ENGINEERING FACTORS RELATING TO THE UTILIZATION OF THE CANNEL COALS OF SOUTHERN UTAH

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by

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and
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Approved by

THE GREAT WHITE THRONE
showing the
Geological Members Contiguous to the Cannel Coal Measures

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INTRODUCTION

The cooperative investigations of the State of Utah with the Federal Government, during the years 1919-1924, proved that Utah contains a number of very important bodies of carbonaceous materials offering excellent opportunities for producing desirable new solid fuels, oil products and gas, and thereby add new wealth to the State. Published data(1) by the investigators are comprehensive, but it is probable that the commercial significance of these researches have not as yet been fully appreciated by the Utah public, otherwise commercial uses of the results of these investigations would undoubtedly have been applied.

Utah contains the largest area of oil shales of any state, and Gavin[2] and Karrick[3] have shown that oils of high quality can be produced from these shales, also that Utah possesses a resource in this deposit amounting to 30 billion barrels of oil. Schmutz[4] has analyzed the economic factors affecting the production

(1) References made to the published data will be found in the bibliography at the end of this report.

of oils from Utah's oil shales and coals, and he brings out the fact that the coals contain 150 billion barrels of oil, also other products. Larsen and Stutz[5] have recently studied factors relating to the design and operation of a low-temperature carbonization plant and refinery contemplated for Carbon County, Utah to produce oils, gas, power and smokeless fuels from the major coal bodies of the State. The researches of Karrick[6] offer many reasons why a large coal-products industry should be established in Utah. Speiker[7] reports that the oil sand (rock asphalt) deposit at Vernal, Utah is probably the residue of a large paraffin-base oil field, its present magnitude being nearly four billion barrels of heavy oil. This oil has now been demonstrated to be an excellent road oil for gravel-mulch surfacing, or it may be cracked into gasoline, deisel oil, and road oil for Utah markets. Brighton[8] has reported on the many types of hydrocarbons occurring in the large bodies in Uinta Basin. Also, Allen[9] and Richardson[10] have reported briefly on the existence of a large body of cannel coal near Cedar City in Southern Utah, it being the only body of this type reported in the far western part of the United States.

The latter deposit of cannel coal has been selected for this thesis investigation since the published data regarding the deposit are meager and there have been no useful data published heretofore on the engineering and economic factors regarding the usefulness of this deposit of coal for fuel and for the manufacture of desirable commodities for the Southern Utah markets. Therefore, in our study we have carefully studied the sources of information regarding the cannel coals of the United States,[11] and have herein presented for the most part the results of our engineering experiments to determine the heat requirements and mechanism of distilling this cannel coal for oils and gases, also our observation as to the burning and handling properties of this remarkable coal.

CANNEL COAL

Ashley[11] states that, "Cannel coal is a massive, non-caking, tough, clean, block coal of fine, even, compact grain, dull luster, commonly conchoidal cross fracture, having a low fuel ratio, a high percentage of hydrogen, easy ignition, long yellow flame, black to brown greasy streak, and moderate ash, which is pulverent in burning. It is essentially a rock derived by solidification and partial distillation or oxidation of water-laid deposits consisting of or containing large quantities of plant spores and pollen grains and more or less comminuted remains of low orders of water plants and animals".

David White,[12] in writing about his microscopical study of the Utah cannel coal, says, "The fuel contains very little if any vestiges of the cell structures of higher plants, being made up largely of lemon-yellow, more or less lenticular, or globular, translucent bodies embedded in a brownish black groundmass of somewhat flocculent aspect. Some of the translucent matter is probably resinous, while it is possible that some of the lemon-yellow substance, less in quantity may be gelatinous, though that is not at all certain. On the whole, the microscopical composition of the coal is essentially that of a high-grade cannel."

It is generally accepted that bituminous coals resulted from woody materials whereas cannel coals appear to have been formed from decayed spores, pollen, leaves and the cuticle material from plants, thus these waxy ingredients account for the high oil yield which is possible from most cannel coals, being usually two to three times the yield from bituminous coals. The same organic constituents are largely responsible for the oil obtainable from oil shales.

Cannel coal is adapted to the common uses of bituminous coals excepting coke manufacture. It is especially an ideal fireplace fuel and for a long period has been accepted as a "deluxe" fuel for this purpose. It is very clean to handle, attractive in appearance, ignites very easily, gives a cheerful, large, bright, orange colored flame, and the ash is in pulverent form. It burns without disintegration and therefore does not yield as much smoke as the common high volatile bituminous coals, thus making for a very popular domestic fuel.

Because of the high volatile content and high candle power of the volatiles, cannel coal has been in use extensively in former years in the eastern United States for coal gas enrichment. In the early days in Utah cannel coals and oil shales were imported from Australia for use in the first gas plant to increase the candle power of the city gas. The principal use of cannel coal in the United States in past years was for the production of oil for refining into the common oil products. As early as 1846 oil was manufactured from coals and in the year 1860, when the first real discovery of petroleum occurred, there were fifty five coal-oil plants operating in the United States, the largest having a distilling capacity of six thousand barrels of oil per day. Kerosene (coal-oil), light lubricants, greases, and wax were the principal refined products, gasoline having no market value at the time. Most of the plants were in Pennsylvania, Kentucky, and West Virginia although one large plant was in Boston. The principal cannel coal deposits are in Pennsylvania, Kentucky, West Virginia, Indiana, Ohio, Tennessee, Missouri, Iowa, Arkansas, Texas and Utah.

UTAH'S CANNEL COAL DEPOSIT

Utah's cannel coal deposit in the Kolob Coal Field, is shown in Figure I to be in the Zion Canyon-Cedar Breaks area, forty miles by road from Cedar City, and occurs mostly in townships 39 and 40 South, Range 9 West. The deposit is now readily reached by road from the Cedar Breaks highway, and it is probable that another road will soon be completed so as to serve the deposit from the Mt. Carmel Highway. The cannel coal crops along the north Fork of the Virgin River in Straight Canyon and is reported to out-crop also in Orderville Gulch, to the south, a tributary to the Virgin River. Richardson[10] reports the seam at both locations to be five feet six inches thick.

The writers inspected the deposit in September 1932 and found the exposed body in Straight Canyon to measure four-feet eight-inches thick overlain with thirty-one inches of sub-bituminous coal and resting upon twenty-four inches of sub-bituminous coal. The bed is substantially horizontal with a slight dip to the northwest. Many other out-crops of the seam were noted and it is probable that the cannel coal extends through much of the

FIG. 1
LOCATION OF
UTAH'S CANNEL COAL DEPOSIT
AND THE
SURROUNDING NATIONAL PARKS AREA

SCALE:- 1" =15 MILES

indicated area in Fig. I. In all probability 500,000 tons of the coal can be mined along the out-crop with steam shovels without the necessity of mining under ground. Fortunately cannel coal does not deteriorate measureably more than an inch or so back from the out-crop and is much like oil shale in this respect. The overlying sub-bituminous coal has, however, weathered for a considerable distance back from the out-crop and will have to be discarded.

There is ample flow of water in the river adjacent to the coal to support a town, also a mining and manufacturing operation. An abundance of nearby timber is available and a number of small sawmills are operating in the locality where mine and camp lumber can be obtained. Deer, trout, and beautiful scenery abound. It is suggested that a "Utah Engineers Summer Camp" (U-Dude Ranch) be developed at the mine site together with a model coal mine and coal-products refinery to become an income asset to the Utah Research Foundation.

This cannel coal occurs in the lower cretacious rocks and may be found in the coal measure about 160 feet below a white sandstone stratum which stands out prominently throughout the area. Also the coal is 100 feet above the conglomerate at the base of the cretacious formation.

A 500-pound sample of the cannel coal was obtained from the deposit which unfortunately was not a true average of the seam but it is believed to be adequately representative of the deposit to suffice for this investigation. Chemical analyses of this sample and other reported analyses on the air-dried basis are as given in Table I.

TABLE I

Proximate	Richardson[10] Top 2 Ft.	Lower 3½ Ft.	Allen[9] Average	Thesis Sample Grab Sample
Moisture	11.77	6.32	-----	4.1
Volatile Matter	43.89	47.45	-----	51.7
Fixed Carbon	29.32	22.73	-----	22.3
Ash	15.02	23.50	22.2	21.9
Sulphur	1.38	1.63	-----	1.78
Ultimate				
Ash	15.02	23.50	-----	-----
Sulphur	1.38	1.63	-----	1.78
Hydrogen	5.87	6.13	-----	-----
Carbon	54.41	52.46	-----	-----
Nitrogen	1.21	1.07	1.30	-----
Oxygen	22.11	15.21	-----	-----
Calories	5,531.00	5,817.00	-----	5,495.00
B.T.U.	9,956.00	10,470.00	-----	9,860.00
Bbls. oil	-----	-----	68.8	65.00

OBJECT OF PLANT TESTS

In the visit to the cannel coal deposit in 1932 information was obtained by the writers showing that the coal deposit was sufficiently extensive and accessible to large markets by truck and rail to justify its early development. This was particularly so in view of the recent completion of the Cedar Breaks and Mt. Carmel highway to the north and south of the deposit leaving only a few miles of private roads to be completed. It was also concluded that because of the pronounced superiority of this coal as compared with all other local coals for domestic fuel and as a source of road oil and motor fuel for the National Parks area shown in Figure 1, that a need existed and an impetus could be given the development of this Utah resource if a study were made of the processing of the slack coal from the deposit. Consequently a study was planned of the heat requirements in treating this coal as well as an investigation of the products formed.

Advantage was taken of the studies made of this coal in 1920 by the State of Utah and the Federal Government in which laboratory processing data were obtained[9] and by which excellent yields and quality of oil were obtained. The destructive distillation method used steam as the heat transferring fluid, the exhaust steam from power plant engines or turbines being superheated and then passed directly through bodies of sized, dust-free, coal. This method(13) had subsequently been developed(5) for commercial uses and appeared to have many advantages, so it was adapted for the thesis study of the cannel coal. In designing the test apparatus the primary objects were to minimize radiated heat losses under all processing conditions and then take temperatures and heat-flow data throughout the coal charges and the apparatus, thus permitting a correlation of products obtained with the most economical use of heat.

This coal treating method used is one of a group being offered to the Utah Research Foundation.

DESCRIPTION OF APPARATUS

For the purpose of carrying out this investigation, a small distilling plant was constructed. Figures 2 and 3 are, respectively, a schematic plant layout and a photograph of the test set-up.

The plant, Figure 2, consisted of a gas fired superheater (a), a coal retort (b) and the condensers (c), (d) and (e).

The combustion chamber (f) of the superheater was constructed of common brick. Heating gas was supplied from the gas line through the control valve (g) and was measured in meter (h). The manometer (i) provided the operator with an instantaneous sight control of the volume of gas delivered to the two burners. These burners consisted of the nozzles (j) and the air and gas mixing tubes (k).

Above one end of the combustion chamber and supported from the wall by means of a bracket, was the steam superheating coil consisting of approximately one hundred feet of ½" standard pipe formed into a coil fifteen inches in diameter and forty-eight inches high. This coil was hung in the annular space between the

