PRELIMINARY EXPERIENCES WITH THE INJECTION OF COLD COAL PASTE
GELSENKIRCHEN-HORST, DECEMBER 2, 1941

One hydrogenation chamber was tentatively equipped for the injection of cold coal paste by installing a connection by-passing the normally used preheater. After the installation of valves and throttling pipes to control the flow, it was possible to operate the reactor satisfactorily. This resulted in an increase in through-put from 28.8 tons of paste per hour (10.8 tons dry coal) to 32.3 tons/hour (12.4 tons of dry coal). The reactor temperature had to be increased by an average of 0.1 mv. (probably iron-constantan thermocouple) in order to keep the quantity of sludge formed equal to that of normal operations. The sludge contains, however, somewhat more solid matter and asphalt and the yield of middle oil recovered in the separator at 626°F. is somewhat smaller.

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Gelsenkirchen-Horst, December 12, 1943

REPORT ON EXPERIMENTS ON HEATING COAL PASTE WITH HOT GAS

A test run over a period of 10 days was made on one unit consisting of 4 reactors and a separator. The experiments were carried out for the following purposes:

1. To investigate the possibility of heating the coal paste to the starting temperature of the reaction by mixing with an economically permissible quantity of hot gas.

2. To find the minimum temperature for starting the reaction in the first reactor.

3. To study the chemical processes in a reactor in which the paste is heated suddenly from the lower swelling temperature to the reaction temperature.

4. To study the behavior of coal paste of normal concentration in the paste heat exchanger (against separator product and exit gas) when the paste containing a small quantity of gas flows inside the tubes, to study the heat transfer obtainable in this case and to determine the wall temperatures of the tubes and the heat transfer for the preheater tubes for heating the mixing gas to about 914°F. (490°C.).

It was intended to preheat the coal paste with a small quantity of paste gas in a heat exchanger and tubular preheater. The starting temperature for the reaction was to be reached by the addition of a larger amount of process gas in two mixing tubes ahead of the first reactor without additional heating.

The tests were carried out as follows:

The coal chamber was heated as usual using 1,940,000 cu. ft./hour of preheated fresh gas and 353,140 cu.ft./hour of heat exchanged paste gas. The amount of paste gas was increased during the starting period to control the heat exchanger temperature. On changing over to coal paste and decreasing the amount of paste gas to 141,200 cu.ft./hour the amount of oil injected could only be cut back to 11.0 tons/hour because further decrease lowered the heat exchanger outlet temperature from 17mV = 644°F. (conversion as given in the original) to 13-14 mV (probably iron-constantan thermocouples). This would give an over-all coefficient of only 12.3 B.t.u./hr./sq.ft.(°F). This condition was also affected by the low yield of the separator product which could have been used to improve heat economy in the exchanger by increasing the temperature difference. By reducing the concentration of solids in the reactor feed and by increasing the yield of separator product it was possible to raise the quantity of paste injected to 27.8 tons/hour. The total quantity of feed to the reactor amounted to 38.8 tons/hour. The feed of paste gas to the heat exchanger was finally raised again from 141,200 cu.ft./hour to 353,140 cu.ft./hour in order to increase the flow rate and the space velocity in the heat exchanger tubes. The addition of oil could be reduced from 11.0 tons/hour to 6.6 tons/hour and the throughput of paste was increased from 27.8 tons/hour to 33.1 tons/hour. It was, however, not possible to maintain this throughput rate without short interruptions (variations in heating value, difficulties with the paste presses). This is due to the fact that even slight variations in the operating conditions which resulted in a decrease in the yield of separator product caused a decrease in the efficiency of the reactors because of insufficient heat available for transfer in the heat exchangers; the reaction then had to be started again which was somewhat difficult.

The following conclusions can be drawn from the results of the test runs:

1) The coal chamber equipped with this preheater can be operated satisfactorily.

2) In spite of the large amount of gas (2,300,000 cu.ft./hour) the reactor started as usual. The temperature in the first reactor rose from 23.2-23.4 mV (probably iron-constantan thermocouple) to 25 mV. Later on it was found advisable to allow the temperature in the first reactor to rise only to about 24.5 mV in order to have sufficient cold gas for the control of the separator exit temperature which had to be kept at 23-23.5 mV because of the low efficiency of the heat exchanger. The heat of reaction in the first reactor was about 164-180 B.t.u./lb. of coal and lies within the limits found for other coal chambers (147-188 B.t.u/lb of coal). This proves that coal paste can be heated with a reasonable quantity of gas (about 48,000 cu.ft./ton of coal paste) of a temperature of 680°F. to a temperature sufficient to start the reaction and it is further proven that starting is not different from that of the conventionally operated units.

