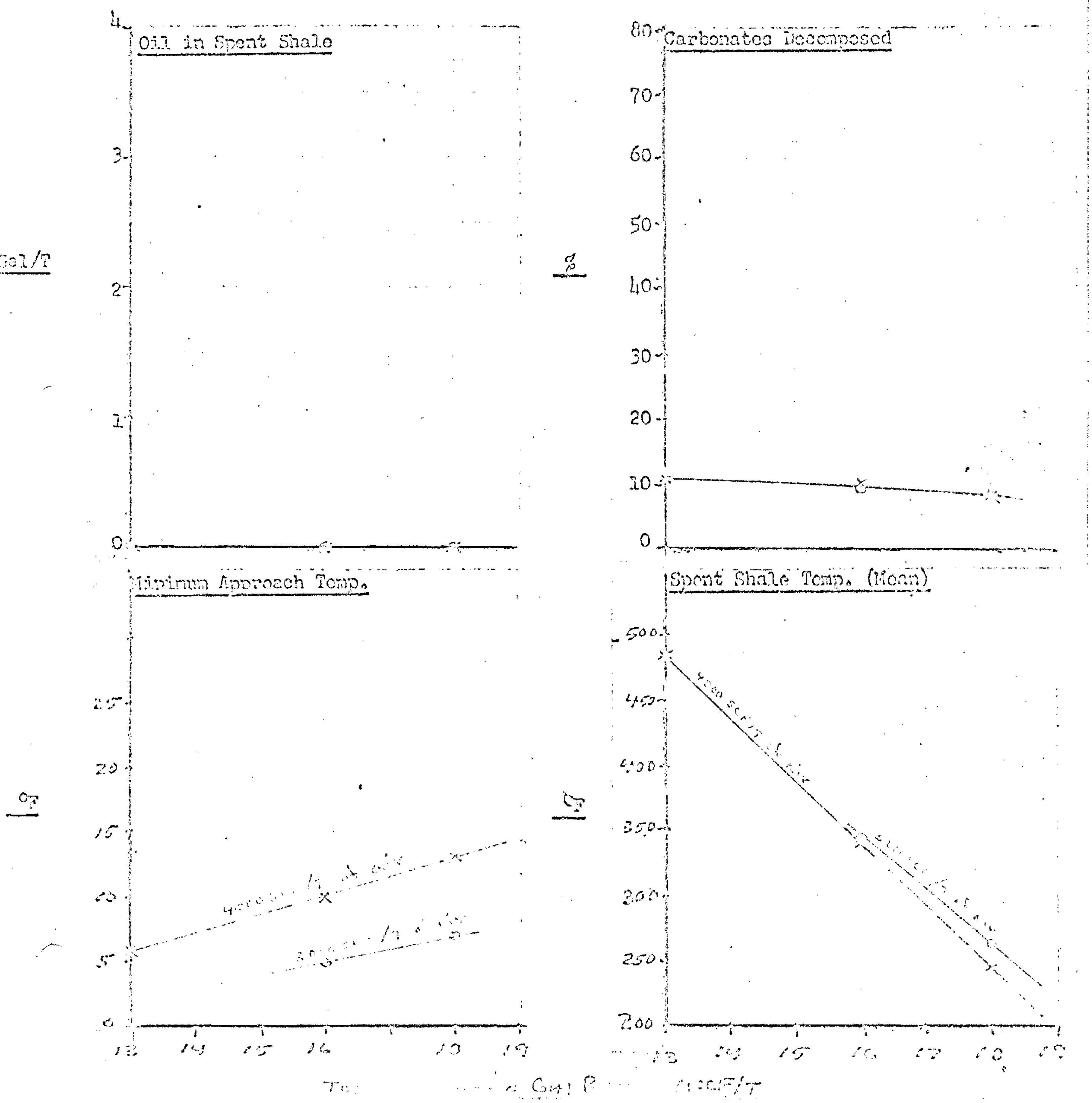
etort Height - 12 Ft
ir Inlet to Top - 6 Ft
ate dd. & Reflux - 45 lbs/T

Shale Part. Size
Shale Rate
Raw Shale Temp. - 60 °F
Air-Dilution Gas Temp.