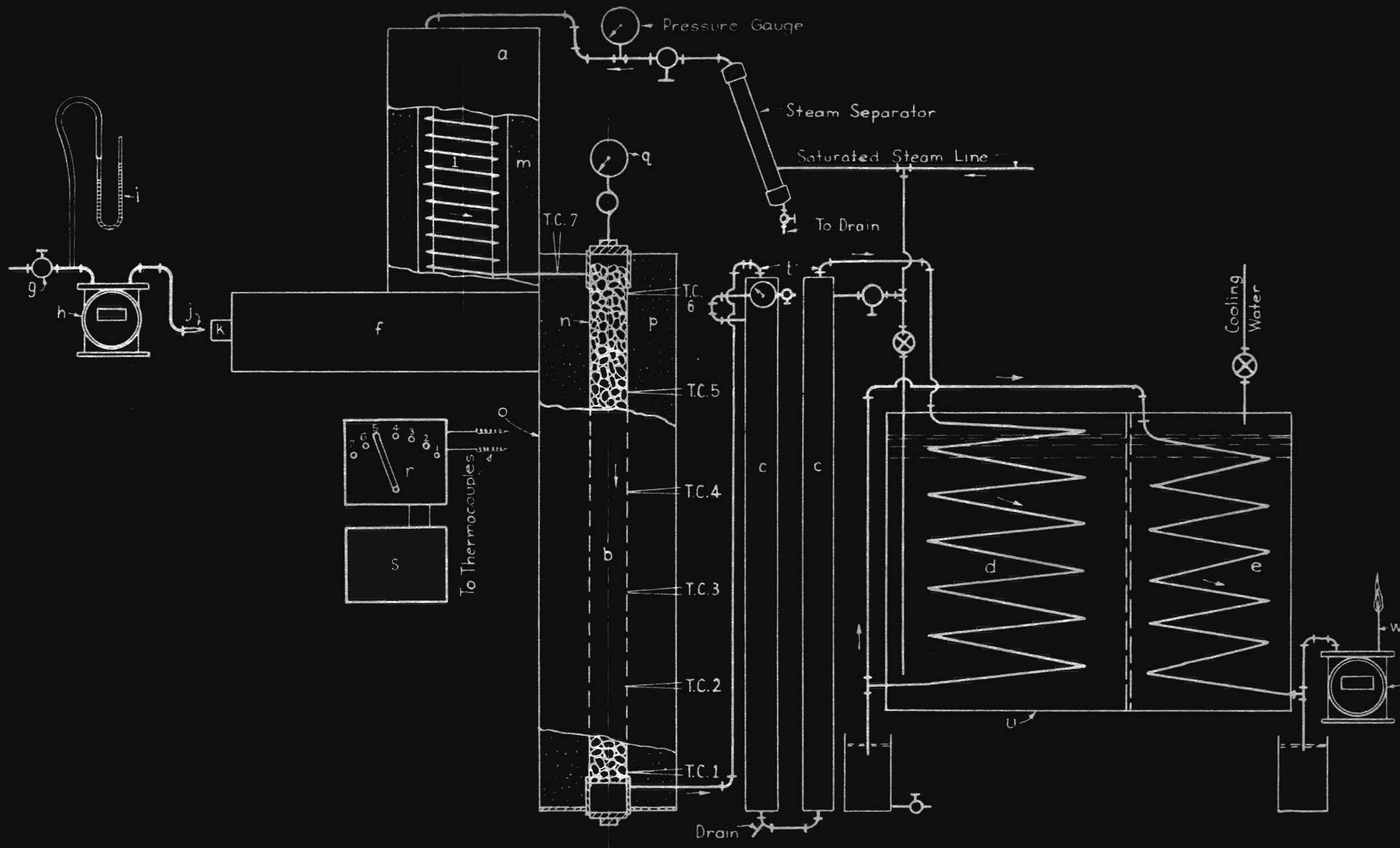


Fig. 2

SCHEMATIC LAYOUT OF TEST PLANT

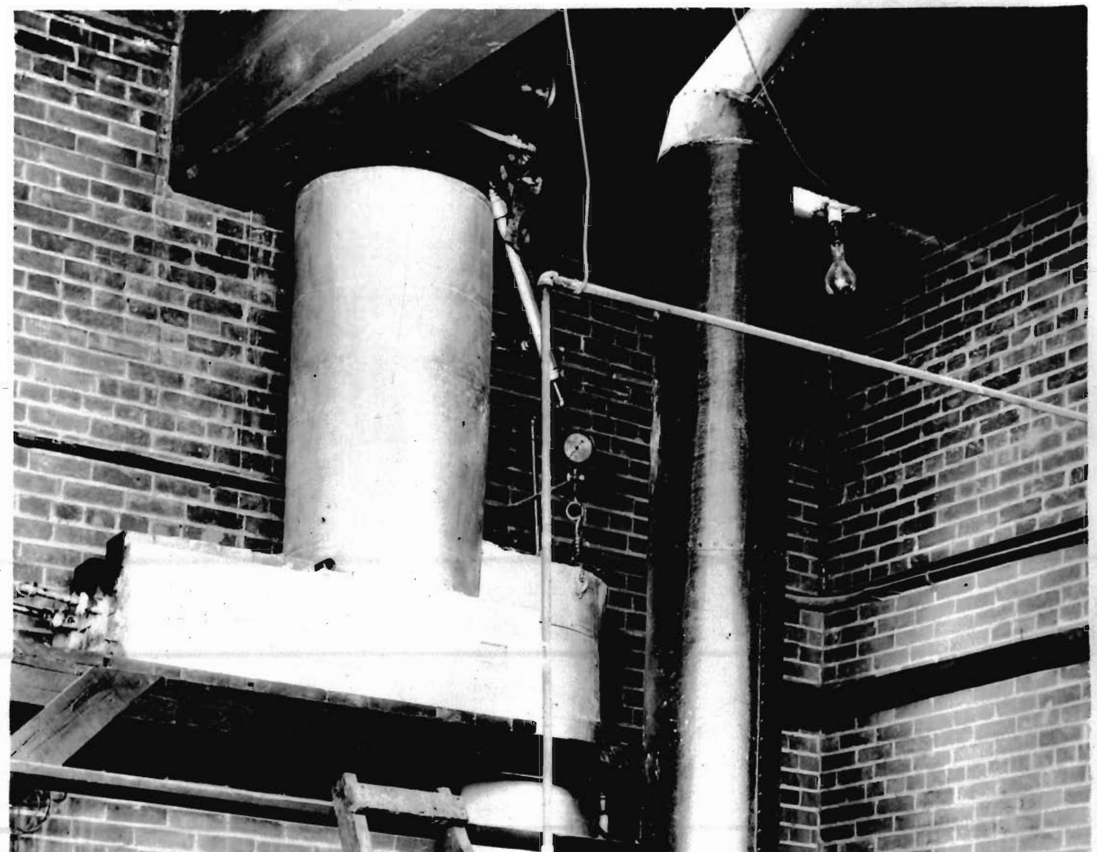


Fig. 3. Test Plant.

cylindrical column (l) and heat-insulating outer wall (m), so that the hot gases from the combustion chamber passed at high velocity over the coil counter-flow to the steam. The outer wall was four inches thick and was comprised of two sheet metal casings filled with "Heatseal", a diatomaceous silica earth mined near Salt Lake City, and provided by the Staats Insulating Company. This structure was supported on a frame work, about ten feet above the floor. At the inlet to the superheating coil there were provided a steam gauge to show the pressure of the steam as it entered the coil, a steam-flow regulating valve, and a steam separator with a drain as shown on the drawing, Figure 2.

The coal-distilling retort (b) consisted of a thin-walled cylinder (n) of 18-gauge black iron with welded seams, five inches in diameter and eight feet high. On the top and bottom ends of the retort were welded five-inch pipe couplings with screw plugs to serve as removable closures. At the top of the retort a flexible connection with the superheater was provided from a multiple-elbow assembly of one-half-inch fittings and nipples, thus relieving strains on the superheater and retort caused by changes of length with temperature.

To further obviate any strains to the connection between the retort and superheater, the retort was made stationary bysuspending it from a wall bracket with wires connected to arms welded to the top of the retort. Changes in length of the retort thus took place downwardly. Likewise a flexible multiple-elbow vapor outlet of three-quarter-inch fittings was provided at the bottom of the retort leading into the condenser (c), this also preventing strains to the equipment due to thermal expansion. The retort was well insulated against heat losses by surrounding the retort with a sheet iron jacket (o), spaced six inches from the retort and filling this annular space (p) with "Heatseal" insulating material. The insulating material and jacket were supported two feet above the floor by a circular steel plate. The lower four inches of the retort and the vapor connections protruded through this plate allowing free vertical movement of the retort by thermal expansion and easy access to the lower retort plug for discharging the treated coal.

The superheated steam connections from the superheater into the top of the retort were buried in the same insulating material up to the top of the five-inch coupling. The remaining exposed portions of the retort and plug were buried under a layer of ground asbestos-magnesia insulating material which was removed while the retort was being charged. A low-pressure steam gauge (q) was screwed into the charging plug and served to indicate the back pressure in the top of the retort above the coal. The lower plug was not covered, the coal being supported well up within the insulated retort shaft.

Six thermocouples (abbreviated to T. C. on Figure 2) were placed in firm contact with the retort walls through holes in the retort casing at sixteen inch intervals, beginning at the bottom of the retort; also one thermocouple was inserted in the superheated steam connection at the top of the retort. The thermocouple leads were run to the selective switch board (r) from which connections were made to the potentiometer (s).

Vapors from the bottom of the retort were carried to the top of condenser (c) through a vertical three-quarter-inch pipe. The condensed vapors were removed at the drain provided, and the remaining vapors were then carried out from the top of the second tube of this condenser to the condensers (d) and (e).

Condenser (c) consisted of two vertical two inch pipes (t) six feet long, joined at their lower ends and containing a spiral metal ribbon which caused rotation of the vapor stream and impingement of condensed particles against the tube walls. Each pipe was surrounded by a steam jacket of four-inch pipe with steam inlets, blow-off, pressure gauge and valves for regulating the steam pressure, and therefore the temperature on the two-inch tube walls. An oil drain was provided in the bottom of the connection between the two two-inch tubes. This condenser thus provided a means of condensing out of the vapor stream only the high-boiling oil vapors while preventing any condensation of water vapor. By thus removing the high-boiling oils, which were found to be heavier than water, the remaining oils and water could be condensed together in another condenser and thence separated by decantation. Without this selective condensatioh this crude oil, which has approximately the same specific gravity as water, could have been separated from the water only with great difficulty.

Condensers (d) and (e) consist of two coils of two-inch pipe placed in series occupying separate compartments in the condenser box (u). Cooling water flowed counter direction to the vapors being cooled, the condensate from condenser (d) being maintained above 70 degrees Fahrenheit so as to prevent the waxy oil condensed from congealing and clogging the coils. The oil and water condensates of condenser (d) were drawn off under a liquid seal and the remaining vapors and gases were passed into condenser (e) surrounded by cold water so as to condense the light oils, the latter being collected in a container shown. The non-condensable gases were measured in the meter (v) and were then burned at torch (w).

GENERAL TEST PROCEDURE

In conducting the test runs made in this study, the following procedure was practiced in obtaining the data and observations recorded on the accompanying data sheets.

A 50 pound, representative sample of raw coal which had been previously sized was charged into the retort and the upper end of the retort closed and insulated with ground asbestos-magnesia material. The superheater fuel gas was then ignited and the superheater allowed to warm up. In the meantime, the steam separator drain was adjusted, condenser (c), Fig. 2, was heated by raising its steam jacket pressure to 5 lbs. gauge, then condenser (d) was heated by bubbling steam into its cooling water in order to raise its temperature between 70 degrees C. and 80 degrees C. where it was maintained thereafter throughout the run by regulating the rate of flow of cooling water, and condenser (e) was cooled by turning cold water into its condenser box.

After containers had been placed under the condensate drains from each condenser, the meter (v) for registering generated gas flow, was read and the retort temperatures were taken and recorded. The saturated steam was then admitted to the superheater at a pressure of 20 lbs. per sq. in. gauge. The meter (h), registering the flow of gas supply to the combustion chamber, was read simultaneously with the admittance of steam. The superheated steam pressure indicated by gauge (q) at the top of the retort was then read and all readings were taken and recorded at 15 minute intervals. during the superheated steam period. This is the period during which superheated steam was being used for distilling the charge.

At the beginning of each run a large volume of gas was supplied to the combustion chamber in order to obtain a rapid rise in the temperature of the superheated steam up to the pre-determined distilling temperature,[1] and thereafter the gas supply was regulated at frequent intervals to maintain this temperature.

When generated fixed gases from the coal began issuing from the torch (w) they were ignited, the time

(1) The final distilling temperature is the approximately constant temperature at which the superheated steam was maintained during the superheated steam period.

was noted and meter (v) read. Condensed steam and the medium gravity oils were collected from condenser (d) in an oil separator, from which the water was drawn off and measured for the duration of the superheated steam period.

The superheater gas supply was then shut off at either of the following two instants; first, at the time when the rate of evolution of the coal gas began to decline which accompanied a change of flame coloration from orange to light yellow, indicating nearly complete distillation of the charge; and second, the time at which it was estimated, by observing the rise of temperature indicated by the various thermocouples that the upper part of the retort and contents had reached a high enough temperature and contained enough heat to raise the lower portion of the retort to a temperature slightly above 360 degrees C. (the initial distilling temperature). It had been proved that this final temperature would complete the distillation at the base of the charge and that it would be attained during the dry-quenching period and thus decrease the length of the superheated steam period.

Superheated steam of high initial temperature was used to cool the retort and its contents during the time designated as the 'dry-quenching period', that is, the period in which steam was passed through the superheater and retort with the superheater fuel gas supply discontinued. Obviously, the residual heat within the superheater kept the steam superheated to some degree after the heating was stopped. This method of cooling was used in all runs except Test No. 8 in which the retort and contents were cooled by the method set forth in the description for that test. The retort temperatures during the first part of the cooling period were read at five minute intervals in order to obtain more complete data on the rapid temperature changes that occurred during this time. Thereafter readings were taken every 15 minutes as before. At the instant the evolution of generated fixed gases ceased, the time and meter (v) were read.

When all the thermocouples indicated temperatures throughout the retort approximating 250 degrees C. the steam was shut off and the coal residue was dropped out of the retort by removing the lower retort plug. This temperature has been demonstrated to be sufficiently low to prevent ignition of the discharged residue. A few moments were allowed for the condensers (c), (d), and (e) to drain, then the oil condensates were mixed together and stored for further study.

Each crude oil sample was distilled under pressure in a two gallon still for the purpose of determining the water contained as emulsion in the crude oil. Thus the amount of dry crude oil was determined and recorded. Analytical distillation analyses have previously been made on the crude oil from this coal which had been produced by the same destructive distillation treatment, and consequently it was not necessary to make these analyses. However, the yield of crude oil and its properties were found to be identical in all of the eight runs and therefore a sample was subjected to a cracking and refining study. The distillation and cracking analyses determined from this sample are recorded herein.

The thermal value of an average sample of the generated fixed gases taken during a typical test run was also determined.

TEST RUN NUMBER 1

The retort was charged with fifty pounds of coal sized to -1" to + ½", which was distilled with superheated steam at 650 Degrees Centigrade (1202 Degrees Fahrenheit).

The accompanying temperature curves and operating data show that superheated steam first entered the retort at 244 Degrees Centigrade and was then raised to 650 Degrees Centigrade by the end of the first hour, whereupon its temperature was maintained substantially constant throughout the remainder of the 'superheated steam period'. By the end of this period, namely, two hours and twelve minutes, the formation of fixed gases had practically stopped, indicating that oil generation had ceased, whereupon the superheated steam was shut off.

In this test run an investigation was made of the thermocouples and each was found to indicate the same temperatures immediately before and after the flow of steam was stopped. This proved that the couples were reading the true temperature of the retort and contents at each of the respective points throughout the length of the retort shaft. Couple six was out of service during this run.

The dry-quenching steam was then admitted into the top of the retort and its flow continued until all thermocouples indicated temperatures within the retort approximating 250 Degrees Centigrade. This preliminary run was made for the purpose of observing the operating characteristics of the retort and to obtain the accompanying data, no heat economies in the use of superheated steam were attempted.

DATA SHEET

LOW-TEMPERATURE CARBONIZATION TEST ON CANNEL COAL FROM SOUTHERN UTAH

University of Utah, May 12, 1933

Test No. 1 . Made by: S. C. Jacobsen and G. W. Carter.
Size of Coal: -1" to + ½" . Superheated Steam Temp. 650 °C.
Pressure of Saturated Steam to Superheater: 20 lb. per sq.in. gauge.
Average Superheated Steam Pressure 2.54 lb. per sq. in. gauge.
Barometer: 25.34 "Hg.
Pounds of Superheated Steam used per hour: 69

Time	Retort Temperatures- °C.							Ave.	Remarks
	1	2	3	4	5	6	7		
1:47	74	40	74	74	74	-	244	97	Superheated Steam Admitted
2:00	85	62	85	85	85	-	365		
2:15	85	68	85	96	132	-	484		Generated Gas Began
2:30	84	74	120	184	224	-	575		
2:45	155	120	258	395	340	-	650		
3:00	308	198	388	428	452	-	658		
3:15	414	292	480	497	508	-	620	468	
3:30	455	334	508	520	536	-	650		Gas Flame Chgd. from Orange to Yellow
3:45	482	364	530	545	555	-	652		
4:00	508	390	545	555	565	-	638		
4:04	Average of No. 1 Thermocouple = 265								Gas Supply Cut
4:30	498	405	518	518	512	-	440		
4:45	475	402	457	448	436	-	316		
5:00	376	357	375	367	365	-	240		
5:30	270	278	258	242	242	-	160		
	End of run.								
Ave.									