3) The chemical behavior is characterized by the following data. The average reactor temperature was for equal throughput about 0.3 mV lower than the regularly operated reactors. The percentage of solids and asphalt in the sludge was 20.1 and 19.8, respectively, and corresponds to normal operating values. The amount of sludge was kept at 44-49%. The middle oil content of the separator product was about 47% which is 1-2% below the normal value but this is due to the large amount of heavy oil recycled. It was found that the experimental operation resulted in better efficiency of the centrifuge operation; the percentage of solid matter increased to 38% in the residue and decreased to 10% in the oil. This effect persisted as long as the experimental operations lasted. During this time it was possible without special effort to reduce the solid matter in the pasting oil from 10.6 to 10.0%. No change was found in the hydrogen consumption. Gas production amounted to 22% and was lower than usual. It can be concluded that the sudden heating of coal paste to the starting temperature has no detrimental effect on the processing properties of the products. It is not entirely clear if the increased efficiency of the centrifuging operation is due to the design of the preheater or separator or due to the temporary shut-down of the neighboring chamber which normally also feeds into the centrifuges.

4) Although the preheated coal paste had only a temperature of 662°F. instead of 680°F. it was possible to reach the calculated mixture temperature by increasing the amount of gas added by about 5%. Mixing of paste and gas took place in a tee in such a way that the hot gas passed into the paste through a tube of 27.6 in. length provided with numerous holes with a diameter of 0.16 in. The gas bubles are sufficiently small to increase the heat transfer area between paste and gas and a special length of pipe for mixing is probably unnecessary.

5) The preheater capacity corresponded to the design figures. 1,940,000 cu.ft./hour of process gas could be heated to 27.0 mV (960°F.). The over-all coefficient for the gas section was found on the average about 20% higher than the calculated value. The wall temperatures rose on the average from 941°F. to 954°F.

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because of the blocking off of a section (for mixing purposes) and the increased heat input (about 1,800,000 B.t.u./hour) necessitated by the low efficiency of the heat exchanger. The fire box temperatures changed accordingly from 1101°F. (14.0 mV) to 1119°F. (14.3 mV). The quantity of heat transferred (15,150,000 B.t.u./hour) is about 8% higher than calculated. The conditions with respect to the coal paste section were even more favorable.

6) For the design of the heat exchanger previous experience with heat exchangers for coal paste of normal concentration was taken as a basis. At a flow rate of about 2.53 ft./sec. for the gas-paste mixture outside the tubes the over-all coefficient remained unchanged at about 51.1 B.t.u./hour/sq.ft. (°F.). Running the mixture of paste with little gas inside the tubes resulted in a decrease of the flow rate to about 1.57 ft./sec. and in accordance with the rules for heat transfer a value for a coefficient of 36.8 was assumed which is 72% of the value found for the higher rate of flow. With this coefficient it should have been possible to heat the mixture to 16.5 mV = 626°F. and it had been shown that this high temperature could actually be reached with coal paste of normal concentration in the region of swelling; a temperature of 174.4 mV = 655°F. at the heat exchanger outlet had previously been reached during the regular operation of one of the other chambers. It was not possible to reach these conditions in the experimental runs. Quite unsatisfactory heat transfer results were obtained with coal paste of the usual concentration and small quantities of gas. In order to keep the unit in operation it was necessary either to drastically reduce the concentration of solids in the paste (by the addition of 6.6 tons/hour of oil) or by increasing the quantity of paste gas to at least 353,140 cu.ft./hour. In spite of these measures only temperatures of 15.8-16.0 mV (608°F.) instead of the intended 16.5 mV (626°F.) and film coefficients of 30.7 instead of 36.8 were reached. The addition of 11.0 tons of oil and 141,200 cu.ft./hour of gas gave the same film coefficients and exchanger exit temperatures as the addition of 6.6 tons of oil and 353,140 cu.ft./hour of gas.