Tot Recycle Gas
Air Rate
Dil. Gas/Air - 0.4 V/V

EFFECT OF GAS RECYCLE RATE

(Runs 31, 32, 33, 34, 435)



B. Economic Analyses (J. E. Burchfield)

1. Effect of Changes in Bases on Retorting Costs

Earlier economic analyses developed the cost of shale oil as a function of mass rate and yield. These costs are being used to guide retort development work currently underway. At this early stage some of the bases require further development, hence the sensitivity of shale oil costs to changes in the bases is of interest. Sensitivity effects on costs have been calculated for changes in costs of mining (shown in last months progress report), investment, operating costs, cost of money (interest rate) and project life. These effects are shown in the attached Figures 8, 9, 10, 11, and 12. Figure 8 which was also shown in last months progress report has been included again for comparison. Figure 9 shows the effect of increasing retorting operating costs by 10% over the base. The increase in shale oil cost is in the range of 2 - 3¢/Bbl for extreme ranges of mass rate and yields. Figure 10 shows the reduction in retorting cost when project life and depreciation are extended from 15 years to 20 years. Again the effect is small, in the range of minus 0.8 - 1.8¢/Bbl over extreme ranges of mass rate and yield. Figure 11 shows a more significant effect for increasing the cost of money from 10% to 12% D.C.F. rate of return on investment. The higher cost of money increases retorting cost by 2.5 - 3.0¢/Bbl of shale oil at high mass rates and by 4.5 - 5.5¢/Bbl of shale oil at low mass rates. Figure 12 shows the effect of increasing investment by 10%. Retorting costs are increased by 1.5 - 3.3¢/Bbl.

As shown above, changes in the above bases result in relatively small changes in the cost of shale oil, and their effect on economic optima in guiding retort development is even smaller. This happens because a change in bases increases cost for the base condition just as it increases cost for any other given condition. Hence, the differential cost change is very small. Thus if Figure 8 is adjusted for any of the above changes in bases the slopes and intercepts will change only slightly. The differences between the yield curves will be affected a negligible amount.

The likelihood of all adverse factors compounding together to increase shale oil costs is an extremely remote possibility. However, it may be interesting to see how much costs might be influenced by the unlikely combination of all adverse factors. The opposite effect, i.e. the extent of shale oil cost reduction from the unlikely combination of all favorable factors, may also be interesting. Therefore the following Table 1 has been calculated which compares the "worst" case costs with "best" case costs in each case over the established base case noted. The net change for the "worst" case is the result of changing the following factors from the base case:

- Mining cost increased 10%
- Crushing cost increased 10%
- Retort gas value decreased 10%
- Retort investment increased 10%
- Retort operating costs increased 10%
- Yield decreased from 90 to 75%
- Rate of return increased from 10 to 12%
- Project life and depreciation remains 15 years
- Mass rate remains 230 lbs/(Hr)(Ft^2)

The net change for the "best" case is the result of the following factors:

- -Mining costs decreased 10%
- -Crushing costs decreased by 10%
- -Retort gas value increased by 10%
- -Retort investment decreased by 10%
- -Retort operating cost decreased by 10%
- -Rate of return remains at 10%
- -Project life and depreciation increased to 20 years
- -Mass rate increased to 800 lbs/(Hr)(Ft^2)
- -Yield increased from 90 to 95%