Test No. 1

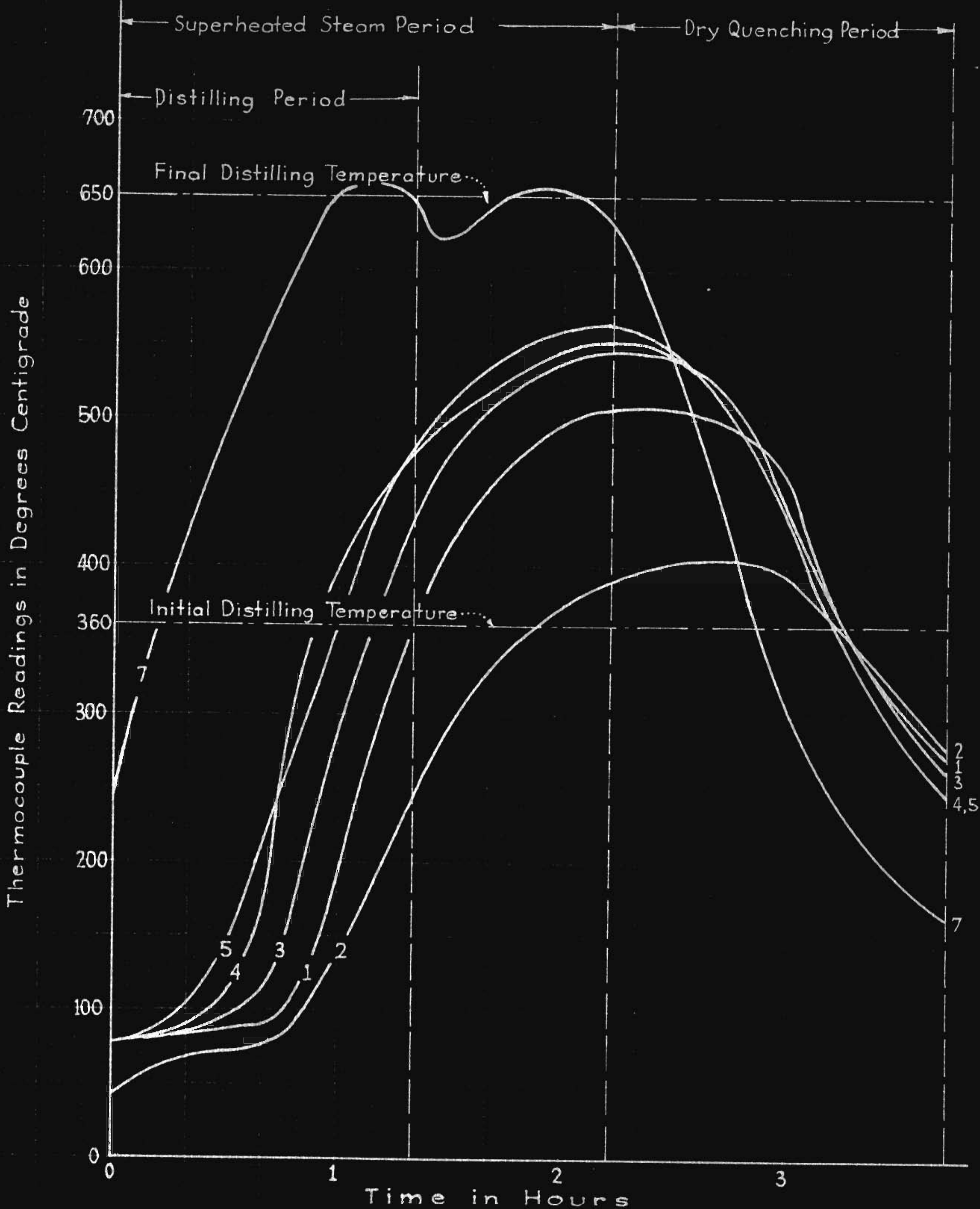
May 12, 1933

TABULATED RESULTS

1. Weight of raw coal charged, pounds.......	50.0
2. Weight of residue from retort, pounds....	23.5
3. Weight of volatiles, pounds..............	26.5
Pounds per ton of coal.....................	1060.
4. Quantity of crude oil, gallons...........	1.6
Gallons per ton of coal.....................	64.
5. Total gas generated, cubic feet..........	170.
Cubic feet per ton of coal..................	6800.
6. Time required for destructive distillation, hours	1.33
7. Time that superheated steam was used, hours	2.27
8. Total time of run, hours.................	3.72
9. Superheated steam required for destructive distillation, pounds	92.
Pounds per ton of coal......................	3680.
10. Total superheated steam used, pounds....	156.
Pounds per ton of coal......................	6250.
11. Heat required for destructive distillation, B.T.U.	10330.
B.T.U. per ton of coal......................	413000.

HEAT DISTRIBUTION IN RETORT

per test charge.	B.T.U.	Percent of total.
1. Total heat content of superheated steam entering the retort	257,000	100.00
2. Heat given to the retort.................	3,380	1.31
3. Heat given to the residue................	2,290	0.89
4. Heat in volatiles plus fixed gases.......	3,870	1.50
5. Heat content of superheated steam leaving the retort..	212,000	82.50
6. Heat unaccounted for.....................	35,460	13.80



LOG OF RETORT TEMPERATURES

TEST No. 1

SIZE OF COAL: -1" TO + 1/2"

TEST RUN NUMBER 2

The retort was charged with fifty pounds of coal sized to -1" to + ½", which was distilled with superheated steam at 760 Degrees Centigrade (1400 Degrees Fahrenheit).

Reference to the accompanying temperature curves and operating data shows that superheated steam entering the retort was raised to 760 Degrees Centigrade by the end of the first one hour and twelve minutes, whereupon its temperature was maintained substantially constant throughout the remainder of the 'superheated steam period'. By the end of this period, namely, one hour and forty minutes, the generated fixed gases had begun to burn with a very blue flame which indicated the production of large quantities of water gas from the superheated steam reacting with the carbon residue. Therefore, the superheater fuel gas supply was shut off and the 'dry-quenching period' was begun and continued until all thermocouples indicated retort temperatures had been reduced approximately to 250 Degrees Centigrade.

This run was made for the purpose of observing the formation of water gas from the coal residue, also the operating characteristics of the retort at a higher temperature, namely 760 Degrees Centigrade, and to obtain the accompanying data. No heat economies were attempted in utilization of the superheated steam.

DATA SHEET

LOW-TEMPERATURE CARBONIZATION TEST ON CANNEL COAL FROM SOUTHERN UTAH

University of Utah, May 12, 1933

Test No. 2 . Made by: S. C. Jacobsen and G. W. Carter.
Size of Coal: -1" to + ½" . Superheated Steam Temp. 760 °C.
Pressure of Saturated Steam to Superheater: 20 lb. per sq.in. gauge.
Average Superheated Steam Pressure 2.7 lb. per sq. in.gauge.
Barometer: 25.34 "Hg.
Pounds of Superheated Steam used per hour: 66.

Time	Retort Temperatures- °C.							Ave.	Remarks
	1	2	3	4	5	6	7		
7:50	54	110	61	61	64	72	80	71	Superheated
									Steam Admitted.
8:00	88	108	88	88	88	145	508		Generated Gas
									Began.
8:15	82	106	96	120	190	350	572		
8:30	100	120	182	232	290	470	652		
8:45	186	172	294	358	392	562	709		
9:00	360	260	452	484	508	620	770	495	
9:15	460	316	524	543	518	660	780		Blue Flame
									(Water Gas)
9:30	526	378	576	592	626	700	782	566	
9:33	Average of No. 1 Thermocouple =							265	Gas Supply Cut.
9:40	552	408	589	606	627	682	664		
9:45	558	418	594	610	624	658	606		
9:50	586	426	596	606	610	670	530		
9:55	563	436	588	594	588	578	468		
10:00	554	436	578	572	566	540	424		
10:15	532	426	512	498	490	436	314		Gas Generation
									Ceased.
10:30	458	394	430	420	420	366	258		
10:45	380	352	360	348	352	302	193		
11:00	304	310	288	282	281	254	150		
11:15	240	270	236	230	236	206	128		
			End of Run.						
Ave.									

Test No. 2

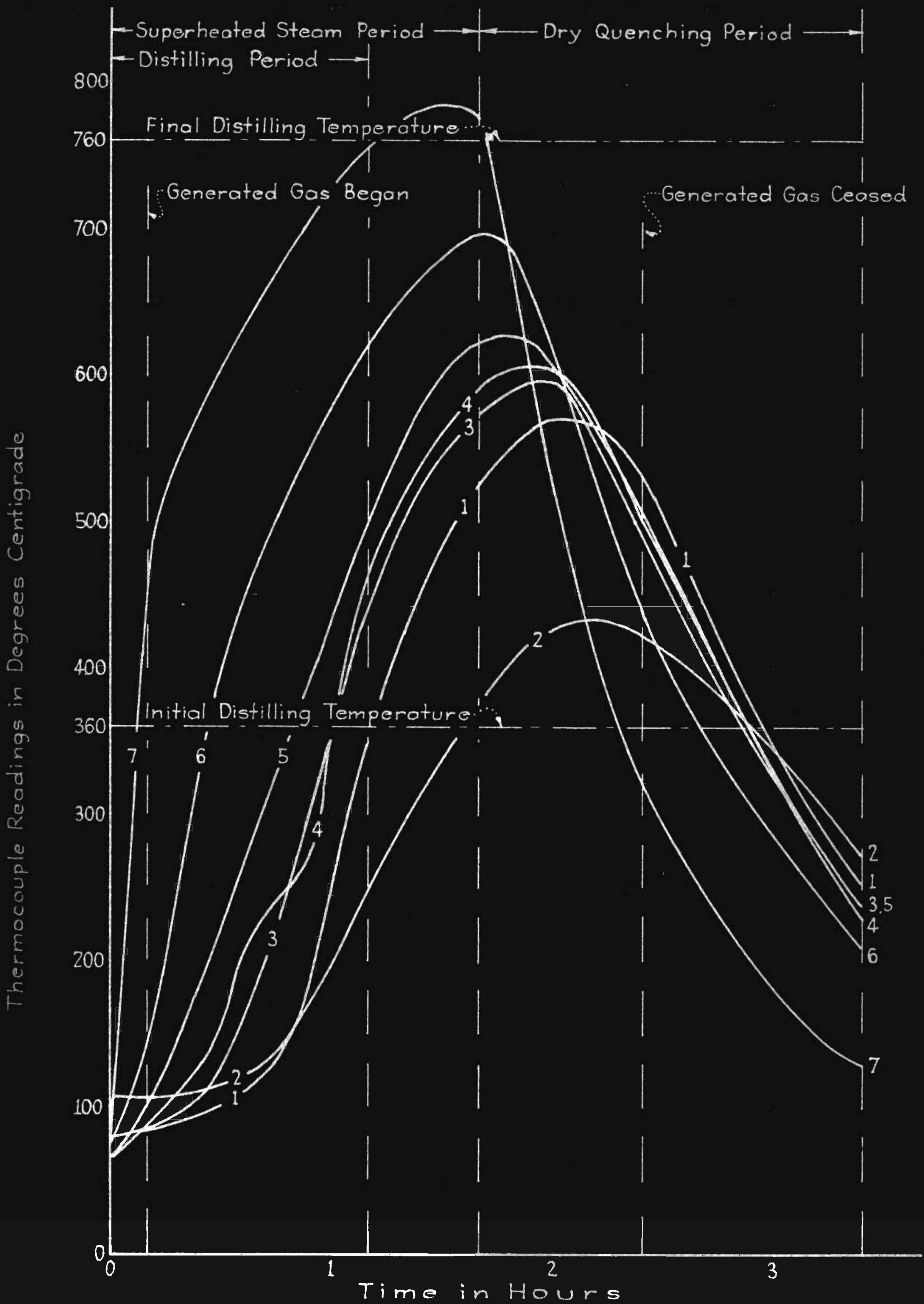
May 12 1933

TABULATED RESULTS

1. Weight of raw coal charged, pounds.......	50.00
2. Weight of residue from retort, pounds....	21.5
3. Weight of volatiles, pounds.............	28.5
Pounds per ton of coal..................	1140
4. Quantity of crude oil, gallons..........	1.58
Gallons per ton of coal.................	63.1
5. Total gas generated, cubic feet..........	365
Cubic feet per ton of coal..............	14600
6. Time required for destructive distillation, hours	1.17
7. Time that superheated steam was used, hours	1.72
8. Total time of run, hours.................	3.42
9. Superheated steam required for destructive distillation, pounds	77.4
Pounds per ton of coal..................	3090
10. Total superheated steam used, pounds.....	113
Pounds per ton of coal..................	4520
11. Heat required for destructive distillation, B.T.U.	11850
B.T.U. per ton of coal..................	474000

HEAT DISTRIBUTION IN RETORT

per test charge.	B.T.U.	Percent of total.
1. Total heat content of superheated steam entering the retort	198,000	100.00
2. Heat given to the retort................	6,200	3.14
3. Heat given to the residue...............	3,840	1.94
4. Heat in volatiles plus fixed gases.......	7,650	3.86
5. Heat content of superheated steam leaving the retort..	156,200	78.9
6. Heat unaccounted for....................	24,110	12.16



LOG OF RETORT TEMPERATURES

TEST NO. 2

SIZE OF COAL: -1" TO + ½"

TEST RUN NUMBER 3

The retort was charged with fifty pounds of coal sized to -1" to + ½", which was distilled with superheated steam at 760 Degrees Centigrade (1400 Degrees Fahrenheit).

Reference to the accompanying temperature curves and operating data shows that superheated steam first entered the retort at 448 Degrees Centigrade and was raised to 760 Degrees Centigrade by the end of the first fifty-five minutes, whereupon its temperature was maintained substantially constant throughout the remainder of the 'superheated steam period'. By the end of this period, namely, one hour and twenty-five minutes, it was estimated that the upper part of the retort and contents were at the proper temperature and contained sufficient heat to complete the distillation in the lower portions of its charge. Therefore, the superheater fuel gas supply was shut off and the dry-quenching period was begun which continued until all thermocouples indicated retort temperatures approximating 250 Degrees Centigrade. Some of the thermocouples were partly, or entirely, out of service during this run but the data were preserved notwithstanding.

This run was made for the purpose of observing the operating characteristics of the retort under conditions applying better heat utilization, wherein it was demonstrated that by discontinuing the heating of the superheater during the latter part of the distilling period it was possible to completely distill the lower part of the charge by utilizing the sensible heat of the coke in the upper portions of the retort. Other data were also recorded.