The quantity of heat exchanged amounts to 8,810,000 B.t.u./hour corresponding to 93% of the calculated quantity; only about 70% of these were transferred to the coal paste. The remainder was used for heating the additional 2.2 tons/hour of oil and 247,000 cu.ft./hour of gas, which means a useless expenditure of 1,440,000 B.t.u./hour and a loss of about 7.7 tons of coal paste.

This unfavorable behavior of the heat exchanger cannot be explained by the change to flowing the coal paste inside the tubes rather than outside because no fundamental differences exist for these two methods of operation as shown by the experience of the Pölitz plant. The presence of only a small quantity of gas also can have no effect since the heat exchanging surfaces are wetted by paste in any case and the heat has to pass through this film to enter the bulk of the mixture. In the paste section of the regular preheaters over-all coefficients of 65.3 to 81.8 (calculated on internal surface) have been found. Consequently the effect of the rate of flow and the distribution of the paste over the toal number of tubes has to be clarified.

The effect of the rate of flow is much greater than expected. During a test on one of the units the over-all coefficient fell from 51.1 to 28 B.t.u./hour/sq. ft. (°F.) by reducing the flow velocity from 2.53 to 1.74 ft./sec. by means of reducing the throughput to 27.6 tons (gas volume 1,060,000 cu.ft./hour, unchanged); these values indicate that gas and coal paste do not have the same velocity. In Politz the same heat transfer values as in regular operation are obtained when running the paste inside the tubes in spite of the reduced

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exchanger surface because the velocity of flow could be increased as required. Downward flow should therefore be advantageous because in this case the paste flows faster than the gas due to the bouyancy of the gas. Since this effect is not noticed with the exchanger of the test unit the reason for its low efficiency seems to be in the distribution of coal paste over the heat exchanger tubes. When operating the exchanger in such a way that the paste flows outside of the tubes the entire diameter of the exchanger is filled. In the case where the paste flows inside the tubes upwards there is a possibility that the small quantity of dispersed gas rises only in the center tubes where it reduces the density of the paste column whereas the outer tubes contain only paste or paste with very little gas. The difference in density counteracts the pressure differential causing flow and reduction or stoppage of flow results which means elimination of the efficiency of the outer tubes. The concept that the tubes fill uniformily in the case of upward flow is only valid for the moment of the first injection of oil and cannot be applied to continuous operation.

When using downward flow inside the tubes differences in density and pressure add which results in equalization of flow and paste without gas can also flow because of its weight. The difficulties with uniform distribution of the paste on the upper exchanger section caused by the high entrance velocity of the paste can be overcome by the installation of distributors of the kind used in absorbers and distillation columns.

Calculations

The entire gas-paste mixture with a heat capacity of 42,300 B.t.u. has to be heated in the first reactor from 779°F. to 878°F. = 99° which results in the absorption of 4,180,000 B.t.u./hour; to this has to be added 1020 B.t.u. x 878°F. - 122°F. = 774,000 B.t.u/hour. For 105,900 cu.ft./hour of cold gas and 180,000 B.t.u./hour for loss by radiation giving a total of 5,134,000 B.t.u./hour. This quantity of heat is produced from 28,500 lbs. of coal which corresponds to a heat of reaction of 180 B.t.u./lb. of coal.

Heat transfer data.