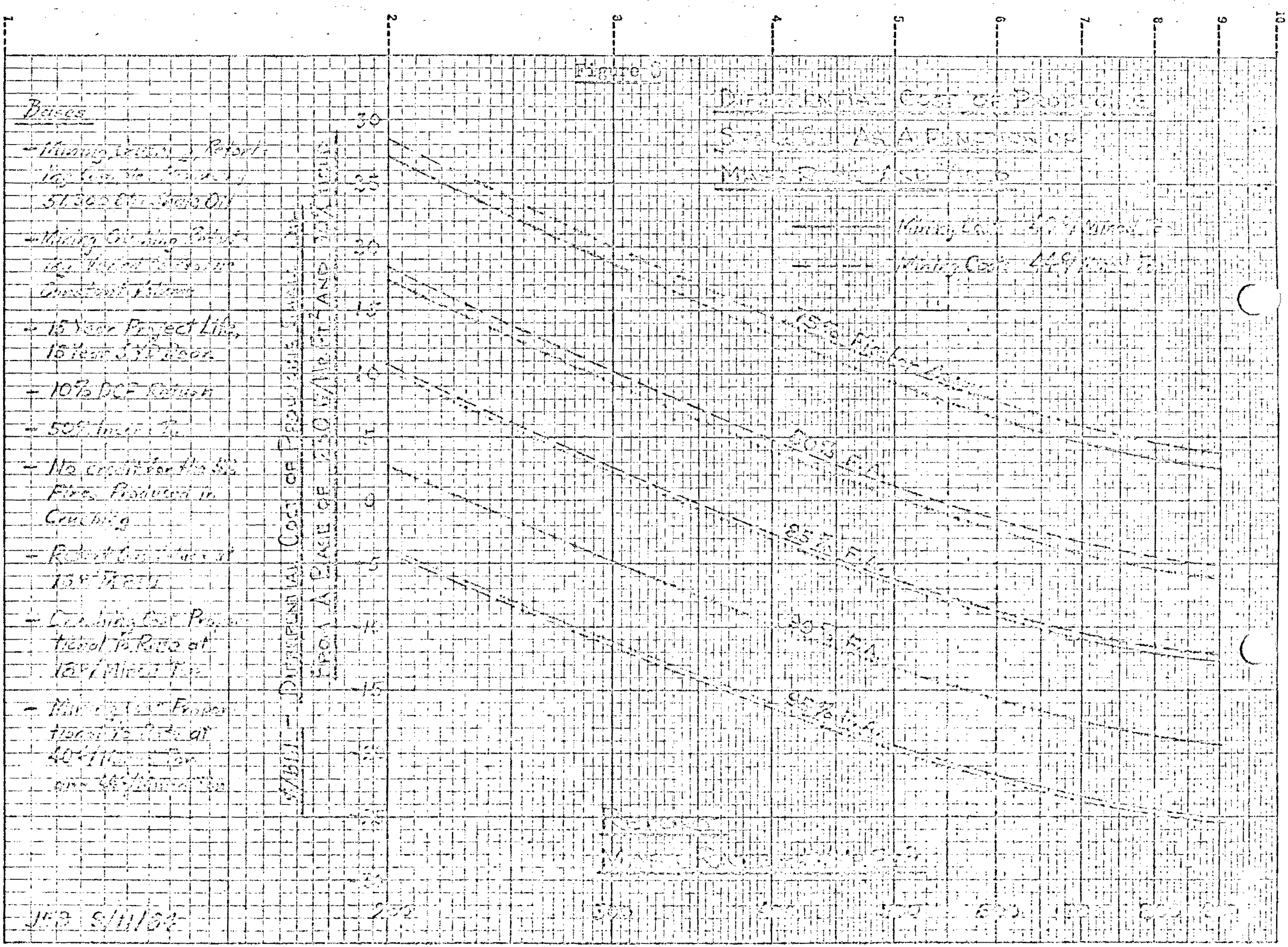
In each case all factors are compounded.

In the "worst" case mining costs show the largest increase. This is the result of higher cost per ton plus more tons/barrel of shale oil required because of reduced yields. In the "best" case the 20¢/Bbl decrease for retorting is due to lower investment and operating costs per unit throughput.

Both cases shown are extremely unlikely cases and represent in all probability the outside limits of shale oil costs. The cost change is about ± 30% from the calculated base shale oil cost.

2. Crushing Costs

More detailed cost analyses are currently underway on crushing. The estimated effect of particle size on power costs and total costs will be investigated. An earlier preliminary estimate of crushing cost indicated it is in the range of 16 - 19¢/Ton crushed.