DATA SHEET

LOW-TEMPERATURE CARBONIZATION TEST
ON CANNEL COAL FROM SOUTHERN UTAH

University of Utah, May 13, 1933

Test No. 3 . Made by: S. C. Jacobsen and G. W. Carter.
Size of Coal: -1" to + ½" . Superheated Steam Temp. 760 °C.
Pressure of Saturated Steam to Superheater: 20 lb. per sq.in. gauge.
Average Superheated Steam Pressure 3.7 lb. per sq. in.gauge.
Barometer: 25.44 "Hg.
Pounds of Superheated Steam used per hour: 56

Time	Retort Temperatures- °C.							Ave.	Remarks
	1	2	3	4	5	6	7		
2:05	82	62	-	74	-	120	448	70	Superheated
									Steam admitted
2:10									Generated Gas
									Began
2:15	82	62	-	76	-	244	508		
2:30	65	66	-	196	-	471	626		
2:45	66	96	-	377	-	578	700		
3:00	118	176	-	460	-	640	764		
3:15	218	260	-	536	-	700	782		
3:30	292	316	-	566	-	722	794	538	Gas Supply Cut
		Average of No. 1 Thermocouple = 118							at 3:34
3:35	330	348	-	-	-	734	762		
3:40	346	358	-	-	-	722	698		
3:45	366	375	-	-	-	686	620	478	
3:50	378	358	-	-	-	654	566		
3:55	363	390	-	-	-	615	516		
4:00	394	396	-	-	-	583	571		
4:05	400	400	-	408	-	531	416		Generated Gas
									Ceased
4:15	398	392	-	390	-	460	368		
4:30	-	396	-	390	-	372	276		
4:45	-	333	-	308	-	320	220		
5:00	-	298	-	308	-	280	192		
5:30	-	236	-	244	-	206	139		
			End of Run.						
Ave.									

Test No. 3

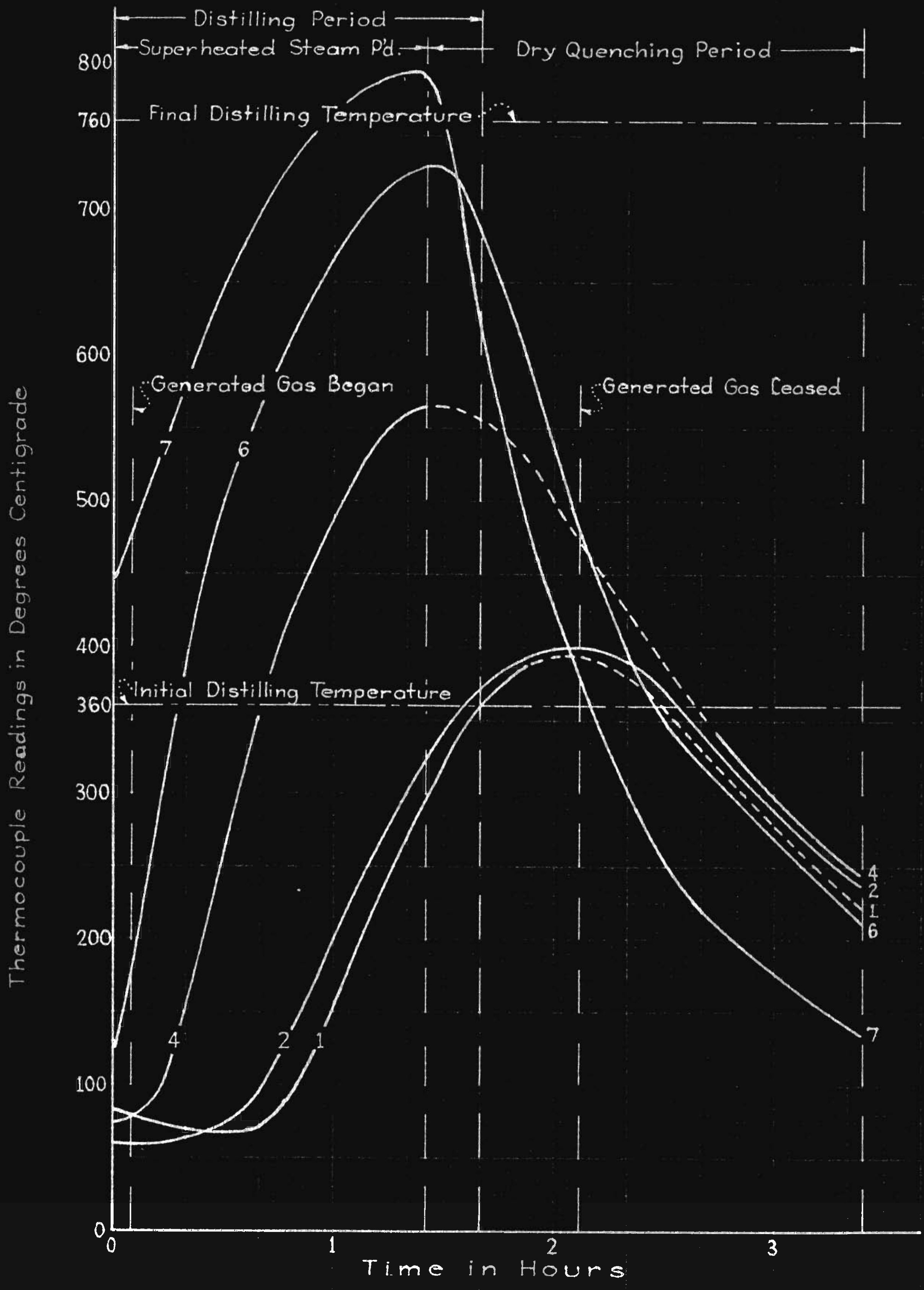
May 13 1933

TABULATED RESULTS

1. Weight of raw coal charged, pounds.......	50.0
2. Weight of residue from retort, pounds....	21.5
3. Weight of volatiles, pounds.............	28.5
Pounds per ton of coal..................	1140.
4. Quantity of crude oil, gallons...........	1.61
Gallons per ton of coal.................	64.5
5. Total gas generated, cubic feet..........	330.
Cubic feet per ton of coal..............	13200.
6. Time required for destructive distillation, hours	1.67
7. Time that superheated steam was used, hours	1.48
8. Total time of run, hours.................	3.0
9. Superheated steam required for destructive distillation, pounds	83.
Pounds per ton of coal..................	3320.
10. Total superheated steam used, pounds.....	83.
Pounds per ton of coal..................	3320.
11. Heat required for destructive distillation, B.T.U.	11350.
B.T.U. per ton of coal..................	454000.

HEAT DISTRIBUTION IN RETORT

per test charge.	B.T.U.	Percent of total.
1. Total heat content of superheated steam entering the retort	146,000	100.00
2. Heat given to the retort................	5,840	4.00
3. Heat given to the residue................	3,620	2.48
4. Heat in volatiles plus fixed gases.......	7,200	4.94
5. Heat content of superheated steam leaving the retort..	105,200	72.00
6. Heat unaccounted for.....................	24,140	16.58



LOG OF RETORT TEMPERATURES

TEST No. 3

SIZE OF COAL: -1" TO +½"

TEST RUN NUMBER 4

The retort was charged with forty-nine pounds of coal sized to -1" to + ½", which was distilled with superheated steam at 535 Degrees Centigrade (995 Degrees Fahrenheit).

Reference to the accompanying temperature curves and operating data shows that superheated steam entering the retort was raised to 535 Degrees Centigrade by the end of the first five minutes, and thereafter its temperature was maintained substantially constant throughout the remainder of the 'superheated steam period'. By the end of this period, namely, one hour and thirty-eight minutes, the rate of formation of fixed gases had decreased to a low value, indicating that distillation of the oils was approaching completion. Therefore the superheater fuel gas supply was shut off and the 'dry-quenching period' was begun which served to complete the distillation and was thereafter continued until all thermocouples indicated retort temperatures approximating 250 Degrees Centigrade.

This run was made for the purpose of observing the operating characteristics of the retort at a lower temperature than was previously used, namely, 535 Degrees Centigrade, and under conditions applying economical heat utilization, and to obtain the accompanying data.

DATA SHEET

LOW-TEMPERATURE CARBONIZATION TEST ON CANNEL COAL FROM SOUTHERN UTAH

University of Utah, May 13, 1933

Test No. 4 . Made by: S. C. Jacobsen and G. W. Carter.
Size of Coal: -1" to + ½" . Superheated Steam Temp. 535 °C.
Pressure of Saturated Steam to Superheater: 20 lb. per sq.in. gauge.
Average Superheated Steam Pressure 2.9 lb. per sq. in.gauge.
Barometer: 25.44 "Hg.
Pounds of Superheated Steam used per hour: 65

Time	Retort Temperatures- °C.							Ave.	Remarks
	1	2	3	4	5	6	7		
8:26	46	80	[illegible]	84	84	56	58	67	Superheated Steam Admitted
8:30	76	84	-	90	92	88	538		
8:33									Generated Gas Began
8:45	78	86	-	90	148	350	534		
9:00	77	90	-	168	302	448	536		
9:15	94	144	-	272	394	482	526		
9:30	174	233	-	328	422	492	545		
9:45	277	304	-	366	444	498	540		
10:00	329	341	-	380	457	506	545	400	
10:03	Average of No. 1 Thermocouple =							143	Gas Supply Cut
10:05	340	348	-	383	459	504	519		
10:10	354	358	-	386	450	484	450		
10:15	360	365	-	382	432	458	396	431	
10;20	368	370	-	370	410	430	342		
10:30	371	364	-	326	356	358	255		Generated Gas Ceased
10:45	341	312	-	276	302	290	206		
11;00	300	276	-	244	258	246	168		
11:15	258	242	-	218	230	206	121		
11:30	223	210	-	194	204	126	120		
			End of run.						
Ave.									

Test No. 4

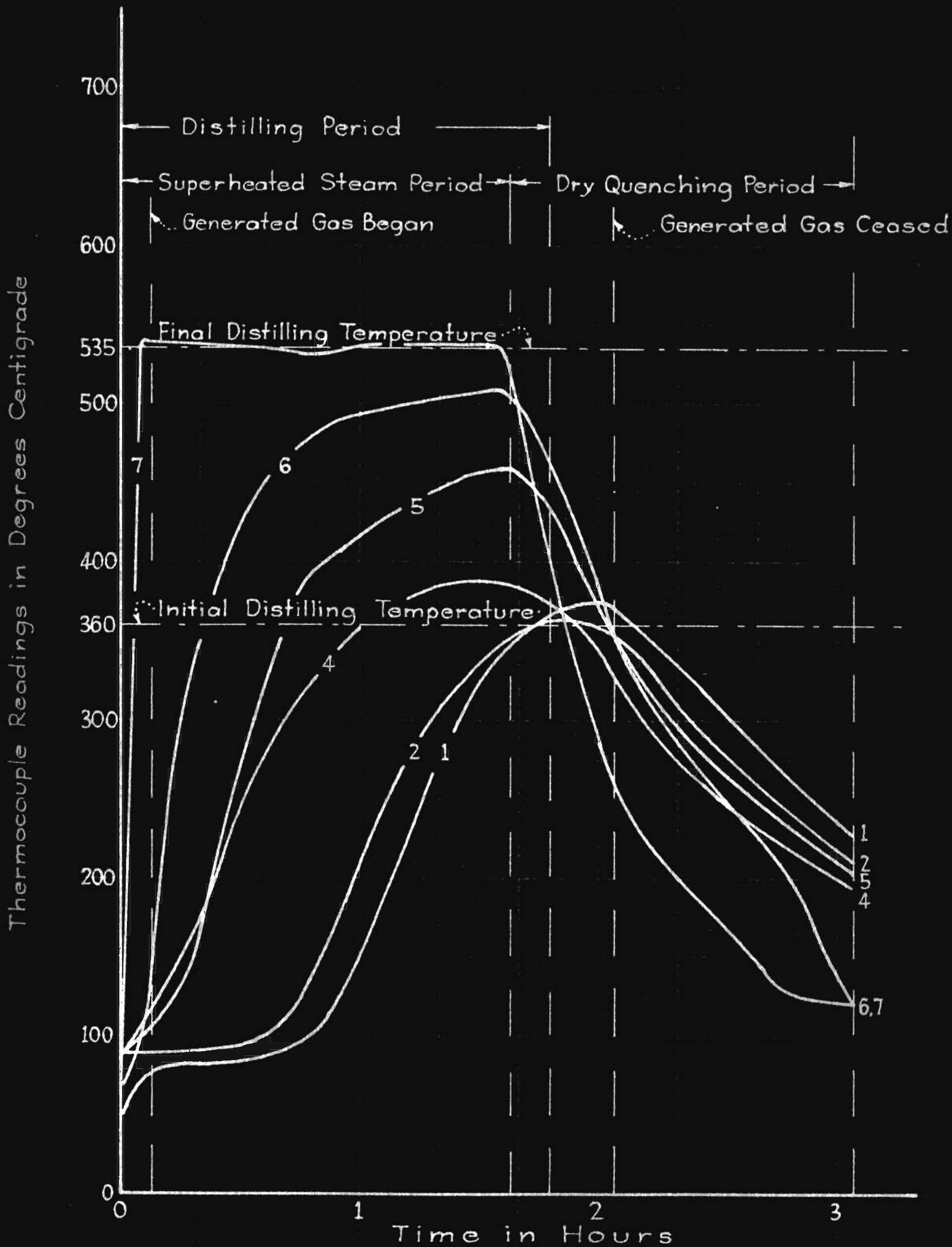
May 13 1933

TABULATED RESULTS

1.	Weight of raw coal charged, pounds.......	49.0
2.	Weight of residue from retort, pounds....	26.0
3.	Weight of volatiles, pounds.............	23.0
	Pounds per ton of coal.................	940.
4.	Quantity of crude oil, gallons..........	1.63
	Gallons per ton of coal................	63.8
5.	Total gas generated, cubic feet.........	75.
	Cubic feet per ton of coal.............	3060.
6.	Time required for destructive distillation, hours	1.82
7.	Time that superheated steam was used, hours	1.62
8.	Total time of run, hours................	2.82
9.	Superheated steam required for destructive distillation, pounds	105.
	Pounds per ton of coal.................	4300.
10.	Total superheated steam used, pounds.....	105.
	Pounds per ton of coal.................	4300.
11.	Heat required for destructive distillation, B.T.U.	9910.
	B.T.U. per ton of coal.................	396400.

HEAT DISTRIBUTION IN RETORT

per test charge.	B.T.U.	Percent of total.
1. Total heat content of superheated steam entering the retort	160,800	100.00
2. Heat given to the retort................	4,160	2.58
3. Heat given to the residue...............	3,120	1.94
4. Heat in volatiles plus fixed gases.......	4,140	2.57
5. Heat content of superheated steam leaving the retort..	132,400	82.40
6. Heat unaccounted for....................	16,980	10.51



LOG OF RETORT TEMPERATURES

TEST No. 4

SIZE OF COAL: -1" TO + ½"

TEST RUN NUMBER 5

The retort was charged with forty-seven pounds of coal sized to $-\frac{1}{2}$" to $+\frac{1}{4}$", which was distilled with superheated steam at 650 Degrees Centigrade (1202 Degrees Fahrenheit).