	Calculated	Experimentally Found
1) Heat exchanger.		
	Material to be heated: 39.7 tons/hour of paste + 4.4 tons/hour of oil + 106,000 cu.ft./hour of paste gas = 23,140 B.t.u., to be heated from 212°F. to 626°F. = 9,550,000 B.t.u./hour (9,720,000 B.t.u. including radiation loss).	Material to be heated: 33.1 tons/hour of paste + 6.6. tons/hour of oil + 353,140 cu.ft./hour of paste gas = 23,600 B.t.u., to be heated from 205°F. to 590°F. = 9,510,000 B.t.u./hour (9,540,000 B.t.u. including radiation loss).
	Material heat exchanged: 2,540,000 cu.ft./hour exit gas + 23.2 tons/hour separator product + 1.1 tons/hour water = 40,000 B.t.u., to be cooled from 824°F. to 481°F. = 9,720,000 B.t.u/hour.	Material heat exchanged: 2,510,000 cu.ft./hour exit gas + 20.9 tons/hour separator product + 1.1 tons/hour of water = 37,500 B.t.u., to be cooled from 842°F. to 603°F. = 9,540,000 B.t.u./hour.
	Over-all coefficient: 37.6 B.t.u./sq. ft./hour (°F.). Exchanger surface: 2020 sq. ft.	Over-all coefficient: 30.9 B.t.u./sq. ft./hour.
2) Preheater.		
	a) Gas section; parallel flow.	
	Material to be heated: 1,835,000 cu. ft./hour of gas = 17,700 B.t.u., to be heated from 541°F. to 914°F. = 6,600,000 B.t.u/hour.	Material to be heated; 1,940,000 cu. ft./hour of gas = 18,700 B.t.u., to be heated from 554°F. to 932°F. = 7,075,000 B.t.u.
	Material heat exchanged; 5,300,000 cu.ft./hour of recycle heating gas = 49,500 B.t.u. to be cooled from 1101°F. to 968°F. = 6,650,000 B.t.u./hour.	Material heat exchanged: 5,300,000 cu. ft./hour = 49,500 B.t.u., to be cooled from 1119°F. to 975°F. = 7,130,000 B.t.u./hour.
	Over-all coefficient; 1.9 B.t.u./sq.ft./Hour (°F.)	Over-all coefficient: 2.23 B.t.u./sq.ft./hour.
	Max. tube temperature = 941°F. - 11.3 mV	Max. tube temperature: 954 = 11.6 mV
	Heating surface: 35,600 sq. ft.	Heating surface: 34,500 sq. ft.

Heat transfer data (cont'd.)

2) Preheater (continued)

b) Gas section: countercurrent flow

Calculated

Material to be heated: 1,835,000 cu.ft./hour of gas = 17,700 B.t.u. to be heated from 122°F. to 541°F. = 7,390,000 B.t.u./hour.

Material heat exchanged: 5,300,000 cu.ft./hour of recycle heating gas = 49,500 B.t.u., to be cooled from 968°F. to 817°F. = 7,430,000 B.t.u./hour.

Over-all coefficient: 1.96 B.t.u./sq.ft./hour.

Heating surface: 15,100 sq.ft.

Experimentally Found

Material to be heated: 1,940,000 cu.ft./hour = 18,700 B.t.u., to be heated from 122°F. to 554°F. = 8,090,000 B.t.u./hour.

Material heat exchanged: 5,300,000 cu.ft./hour of recycle heating gas = 49,500 B.t.u., to be cooled from 975°F. to 811°F. = 8,100,000 B.t.u./hour.

Overall-coefficient: 2.52 B.t.u./sq.ft./hour.

Heating surface: 12,920 sq.ft.

c) Paste section; countercurrent flow

Calculated

Material to be heated: 39.7 tons/hour of paste + 4.4. tons/hour of oil + 106,000 cu.ft./hour of paste gas = 23,140 B.t.u., to be heated from 626°F. to 680°F. = 1,250,000 B.t.u./hour.

Material heat exchanged: 5,300,000 cu.ft./hour recycle heating as = 49,500 B.t.u., to be cooled from 817°F. to 790°F. = 1,350,000 cu.ft./hour.

Over-all coefficient: 1.31 B.t.u./sq.ft./hour.

Heating surface: 14,000 sq.ft.

Experimentally Found

Material to be heated: 33.1 tons/hour of paste + 6.6 tons/hour of oil + 353,140 cu.ft./hour of paste gas = 23,600 B.t.u., to be heated from 690°F. to 662°F. = 1,696,000 B.t.u.

Material heat exchanged: 5,300,000 cu. ft./hour recycle heating gas = 49,500 B.t.u., to be cooled from 811°F. to 777°F. = 1,710,000 B.t.u./hour.

Over-all coefficient: 2.06 B.t.u./sq.ft./hour.

Heating surface: 10,764 sq. ft.

3) Mixing temperature

Calculated

~~Gas: 1,835,000~~ cu.ft./hour = 17,700 B.t.u., at 914°F. = 15,640,000 B.t.u./hour.

Paste: 23,140 B.t.u., at 680°F = 15,000,000 B.t.u./hour.

Gas-paste mixture: 40,840 B.t.u., at 779°F. = 30,600,000 B.t.u./hour.

The mixture temperature is accordingly 779°F.

Preheater losses: 371,000 sq.ft. flue gas of 3500 B.t.u., at 788°F. = 2,700,000 B.t.u.