Figure
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Mining Cost
Bases
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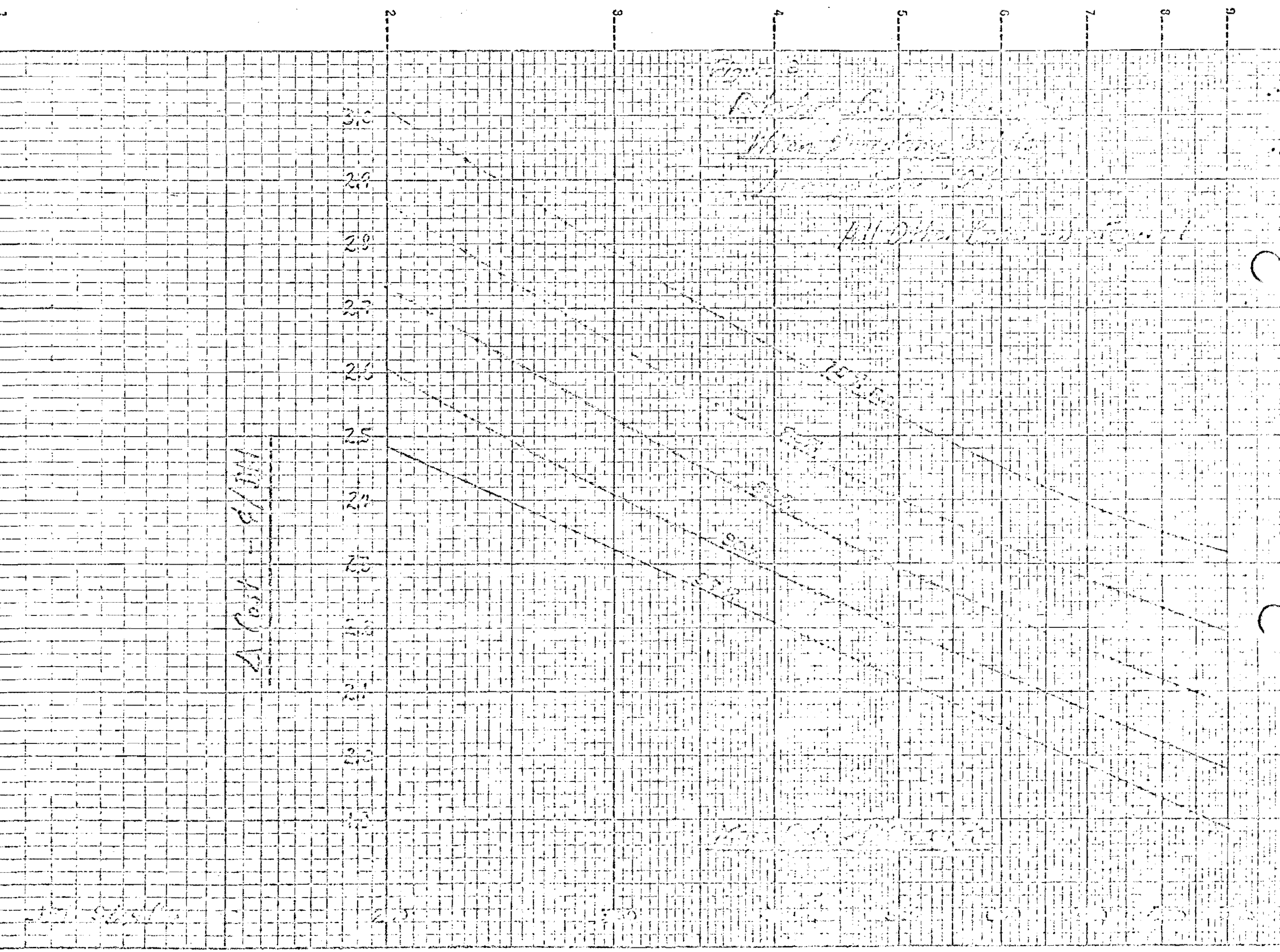