Reference to the accompanying temperature curves and operating data shows that superheated steam entering the retort was raised to 650 Degrees Centigrade by the end of the first fifty-five minutes, whereupon its temperature was maintained substantially constant throughout the remainder of the 'superheated steam period'. By the end of this period, namely, one hour and thirty minutes, the rate of formation of fixed gases had decreased to a very low value and all thermocouples indicated retort temperatures above the 'Initial distilling temperature'. Since these two conditions are indicative of completion of distillation, the superheater fuel gas supply was then shut off and the 'dry-quenching period' was begun, which continued until all thermocouples indicated retort temperatures approximating 250 degrees Centigrade.

This run was made for the purpose of observing the operating characteristics of the retort using the smaller sized coal, namely, $-\frac{1}{2}$" to $+\frac{1}{4}$", and to obtain the accompanying data.

DATA SHEET

LOW-TEMPERATURE CARBONIZATION TEST
ON CANNEL COAL FROM SOUTHERN UTAH

University of Utah, May 14, 1933

Test No. 5 . Made by: S. C. Jacobsen and G. W. Carter.
Size of Coal: -½" to + ¼" . Superheated Steam Temp. 650 °C.
Pressure of Saturated Steam to Superheater: 20 lb. per sq.in. gauge.
Average Superheated Steam Pressure 4.16 lb. per sq. in.gauge.
Barometer: 25.46 "Hg.
Pounds of Superheated Steam used per hour: 53.6

Time	Retort Temperatures- °C.							Ave.	Remarks
	1	2	3	4	5	6	7		
10:50	70	86	63	62	62	38	32	59	Superheated
									Steam Admitted
10:55	64	78	58	58	66	66	428		
11:00	86	86	74	68	68	80	468		
11:12									Generated Gas
									Began
11:15	86	89	76	72	120	310	570		Generated Gas
11:30	82	86	86	172	316	468	622		Meter out of
11:45	80	134	222	258	404	536	651		Order
12:00	198	248	322	344	464	560	656		
12:15	392	362	390	398	490	578	640	464	
12:20	Average of No. 1 Thermocouple =							174	Gas Supply Cut
12:25	406	384	408	414	494	582	596	469	
12:30	418	396	416	416	486	560	522		
12:35	430	404	418	408	468	524	457		Generated Gas
									Ceased
12:40	438	408	416	394	446	494	412		
12:45	442	408	404	375	422	452	344		
1:00	398	366	350	306	358	350	232		
1:15	316	298	286	254	292	276	184		
1:30	264	258	250	222	252	232	150		
				End of run.					
Ave.									

Test No. 5

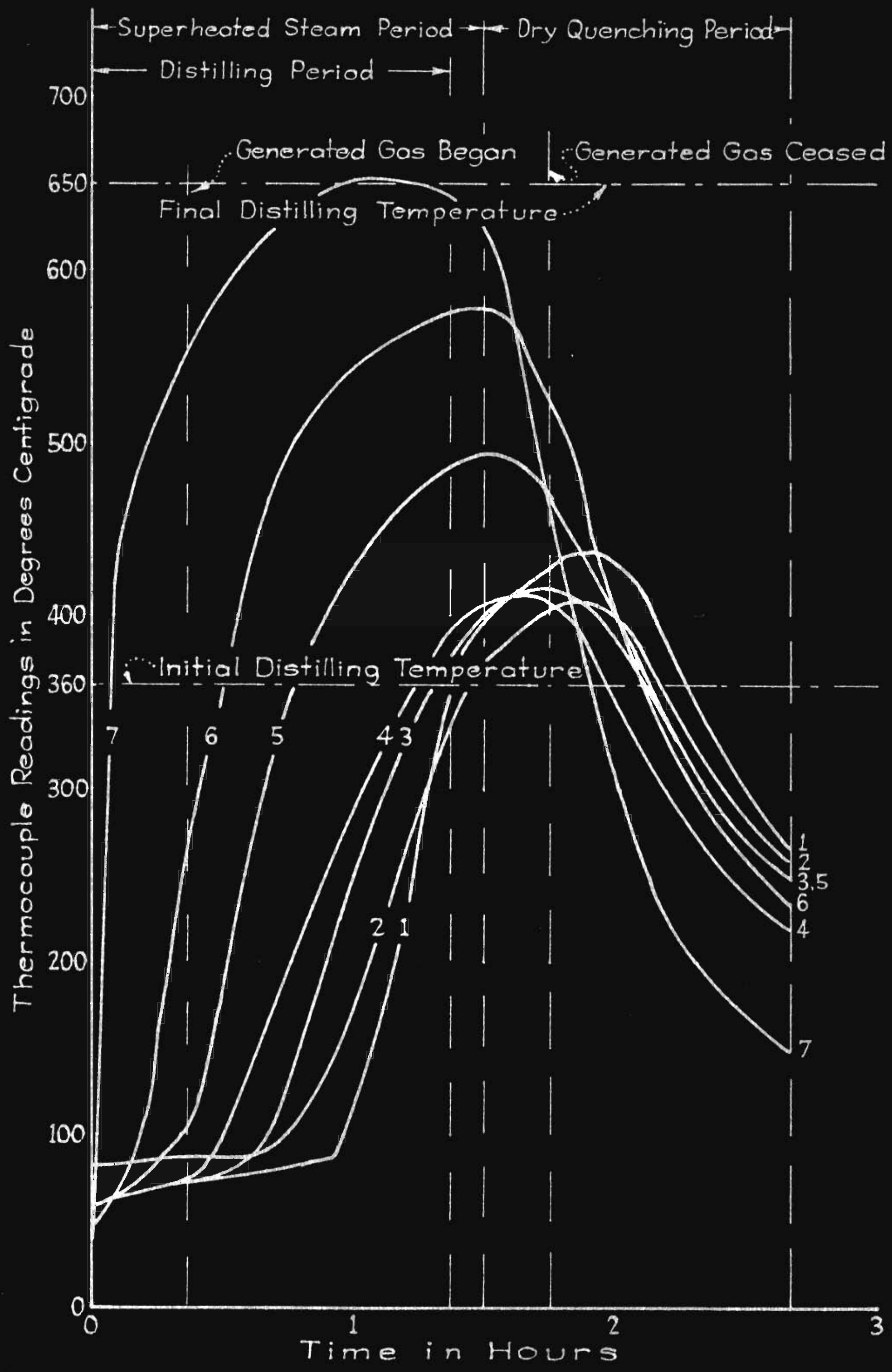
May 14 1933

TABULATED RESULTS

1. Weight of raw coal charged, pounds.......	47.0
2. Weight of residue from retort, pounds....	24.0
3. Weight of volatiles, pounds.............	23.0
Pounds per ton of coal..................	976.
4. Quantity of crude oil, gallons..........	1.73
Gallons per ton of coal.................	65.
5. Total gas generated, cubic feet.........	(Meter out of
Cubic feet per ton of coal..............	order)
6. Time required for destructive distillation, hours	1.37
7. Time that superheated steam was used, hours	1.5
8. Total time of run, hours................	2.67
9. Superheated steam required for destructive distillation, pounds	73.6
Pounds per ton of coal..................	3140.
10. Total superheated steam used, pounds.....	80.5
Pounds per ton of coal..................	3420.
11. Heat required for destructive distillation, B.T.U.	10600.
B.T.U. per ton of coal..................	424000.

HEAT DISTRIBUTION IN RETORT

per test charge.	B.T.U.	Percent of total.
1. Total heat content of superheated steam entering the retort	132,000	100.00
2. Heat given to the retort................	5,120	3.88
3. Heat given to the residue...............	3,540	2.68
4. Heat in volatiles plus fixed gases.......	5,090	3.86
5. Heat content of superheated steam leaving the retort..	105,800	80.10
6. Heat unaccounted for....................	12,450	9.48



LOG OF RETORT TEMPERATURES

TEST NO. 5

SIZE OF COAL: −½" TO +¼"

TEST RUN NUMBER 6

The retort was charged with fifty pounds of coal consisting of two selected sizes, namely, -1" to + ½" and -½" to + ¼", each of twenty-five pounds weight. The larger size filled the lower half of the retort and the smaller size the upper half, and the entire charge was distilled with superheated steam at 650 Degrees Centigrade (1202 Degrees Fahrenheit).

The accompanying temperature curves and operating data show that superheated steam entered the retort at 101 Degrees Centigrade, and by the end of the first forty-four minutes it had reached 650 Degrees Centigrade, whereupon its temperature was maintained substantially constant throughout the remainder of the 'superheated steam period'. By the end of the period, namely, one hour and nine minutes, it was estimated that the upper part of the retort and contents were at the proper temperature and contained sufficient heat to complete the distillation of the coal in the lower portions of the retort. Therefore, the superheater fuel gas supply was shut off and the dry-quenching period was begun which continued until all the thermocouples indicated retort temperatures approximating 250 Degrees Centigrade.

This run was made for the purpose of observing the operating characteristics of the retort using mixed size coal under conditions applying economical heat utilization and to obtain the accompanying data.

DATA SHEET

LOW-TEMPERATURE CARBONIZATION TEST ON CANNEL COAL FROM SOUTHERN UTAH

University of Utah, May 14, 1933

Test No. 6 . Made by: S. C. Jacobsen and G. W. Carter.
Size of Coal: * . Superheated Steam Temp. 650 °C.
Pressure of Saturated Steam to Superheater: 20 lb. per sq.in. gauge.
Average Superheated Steam Pressure 3.6 lb. per sq. in.gauge.
Barometer: 25.46 "Hg.
Pounds of Superheated Steam used per hour: 56

Time	Retort Temperatures- °C.							Ave.	Remarks
	1	2	3	4	5	6	7		
3:01	74	106	102	106	106	80	101	96	Superheated
									Steam Admitted
3:05	92	110	106	106	106	84	560		
3:08									Generated Gas
									Began
3:15	90	106	102	102	106	248	610		
3:30	88	106	115	184	346	482	642		
3:45	102	154	240	308	448	552	652		
4:00	240	292	360	386	510	578	652		4:10- Gas
4:15	346	370	408	414	532	588	612	456	Supply Cut
	Average of No. 1 Thermocouple =							148	
4:20	404	394	424	424	514	566	524		
4:25	422	410	428	422	490	532	460		
4:30	434	418	426	406	466	484	398		Generated Gas
									Ceased
4:45	426	412	384	350	392	384	272		
5:00	360	342	324	288	322	310	214		
5:15	278	277	280	244	256	244	126		
5:30	253	258	243	222	242	218	134		
				End of run.					
Ave.									

* 25 lbs. -1" to + $\frac{1}{2}$"
25 lbs. -$\frac{1}{2}$" to + $\frac{1}{4}$"

Test No. 6

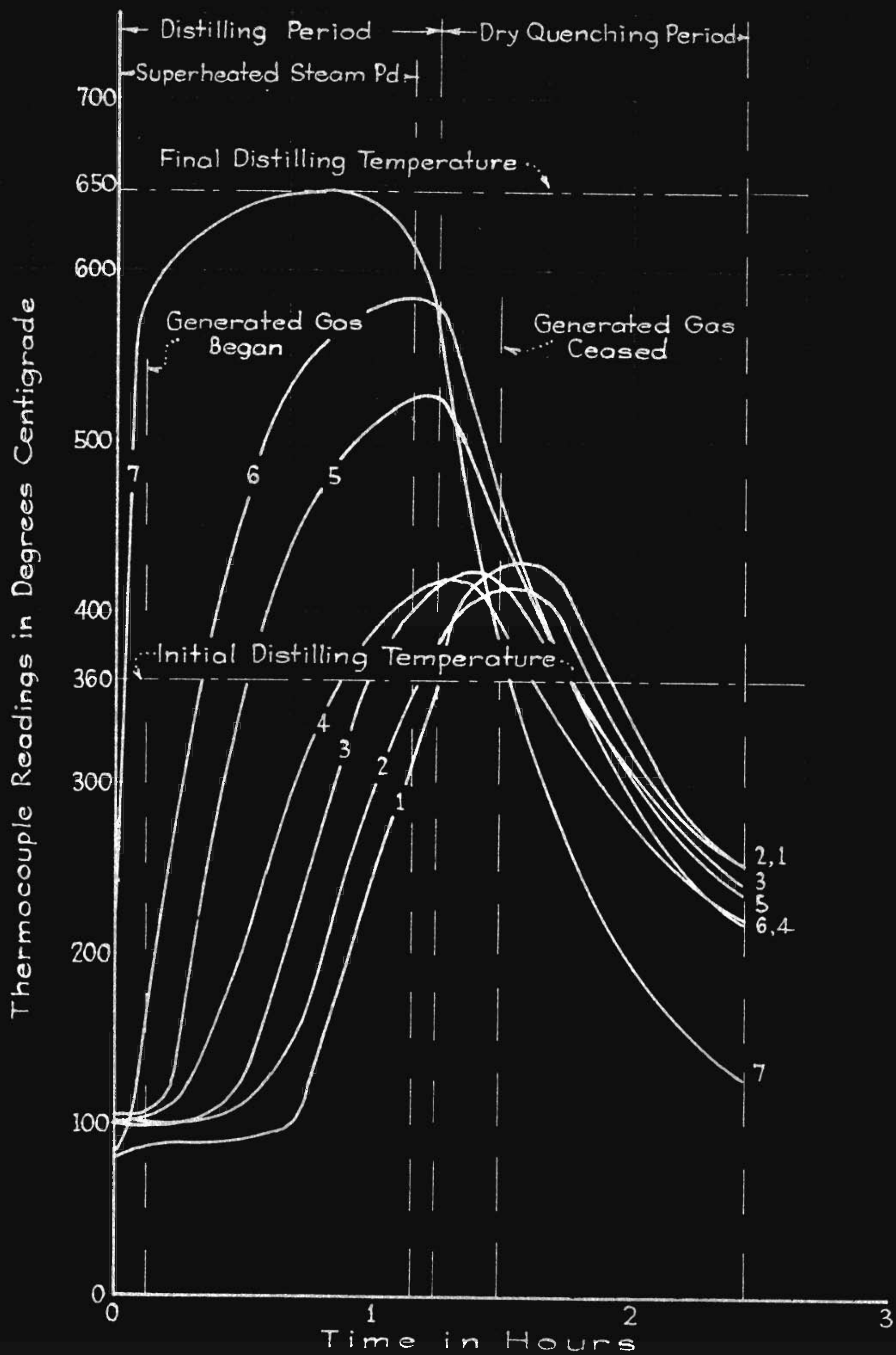
May 14 1933

TABULATED RESULTS

1. Weight of raw coal charged, pounds.......	50.0
2. Weight of residue from retort, pounds....	25.00
3. Weight of volatiles, pounds..............	25.0
Pounds per ton of coal.....................	1000.
4. Quantity of crude oil, gallons...........	1.62
Gallons per ton of coal....................	64.75
5. Total gas generated, cubic feet.........	(Meter out of
Cubic feet per ton of coal.................	order)
6. Time required for destructive distillation, hours	1.25
7. Time that superheated steam was used, hours	1.15
8. Total time of run, hours.................	2.4
9. Superheated steam required for destructive distillation, pounds	64.4
Pounds per ton of coal.....................	2574.
10. Total superheated steam used, pounds.....	64.4
Pounds per ton of coal.....................	2574.
11. Heat required for destructive distillation, B.T.U.	10600.
B.T.U. per ton of coal.....................	424000.