Heating gas requirements: 15,300,000 B.t.u./hour 27,000,000 B.t.u./hour = 43,300,000 B.t.u./hour, about equal as in normal operation without paste heat exchangers.

Efficiency of preheater: 85%

Experimentally Found

Gas: 1,940,000 cu.ft./hour = 18,700 B.t.u., at 932°F. = 16,830,000 B.t.u./hour.

Paste: 23,600 B.t.u., at 662°F. = 14,850,000 B.t.u./hour.

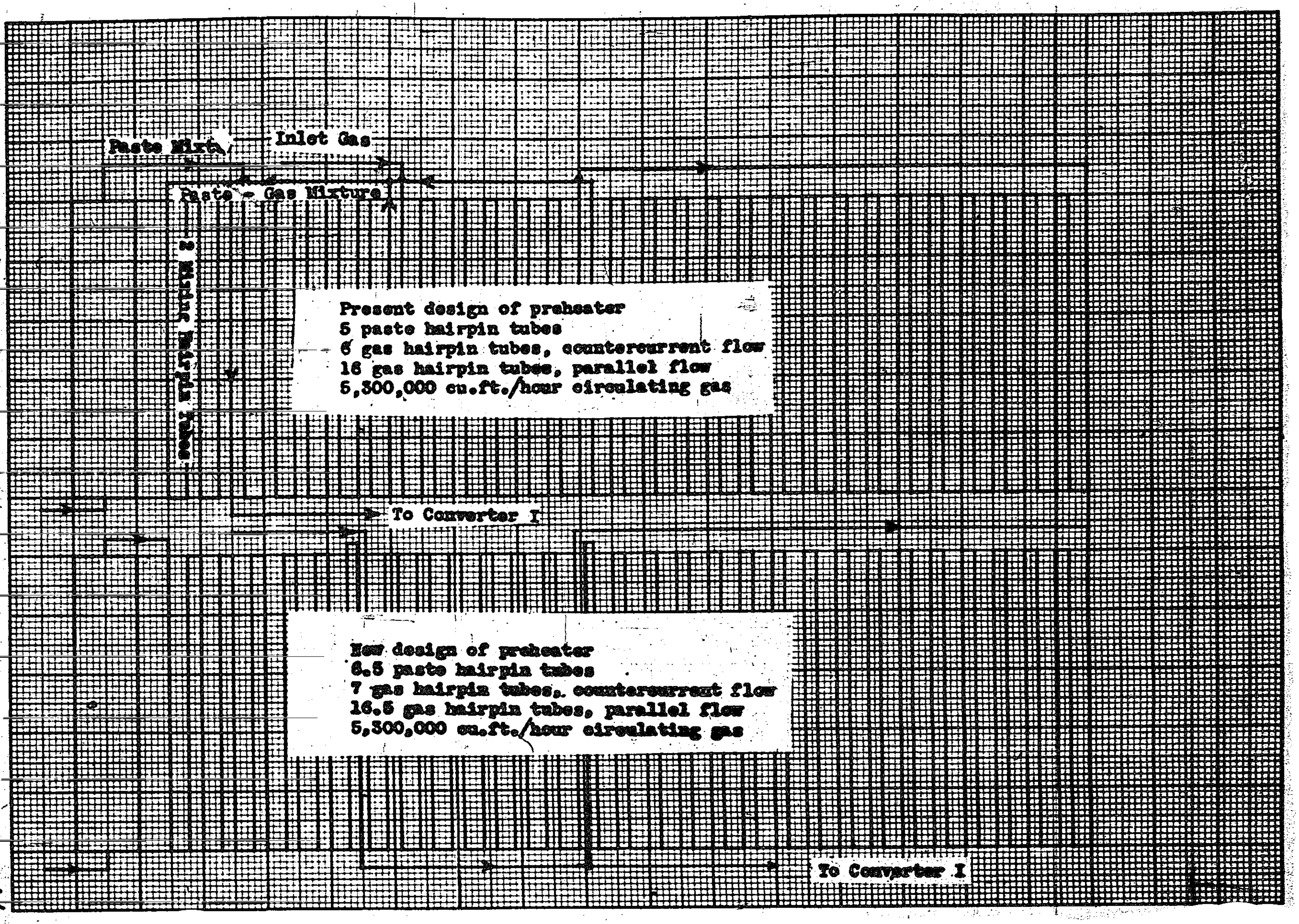
Gas-paste mixture: 42,300 B.t.u., at 779°F. = 31,640,000 B.t.u./hour.