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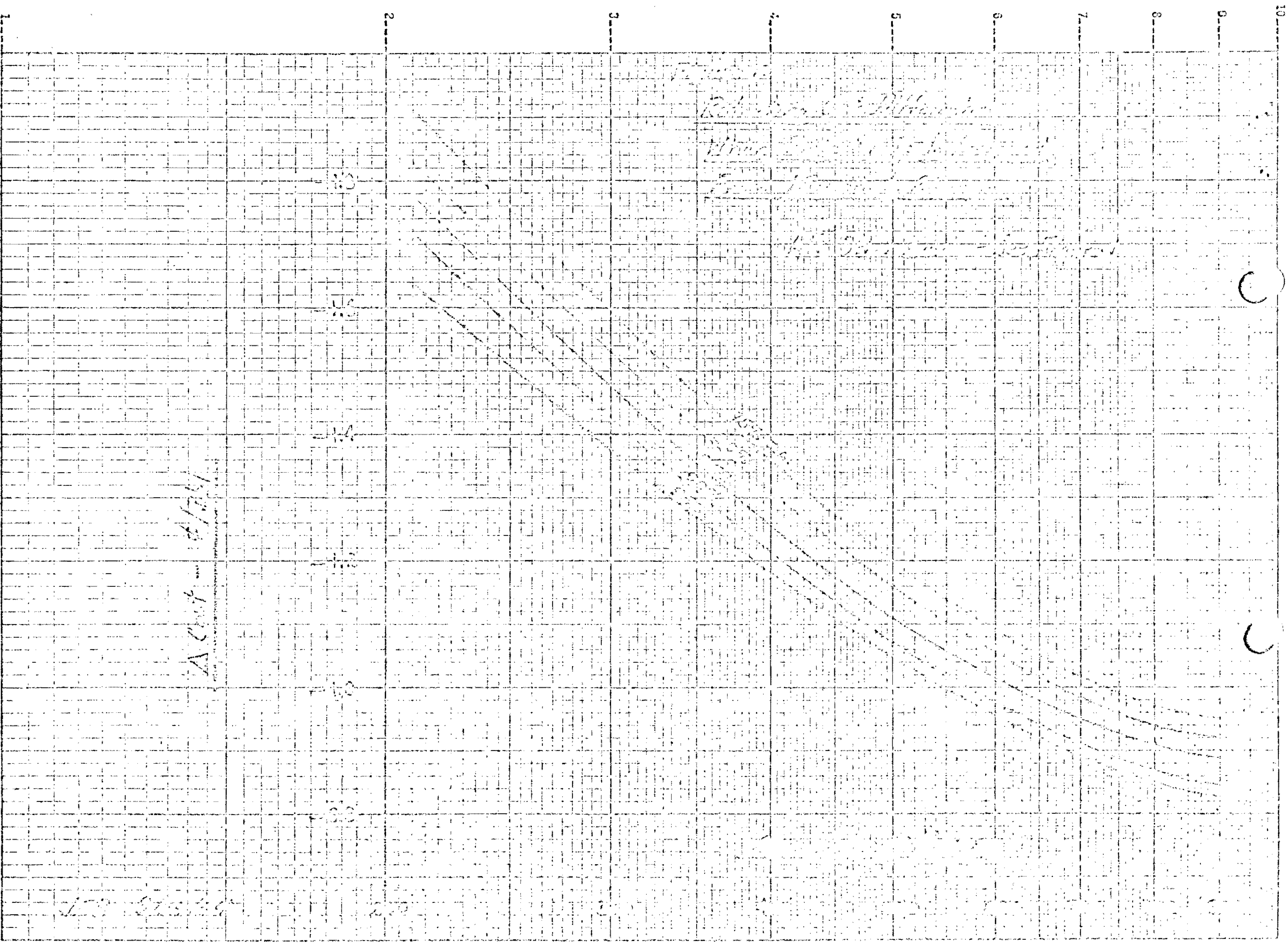