HEAT DISTRIBUTION IN RETORT

per test charge.	B.T.U.	Percent of total.
1. Total heat content of superheated steam entering the retort	104,000	100.00
2. Heat given to the retort................	4,540	4.36
3. Heat given to the residue...............	3,410	3.28
4. Heat in volatiles plus fixed gases.......	1,640	1.58
5. Heat content of superheated steam leaving the retort..	84,500	81.20
6. Heat unaccounted for....................	9,910	9.5



LOG OF RETORT TEMPERATURES

TEST No. 6

SIZE OF COAL: -1" TO +½"; -½" TO +¼"

TEST RUN NUMBER 7

The retort was charged with forty-eight pounds of coal, sized and placed in the retort, from bottom to top, in the following order: 16.5 pounds of -1" +$\frac{1}{2}$"; 16.5 pounds of -$\frac{1}{2}$" to +$\frac{1}{4}$"; and 15 pounds of -$\frac{1}{4}$" to + 1/8". The charge was distilled with superheated steam at 760 Degrees Centigrade (1400 Degrees Fahrenheit).

Reference to the accompanying temperature curves and operating data shows that superheated steam entered the retort at 484 Degrees Centigrade and was raised to 760 Degrees Centigrade by the end of the first forty-four minutes, whereupon its temperature was maintained substantially constant throughout the remainder of the 'superheated steam period'. By the end of this period, namely, one hour and thirty-five minutes, the formation of fixed gases had ceased, indicating that distillation was complete, whereupon the superheated steam supply was shut off.

Advantage was taken of the opportunity to study the temperatures throughout the retort insulating wall by periodically moving all of the thermocouples at one inch intervals outwardly from the retort surface, to the retort casing surface. (See Figure 4 , Page 52). The dry-quenching steam was then admitted to the retort and its flow continued until all thermocouples indicated temperatures approximating 250 Degrees Centigrade.

This run was made for the purpose of observing the operating characteristics of the retort using coal of three different sizes, also to obtain retort insulation temperature gradients, and to obtain the accompanying data. No heat economies were attempted.

DATA SHEET

LOW-TEMPERATURE CARBONIZATION TEST ON CANNEL COAL FROM SOUTHERN UTAH

University of Utah, May 15, 1933

Test No. 7 . Made by: S. C. Jacobsen and G. W. Carter.
Size of Coal: * . Superheated Steam Temp. 760 °C.
Pressure of Saturated Steam to Superheater: 20 lb. per sq.in. gauge.
Average Superheated Steam Pressure 3.3 lb. per sq. in.gauge.
Barometer: 25.3 "Hg.
Pounds of Superheated Steam used per hour: 61

Time	Retort Temperatures- °C.							Ave.	Remarks
	1	2	3	4	5	6	7		
3:44	38	38	38	40	58	60	484	70	Superheated
									Steam Admitted
3:52									Generated Gas
									Began
4:00	76	64	64	52	116	358	594		
4:15	70	66	76	148	366	486	664		
4:30	76	134	250	298	468	586	772		
4:45	220	278	360	378	552	654	774		
5:00	344	556	408	404	542	648	798	500	
5:15	430	404	448	464	592	706	805	550	
5:20	Average of No. 1 Thermocouple =							150	Gas Supply Cut
									Steam Supply
									Cut
The following data was taken to determine the temperature gradient from the retort outward to the casing.									
5:25	238	220	286	258	376	436	-	302	1" from retort
5:32	96	80	146	142	232	328	-	107	2" from retort
5:35	56	50	82	70	106	158	-	87	3" from retort
5:40	32	34	40	34	64	84	-	48	4" from retort
5:45	24	-	32	30	46	-	-	33	5" from retort
5:50	29	29	28	29	29	28	-	28	Surface of
Note: The last series of temperatures were									retort casing
taken with a mercurial thermometer.									Mean of the
6:15	422	366	396	366	418	422	258		ave.temp.from
6:30	346	312	314	288	322	296	150		5:25 to5:50 was
6:45	266	258	258	244	274	244	120		168

* 16.5 of -1" to + ½"; 16.5 of -½" to + ¼"; 15.0 of -¼" to + 1/8"

Test No. 7

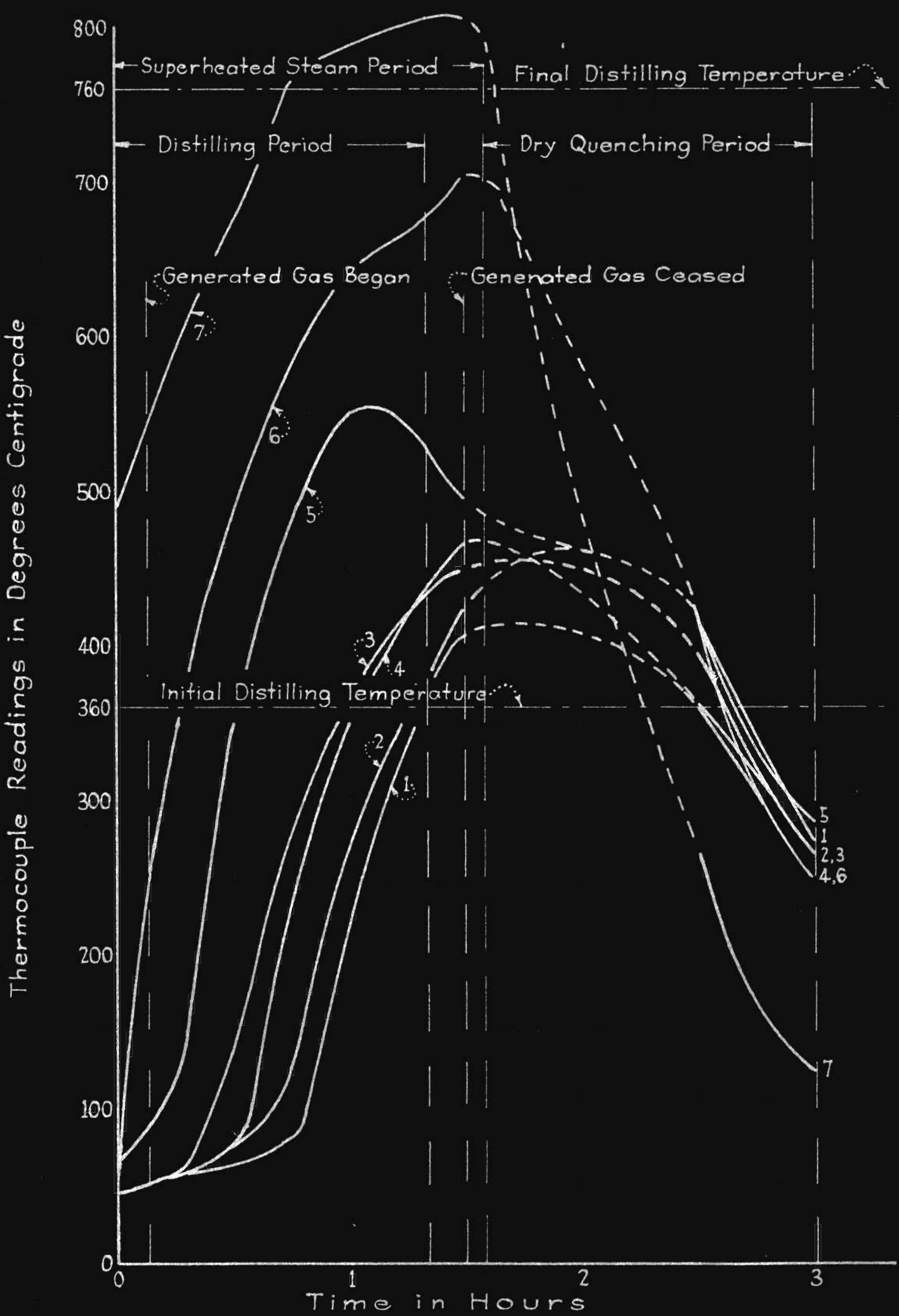
May 15 1933

TABULATED RESULTS

1. Weight of raw coal charged, pounds.......	48.0
2. Weight of residue from retort, pounds....	22.0
3. Weight of volatiles, pounds............	26.0
Pounds per ton of coal..................	1080.
4. Quantity of crude oil, gallons..........	1.72
Gallons per ton of coal.................	66.
5. Total gas generated, cubic feet..........	(Meter out of
Cubic feet per ton of coal..............	order)
6. Time required for destructive distillation, hours	1.33
7. Time that superheated steam was used, hours	1.6
8. Total time of run, hours................	3.0
9. Superheated steam required for destructive distillation, pounds	81.2
Pounds per ton of coal..................	3380.
10. Total superheated steam used, pounds.....	98.
Pounds per ton of coal..................	4080.
11. Heat required for destructive distillation, B.T.U.	11500.
B.T.U. per ton of coal..................	460000.

HEAT DISTRIBUTION IN RETORT

per test charge.	B.T.U.	Percent of total.
1. Total heat content of superheated steam entering the retort	171,000	100.00
2. Heat given to the retort................	6,000	3.51
3. Heat given to the residue...............	3,800	2.22
4. Heat in volatiles plus fixed gases.......	6,750	3.94
5. Heat content of superheated steam leaving the retort..	124,000	72.50
6. Heat unaccounted for....................	30,450	17.83



LOG OF RETORT TEMPERATURES

TEST No. 7

SIZE OF COAL: -1" TO +1/2"; -1/2" TO +1/4"; -1/4" TO +1/8"

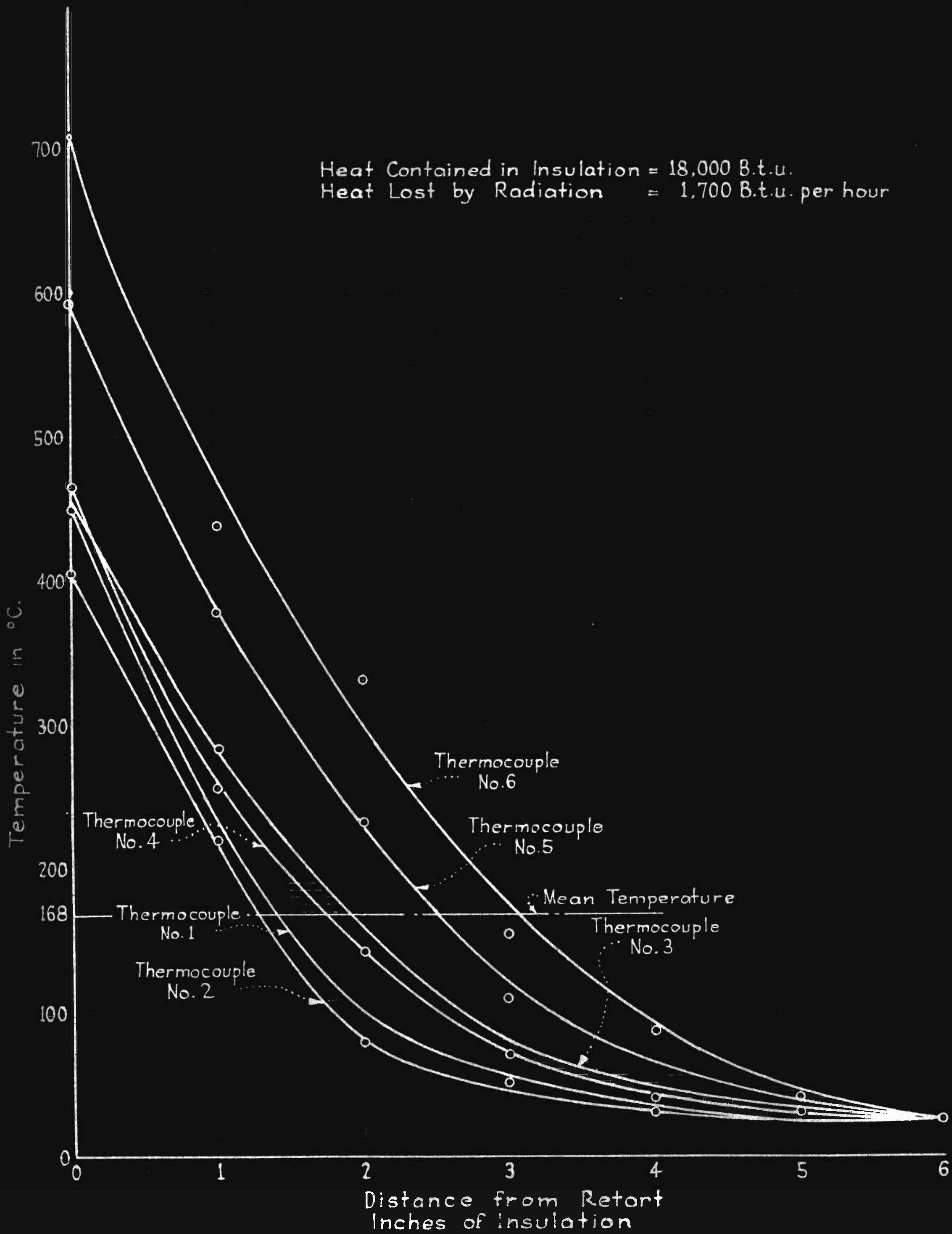


FIG. 4

TEMPERATURE GRADIENTS IN THE RETORT INSULATION

TEST RUN NUMBER 8

The retort was charged with fifty pounds of coal sized to -1" to +½", which was distilled with superheated steam at 760 Degrees Centigrade (1400 Degrees Fahrenheit).

Reference to the accompanying temperature curves and operating data shows that superheated steam entered the retort and was raised to 300 Degrees Centigrade by the end of the first twenty minutes, whereupon its temperature was maintained substantially constant for the remainder of the 'preheating period'. By the end of this period, namely, one hour and ten minutes, number one thermocouple had reached 135 Degrees Centigrade. The superheated steam temperature was then raised to 760 Degrees Centigrade where it was maintained substantially constant for the remainder of the 'superheated steam period'. At the end of this period, namely, one hour and ten minutes, the superheated steam was shut off, the upper retort plug removed, and saturated steam passed through the superheater and exhausted to the atmosphere until the superheated steam had been reduced to a temperature of 200 Degrees Centigrade. Meanwhile, all retort temperatures were read and recorded. The retort plug was then replaced and steam from the cooled superheater was then passed through the retort until all thermocouples indicated retort temperatures approximating 250 Degrees Centigrade.

This run was made for the purpose of observing the operating characteristics of the retort when low temperature superheated steam was used for preheating the charge, also for cooling all of the residue, which results appear in the accompanying data.

DATA SHEET

LOW-TEMPERATURE CARBONIZATION TEST ON CANNEL COAL FROM SOUTHERN UTAH

University of Utah, May 17, 1933

Test No. 8 . Made by: S. O. Jacobsen and G. W. Carter.
Size of Coal: -1" to + ½" . Superheated Steam Temp. 760 °C.
Pressure of Saturated Steam to Superheater: 20 lb. per sq.in. gauge.
Average Superheated Steam Pressure 3.1 lb. per sq. in.gauge.
Barometer: 25.18 "Hg.
Pounds of Superheated Steam used per hour: 60.0

Time	Retort Temperatures- °C.							Ave.	Remarks
	1	2	3	4	5	6	7		
3:50	18	24	20	20	16	22	40		
4:10	84	54	58	56	92	222	298		
4:20	82	60	124	82	124	244	302		
4:42	86	86	146	154	210	270	298		
4:50	104	108	166	166	218	274	300		
5:00	132	134	180	176	228	280	306	205	-
5:02									(Superheated)
									(Stm. Temp.)
5:05	154	150	190	180	230	282	394		(Increased)
5:15	174	164	204	192	254	356	552		Generated Gas
									Began
5:30	192	182	278	235	324	472	660		
5:45	230	222	282	312	418	566	735		
6:00	280	268	358	398	492	614	760		
6:11									Sup.Steam and
6:13	332	318	406	427	540	642	700	481	Gas Cut.
6:29	Steam turned through superheater, but exhausted to the atmosphere until thermocouple No. 7 reached 415.								
6:45	248	320	394	408	524	490	406		
7:00	225	317	382	394	522	400	292		
7:15	206	316	376	380	502	342	236		
7:35	178	304	364	364	464	282	200		
7:47	286	316	354	316	342	230	170		Saturated Stm.
7:52	306	306	321	276	304	218	154		Admitted.
8:00	300	277	277	243	270	203	136		
8:15	238	233	233	209	233	181	120		

Note: This charge was preheated to an average of 205° C. before carbonization began.

Test No. 8

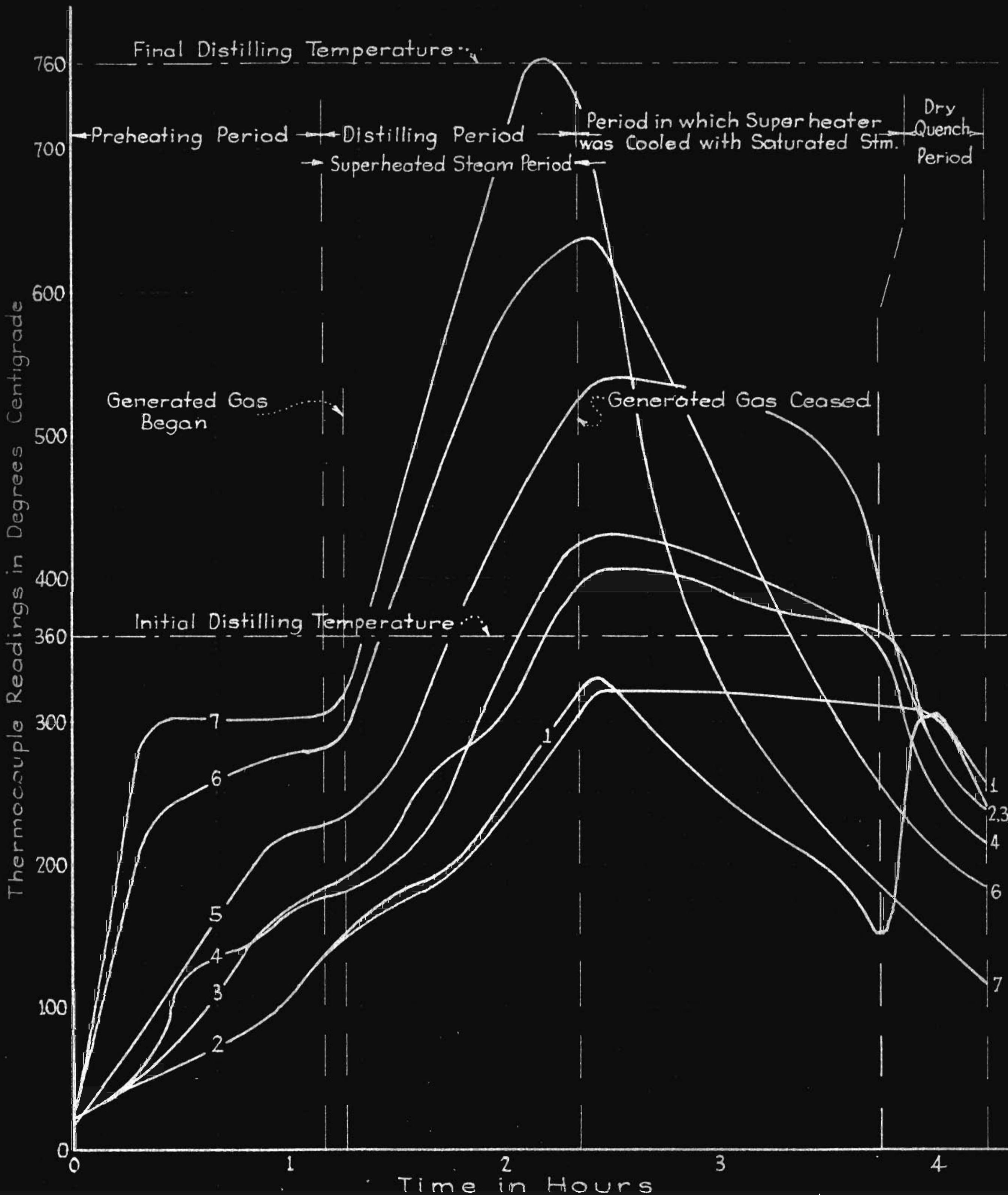
May 17 1933

TABULATED RESULTS

1. Weight of raw coal charged, pounds.......	50.0
2. Weight of residue from retort, pounds....	22.0
3. Weight of volatiles, pounds.............	28.0
Pounds per ton of coal..................	1120.
4. Quantity of crude oil, gallons..........	1.625
Gallons per ton of coal.................	65.
5. Total gas generated, cubic feet..........	(Meter out of
Cubic feet per ton of coal..............	order)
6. Time required for destructive distillation, hours	1.15
7. Time that superheated steam was used, hours	1.15
8. Total time of run, hours.................	3.22
9. Superheated steam required for destructive distillation, pounds	69.5
Pounds per ton of coal..................	2780.
10. Total superheated steam used, pounds.....	69.5
Pounds per ton of coal..................	2780.
11. Heat required for destructive distillation, B.T.U.	7710
B.T.U. per ton of coal..................	308,400

HEAT DISTRIBUTION IN RETORT

per test charge.	B.T.U.	Percent of total.
1. Total heat content of superheated steam entering the retort	121,000	100.00
2. Heat given to the retort.................	3,450	2.83
3. Heat given to the residue................	2,190	1.80
4. Heat in volatiles plus fixed gases.......	4,170	3.42
5. Heat content of superheated steam leaving the retort..	95,200	78.73
6. Heat unaccounted for.....................	15,990	13.22



LOG OF RETORT TEMPERATURES
TEST No. 8
SIZE OF COAL: -1" TO +1/2"

HEAT CALCULATIONS FOR TEST RUN NO. 6

The following information is presented to show the bases upon which the tabulated results and the figures representing the heat distribution in the retort were calculated. Test No. 6 is chosen for this purpose, since it is typical of the series of tests made. The numbers of the items appearing below correspond to similar numbers presented on page 47. For figures used in the calculations see data sheet, page 46. Items not listed are self-explanatory.

TABULATED RESULTS

3. Weight of volatiles, pounds

This is the difference between the weight of the raw coal charged and the weight of the residue, which is:

$$50 - 25 = 25 \text{ pounds.}$$

6. Time required for destructive distillation, hours

This is the total elapsed time from the instant superheated steam was admitted to the retort to the instant that thermocouple number one reached the initial distillation temperature, namely 360 degrees Centigrade.

7. <u>Time that superheated steam was used, hours</u>

This is the total elapsed time from the instant superheated steam was admitted to the retort to the instant that the superheater gas supply was shut off.

8. <u>Total time of run, hours</u>

This is the total elapsed time from the instant superheated steam was admitted to the retort to the instant that thermocouple number one reached 250 degrees Centigrade while the retort was being cooled.

9. <u>Superheated steam required for destructive distillation, pounds</u>

This is the total superheated steam used in the time specified in item 6 above.

10. <u>Total superheated steam used, pounds</u>

This is the total superheated steam that was passed into the retort during the time specified in item 7 above.

11. <u>Heat required for distilling the coal, B.T.U.</u>

This is the heat given to the coal charge itself during the time specified in item 6 above. This is the product of the weight of raw coal charged, times the specific heat of the raw coal, times the temperature difference between the figure representing the average of the thermocouple readings at the end and the figure for the average temperature at the beginning of the period specified in item 6 above. Substituting gives: 50x.31x682 = 10,600 B.T.U.

HEAT DISTRIBUTION IN RETORT, B.T.U.

1. Total heat content of superheated steam entering retort

Since the published steam tables do not give the properties of superheated steam above 1000 degrees Fahrenheit, it was found necessary to substitute in Goodenough's empirical equation:

$$H_s = 0.320\ T_a + 0.000063\ T_s^2 - \frac{23.583}{T_s} - \frac{C_{3p}(1+0.0342_0^{\frac{1}{2}})}{T_s^4}$$

$$+ 0.00333p + 948.7$$

in which

H_s = total heat of one pound of superheated steam above 32 degrees F.

T_s = superheated steam temperature- degrees Fahr. absolute.

C_3 = a constant, the logarithm of which is 10.7915

p = pressure of superheated steam, pounds per sq. in. absolute.

HEAT DISTRIBUTION IN THE RETORT, B.T.U. (Con't.)

The superheated steam temperature corresponding to 625 degrees C. (the average temperature during the superheated steam period) is:

$$T_s = 1157 + 460 = 1617 \text{ degrees F. absolute.}$$

The average superheated steam pressure was found by adding the average reading of the gauge to the barometric pressure. Thus

$$p = 3.6 + \frac{25.46}{2.04} = 3.6 + 12.48 = 16.08 \text{ lb. per sq. in. absolute.}$$

Substituting the above values in Goodenough's equation gives the total heat of one pound of superheated steam as being 1616 B.T.U.

The total heat content of the superheated steam entering the retort is the product of heat content of one pound of steam, the pounds of steam used per hour, and the time[1] in hours, which is:

$$1616 \times 56 \times 1.15 = 104{,}000 \text{ B.T.U.}$$

2. Heat content of retort

This quantity is equal to the product of the weight of the retort shell and the specific heat of the

(1) As herein used, this time is that specified in item 7 under "Tabulated Results".

sheet steel, plus the product of the weight of the retort pipe couplings and plugs and the specific heat of cast iron, each product being multiplied by the temperature difference.[1]

Weight of retort shell equals weight in pounds of one square foot of U. S. Standard Gauge sheet metal, times the square feet of retort surface:

2.5 x pi x 5/16 x 8 = 26 pounds.

Weight of 5" cast iron pipe couplings @ 10 lbs. each =	20 lbs.
Weight of 5" cast iron pipe plugs @ 5 lbs. each =	10 lbs.
Total	30 lbs.

Specific heat of sheet steel = 0.117
Specific heat of cast iron = 0.1298

Therefore the heat given to the retort is:

(26x0.117+30x0.1298) (853 - 205) = 4540 B.T.U.

3. <u>Heat given to the residue</u>

This quantity is equal to the product of the weight of the residue, the specific heat of the residue, and the temperature difference, between the average maximum temperature of the residue and the temperature of the coal as it entered the retort, is

25 x 0.2 x (752 - 70) = 3410 B.T.U.

(1) As herein used, the temperature difference is the difference between the average of the thermocouple readings in degrees F. at the end and beginning of the time as described in the first footnote, on the preceding page.

4. <u>Heat in volatiles plus fixed gases</u>

This quantity is equal to the product of the weight of the volatiles, the specific heat of the volatiles, and the temperature difference between the average temperature of the vapor as it left the retort during the superheated steam period and the temperature of the coal as it entered the retort, which is:

$$25 \times 0.3 \times (289 - 70) = 1640 \text{ B.T.U.}$$

5. <u>Heat content of superheated steam leaving retort</u>

This quantity is based on the average readings of number one thermocouple during the time as herein specified, and a pressure of 14 pounds per sq. in. absolute. This is higher than atmospheric pressure by the amount of the friction head in the condensers and the piping. The heat content of one pound of steam based on an average temperature of the vapor as it left the retort at 289 degrees F. was found from steam tables to be 1182 B.T.U. Therefore the total heat of superheated steam was

$$1182 \times 62 \times 1.15 = 84{,}500 \text{ B.T.U.}$$

6. <u>Heat unaccounted for</u>

This quantity is the heat imparted to the insulating material, plus the heat lost by radiation from the retort casing surface, from the highly heated retort cap, and probably from errors in observed exit steam temperatures. This amounts approximately to 4,000 B.T.U. the heat imparted to the insulation, assuming the 2-inch layer of insulation next to the retort fluctuates about 500 degrees F. in heating and cooling, and is unaffected beyond a point 2 inches from the retort, also 2000 B.T.U. lost by radiation. This total of 6,000 B.T.U. subtracted from the 9,910 B.T.U. shown in the unaccounted for heat in the "Tabulated Results" for Test 6, still leaves 3,910 B.T.U. unaccounted for which must be the heat lost from the very high temperature surfaces at the top of the retort and probably errors in the observed temperatures of the discharged steam and volatiles. All thermocouples, excepting No. 7 which was inserted within the superheated steam line, were placed in contact with the outer wall surface of the retort and undoubtedly gave low readings.