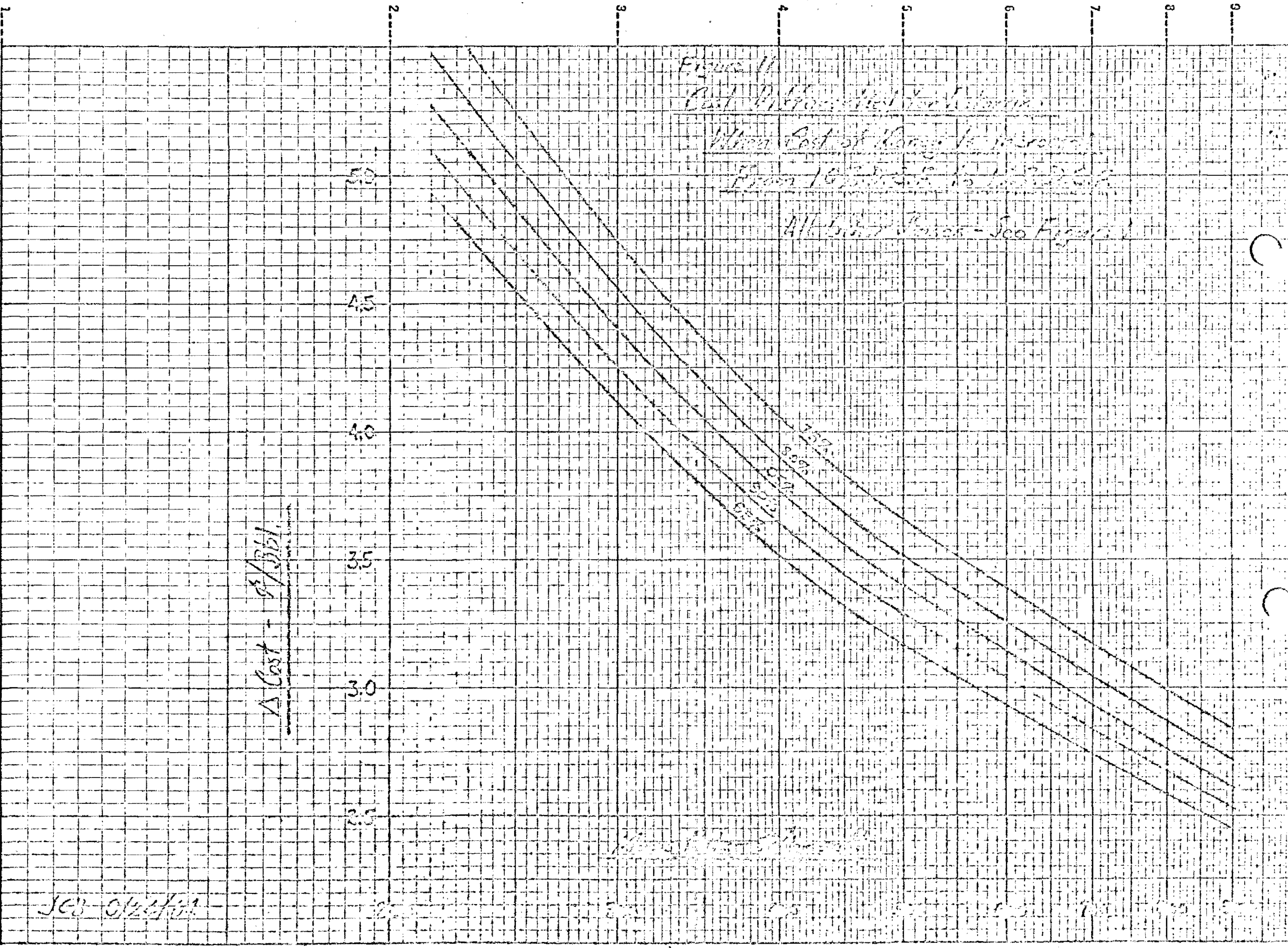
Figure 11
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Δ Cost - $/BBL

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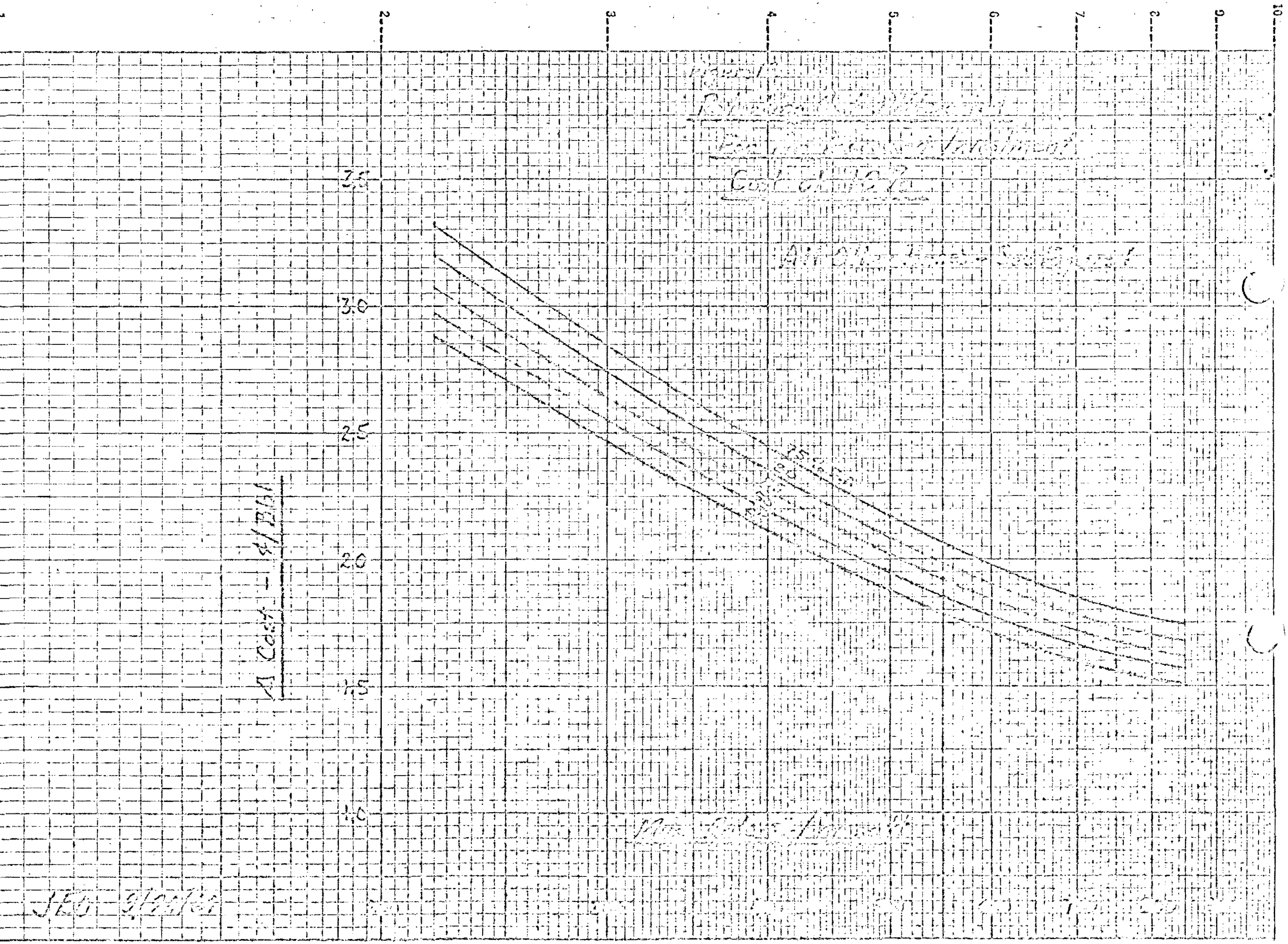

TABLE 1

RANGE OF SHALE OIL COSTS FOR MULTIPLE COMPOUNDED CHANGES OF BASES

	Base Conditions (1)	"Worst" Case (2) Case Condition	"Worst" Case (2) Incr. Cost ¢/B	"Best" Case (3) Case Condition	"Best" Case (3) Incr Cost c/B
Mining	40¢/T	44¢/T	+21.0	36¢/T	- 9.7
Crushing	18¢/T	+10%	+ 9.4	-10%	- 4.3
Retorting Gas Credit	16¢/MBtu	-10%	+ 0.9	+10%	- 1.7
Retorting	(1)	(2)	+ 7.4	(3)	-20.0
Investment	(1)	+10%	+ 0.4	-10%	- 1.4
Operating Cost	(1)	+10%	+ 0.4	-10%	- 0.6
Rate of Return, %DCF	10%	+2%	+ 0.7	-	-
Project Life, Yr.	15	-	-	20	- 0.8
Total - Net Change in Cost From Base Cost			+40.2		-38.5

(1) Base conditions 230 lb/(Hr)(Ft^2), 90% Yield
(2) "Worst" case conditions 230 lb (Hr)(Ft^2), 75% Yield
(3) "Best" case conditions 800 lb/(Hr)(Ft^2), 95% Yield