DISCUSSION OF RESULTS

GENERAL. The purpose of the foregoing curves is to show the instantaneous temperatures and particularly the rate of change of temperature, of the superheated steam and the coal throughout the retort during the progress of the test runs. The thermocouples placed at regular intervals along the length of the retort, as previously described, are numbered from 1 to 6 inclusive, the one at the vapor outlet being designated as number 1. The temperature of the superheated steam as it entered the retort was determined by thermocouple number 7.

Except for the graph representing conditions of test No. 8 in which the charge was preheated and finally dry-quenched with relatively low-temperature superheated steam, the curves herein presented are substantially of the same general shape.[1] Throughout all of the tests, it is interesting to note the consistent lagging of the temperatures near 100 degrees C., as indicated particularly by thermocouples No's. 1, 2 and 3,

(1) Dotted curves indicate probable temperatures. Thermocouples in these cases were either out of order or being used to obtain temperatures in the retort insulation.

during the first part of the superheated steam period when the coal in the lower zones was being heated up by condensation of the steam, following this the subsequent rate of temperature increase as indicated by the slope of the curves, and then the crossing of the curves as the retort is cooled, ultimately resulting in reversing the final arrangement of the curves.

COAL SIZE vs DISTILLING PERIOD. Tests No. 1 and No. 5 show the influence of the size of coal on the length of time required for distillation at the same final distilling temperature. The charge used in Test No. 1 was sized to -1" to + ½" and that used in Test No. 5 to -½" to +¼". Comparison of the distilling periods as indicated on the curves shows the period in No. 5, exceeding by 2 minutes that in No. 1 in which the larger coal was used. This appears to be in a direction contrary to the expected results. However, it was observed that this cannel coal tended to fracture when it was crushed, into flat laminated pieces which were thin in section and yet large enough in the other dimensions to be withheld by a ½" mesh. Hence, the larger size of coal was usually no thicker in its smallest dimension than the smaller size and will distill in like periods of time, also the pieces became porous with many small cracks parallel to the bedding plane which made them permeable to the superheated steam. This effect would not be measurable in treating coal lumps of much larger sizes. Also, it should be noted, that the distillation progressed down through the 8-foot column of coal, in both instances, at the rate of 1-foot in each 10 minute interval. Or, if we consider the range of temperature within which the coal is distilled as 360 degrees C. to 450 degrees C., then in each instance the average period that the coal particle is undergoing distillation is twenty minutes. Previous work, however, has demonstrated that coal of the two sizes used will actually distill in less than twenty minutes, and therefore the distilling period is in these tests entirely governed by rate of heat supply and not by coal particle size. With coal charges composed of lumps having minimum dimensions of 1 inch the effect of lump size on distilling rate would be important. Lumps 1-inch minimum diameter will require approximately 1 hour to distill and 2-inch lumps nearly 3 hours under the above conditions.

<u>SUPERHEATED STEAM PERIODS vs ECONOMY.</u> The charge used in Test No. 5 was heated with superheated steam until

after the end of the distilling period, while in Test No. 6 the heating gas supply of the superheater was shut off before distillation was completed in an effort to use the steam most economically (note the length of superheated steam period in each case). An inspection of the curves for Tests No. 5 and No. 6 shows that using the same final distilling temperature (650 degrees C.) and securing complete distillation in both cases, the superheated steam period was 20 minutes shorter in Test No. 6 in which steam economy was practiced than in Test No. 5. Obviously, then it is distinctly advantageous from the standpoint of economy to shut off the superheater gas supply before distillation is complete, since the same end conditions of distillation result. The practical application of the economy would be to divert the superheated steam into another retort at this moment. Curves for Tests No. 2 and No. 3 show a similar saving of superheated steam at a higher final distilling temperature (760 degrees C.).

DISTILLING PERIOD vs FINAL DISTILLING TEMPERATURE. Test No. 3 and Test No. 4 were both run with an attempt to secure superheated steam economy, but different superheated steam temperatures were used, No. 4 being

535 degrees C. and No. 3, 760 degrees C. By reference to the curves it is seen that the distilling period for No. 4 at the lower temperature is 8 minutes longer than No. 3. It will also be noted however, that the rate of temperature increase as of thermocouple No. 7, indicated by the slope of the curve, is much slower in Test No. 3 than in Test No. 4. Hence if superheated steam had been raised to its final temperature in equal periods of time, then, with the same flow of steam, the distilling period of Test No. 3 at the higher distilling temperature would have been much further reduced. It may be concluded, therefore, that the higher superheated steam temperatures will decrease the length of the distilling period as well as the consumption of superheated steam.

GENERATION OF WATER GAS. It was found in the runs using superheated steam at temperatures of 650 degrees C. and above, that large quantities of gas were generated, as may be seen by reference particularly to the data sheet of Test No. 3, the steam temperature of which was 760 degrees C. This gas was identified by the flame color and behavior in burning as blue water gas produced by the combination of the chemically reactive coal residue with the highly heated steam, in accordance with the following reactions:

$$C + H_2O = CO + H_2$$

$$C + 2H_2O = CO_2 + 2H_2$$

Mixed with this gas was also some of the gas formed from the residual volatiles of the coke residue consisting of methane and hydrogen, also possibly some distillation gases.

PREHEATING EFFECTS. The curves for Test No. 8 show that thermocouples No. 1 and No. 2 reached a temperature of 135 degrees C. in 70 minutes while the preheating of the charge with superheated steam at 300 degrees C was in progress. In Test No. 3 made at 760 degrees C. the curves show that these thermocouples did not reach this same temperature until 55 minutes of the superheated steam period. Also in Tests No. 2 and 7 made at 760 degrees C. at the end of 55 minutes of the superheated steam periods, these thermocouples indicated 250 degrees C. It will be noted further that in dry-quenching the charges in all the various tests the lowest temperature reached by the steam leaving the retort, couple No. 1, was approximately 250 degrees C.

Therefore it is obvious that by the proposed method of using this steam leaving the retort, during the dry-quenching period, for preheating a fresh coal charge in another retort, that much high-temperature steam would be saved. The superheated steam period was 70 minutes in Test 8, 95 minutes in Test 7, 85 minutes in Test 3, and 100 minutes in Test 2. Had it been that the superheated steam used in Test 8 was initially at 760 degrees C., as would be the case in a commercial plant where the steam at constant temperature is diverted from one retort to the next, it is probable that the superheated steam period and the preheating period would each have been 60 minutes or less, making a total period of 120 minutes.

There are good evidences why the entire outflow of steam, oil vapors, and gases from the base of one retort should pass through the next retort of fresh coal enroute to the condensers, thus serving to preheat the new coal with both the exit superheated steam and the dry-quenching steam, and continuing until the new charge has stored within it the greatest quantity of heat. In the case of cannel coal, from which the coal residue will not have extensive market value because of its high ash content, the final cooling of the residue to a safe temperature for storing might be advantageously done by discharging it and spraying with water. This procedure serves to keep the retorts free for distilling purposes during the greatest percentage of their time, which would not be the case if they were used to serve as dry-quenching chambers. In the case of coals such as the Carbon County coals from which the smokeless fuel residue is the important product desired, the coke should be dry-quenched with steam in the retorts to the safe storage temperature thus keeping the product physically dry. In this procedure the dry-quenching steam might be best derived by recovering the sensible and latent heat of the volatiles issuing from one retort by condensing them in an evaporator type of condenser, the new low-pressure steam then being passed through the coal residue immediately following the diverting of the superheated steam into the next retort.

<u>DISTILLING GRADED SIZES OF COAL.</u> As shown above, there was no reduction in time consumed in distilling the charges comprising the different sizes of cannel coal, this being because of the fact that the largest lumps

used, namely, - 1 ≁ ½ inch actually required much less time to distill them than the time for the distilling heat-wave (360 degrees C. to 450 degrees C.) to pass entirely through the retort from top to bottom. Had the lumps been over 1-inch in minimum dimensions a coal charge of the height, or even greater or less height, and with the same flow of steam, would have consumed more time. However, there is the practical consideration to be met as to the best way to effectively distill the maximum quantity of the slack coal at the proposed cannel coal mine. It would appear from the foregoing data that the slack coal should be screened to several sizes and these placed severally into the retort with the coarsest at the base and the finest dust free size, say - ¼" ≁ 1/8", at the top as applied in Test No. 7. The size from dust up to 1/8-inch would then serve for stoker fuel under the boiler or for heating the separately fired superheater. In a stoker this high oil-yielding fuel should undergo combustion much like an oil fire. In the treatment of Carbon County slack coal the physical properties, crushing strength and insipient fusibility of the coal while undergoing distillation, requires that the retort charge be composed of stratified layers with the coarsest (the strongest) lumps at the base of the charge so as to avoid crushing and yet compress slightly while improving the density and hardness of the smokeless fuel product.

RETORT INSULATION AND TEMPERATURE GRADIENTS. Figure 4 shows the temperatures along the retort surface and at six equidistant points throughout the thickness of the insulating wall at the thermocouple positions shown in Figure 2. These measurements were taken during Test No. 7 after the production of oil had ceased and the retort had therefore been receiving heat for approximately 1½ hours. The temperature readings on the retort wall were taken after the flow of steam had been shut off. Each thermocouple starting with No. 1 was read and then moved out 1 inch from the wall into the insulation. After No. 7 was read a second reading was made of No. 1 and it was then moved out another inch. Thus the measurements were taken out to and including the surface temperature of the insulating wall, the entire set of temperature readings requiring about 50 minutes.

It is recognized that the temperature gradient through the wall at each thermocouple position should be a curve of logarithmic form if the temperature of the heat-receiving surface had been constant. This, however, was not the case since during the progress of the distillation all points along the retort had been gradually rising in temperature in accordance with the records shown in Test 7 graphs. Consequently it may be stated that the points on each thermocouple curve above the abscissa, figures 1 to 6, are instantaneous records of the temperature of the insulating material, which is the additive effect of an infinite series of heat impulses, of increasing potential, moving out through the insulating wall. Therefore the curve is steeper than if the temperatures had been stationary. The temperature of the outer surface will, of course, move up and down as the waves of heat pass down the retort in successive distillation tests. The figure shown on Figure 4 for the surface temperature was used in calculating the heat loss.

<u>YIELD OF PRODUCTS.</u> It will be observed by referring to the data on each test that the oil yield was the same in all instances within the range of possible experimental error in collecting the oil and its distillation to remove the contained water. It is logical to conclude that the yields actually were the same considering that

the particles of coal throughout the charge experienced practically the same rate of rise of temperature in all tests while passing through the distillation range (360 degrees C. to 450 degrees C.). Although the contents of the retort were heated hotter in some tests, this occurred after the oil was removed and carried out of the retort[14].

The average yield of crude oil in this study was 64.0 gallons per ton of coal, that reported by Allen 68.8.

The latter analysis was made by Karrick in the U. S. Bureau of Mines in which the following data regarding the oil also appear:

"Specific gravity of crude oil - .918 at 15.56 degrees C.; Baumé 22.5.

Viscosity of crude oil at 60 degrees C. - 57 Saybolt.

Setting Point of crude oil - 34 degrees C.

DISTILLATION ANALYSIS		PERCENT	SPECIFIC GRAVITY
First drop	49 deg.C.		
Percent to	150 deg.C.	4.34	.767
" "	200 deg.C.	11.54	.830
" "	275 deg.C.	16.67	.865

VACUUM ANALYSIS:	PERCENT	SPECIFIC GRAVITY	VISCOSITY	SETTING POINT
Percent to 200 deg.C.	1.87	.889	40	-15 deg.C.
" " 275 deg.C.	27.14	.920	66	36 deg.C.

Residium Waxy and oil probably will yield good percentage of high melting point wax."

Thesis cracking analysis at 120 lbs. pressure, gave 15 gal. refined gasoline, 12 gal. kerosene, 15 gal. fuel oil from which diesel oil and road oil can be refined, 2 gal. of cresylic acid, 52 lbs. of ashless coke from each ton of coal.

The measurements of coal gas were made and recorded for each test and it was found that the average distillation gas had a fuel value of   B.T.U.

The cannel coal residue was easily kindled and burned very well without smoke.

SUMMARY

An engineering investigation has been made of a valuable natural resource of the State of Utah, - the cannel coal body in the Zion Canyon - Cedar Breaks area of Southern Utah. The availability of this undeveloped body is noted, also its probable economic importance to the State. Attention is now directed to the potential usefulness of this great body, offering many new Mechanical, Mining, and Chemical Engineering studies for engineering students of the University, also as a source of revenue for the Utah Research Foundation which has just been created.

A "heat" and "products" study has been made in the destructive distillation of this cannel coal. Super-heated steam was used as the heat-transferring fluid, wherein the heat units involved have been measured and their distribution traced during the mechanism of the heat transfer steps while heating, also while abstracting heat, "dry-quenching" the residue, with low temperature steam. The quantity of coal gas and the semi-coke were determined, also the crude oil product was refined into desirable petroleum derivatives.

Steam from turbine exhaust or other economical

source, when reheated, provides an effectual way of transferring the necessary heat into batches of dust-free slack coal and accomplishing very rapid distillation. Important economies in steam consumption are obtained, (1) by preheating the coal, (2) by using maximum steam temperature, (3) by using physically dry coal, (4) by reducing heat absorption in walls of retort by using retort covering of low conductivity and heat capacity, therefore by using large diameter charge of coal to minimize surface loss factor, (5) by reducing radiation losses, (6) by utilizing the heat stored in top portion of coal charge to distill by transfer of its heat to the lower portion of coal charge, (7) by using sensible heat of coal residue to preheat new coal, (8) by condensing the issuing steam and oil vapors in an evaporator and using the new steam generated to dry-quench and preheat other new coal charges, (9) by using very tall retorts full of properly sized coal. The data indicate that the small diameter retort used in these studies can apply economies and distill coal with less than one pound of steam per pound of coal treated.

This cannel coal, unlike the fusing types of bituminous coking coals, has the desirable physical property of holding its form without crushing or cohesion while passing through the treatment. The solid residue is active chemically, though high in ash, and should be a good smokeless domestic fuel or fuel for industrial gas. The crude oil was readily cracked into a color-stable, non gum-forming gasoline with small refining loss.

The slack coal should provide a permanent supply of low-priced city gas and diesel power-plant oil for Cedar City, also motor fuel and road oil for the National Parks area, and develop a new coal mining industry of a remarkable coal with steady employment for labor in Southern Utah.

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