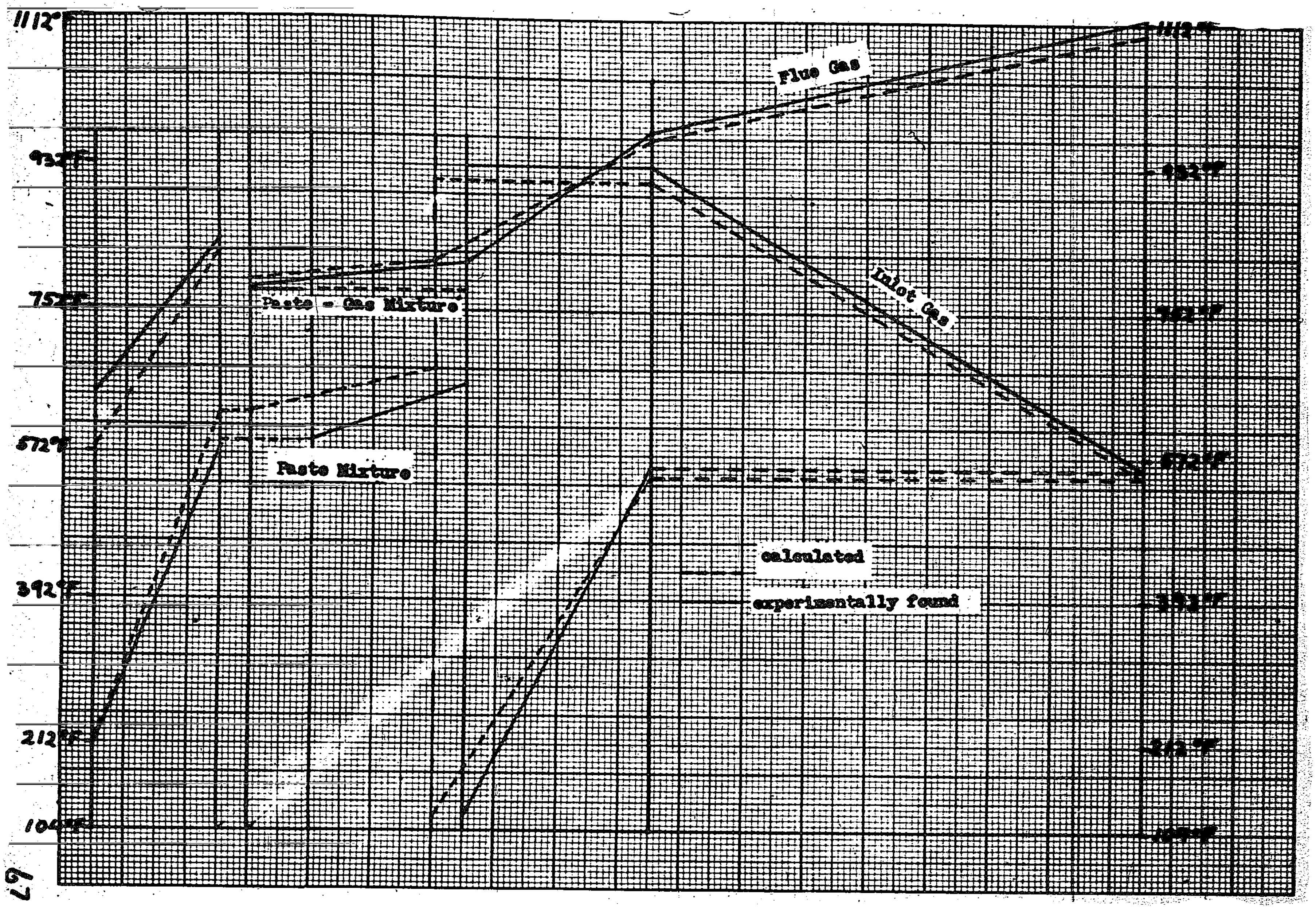
The mixture temperature was found to be 779°F. as is in agreement with the calculations; the heat was, therefore, transferred by mixture with theoretical Efficiency.

Preheater loss: 424,000 sq.ft. flue gas of 4000 B.t.u., at 777°F. = about 3,100,000 B.t.u./hour.

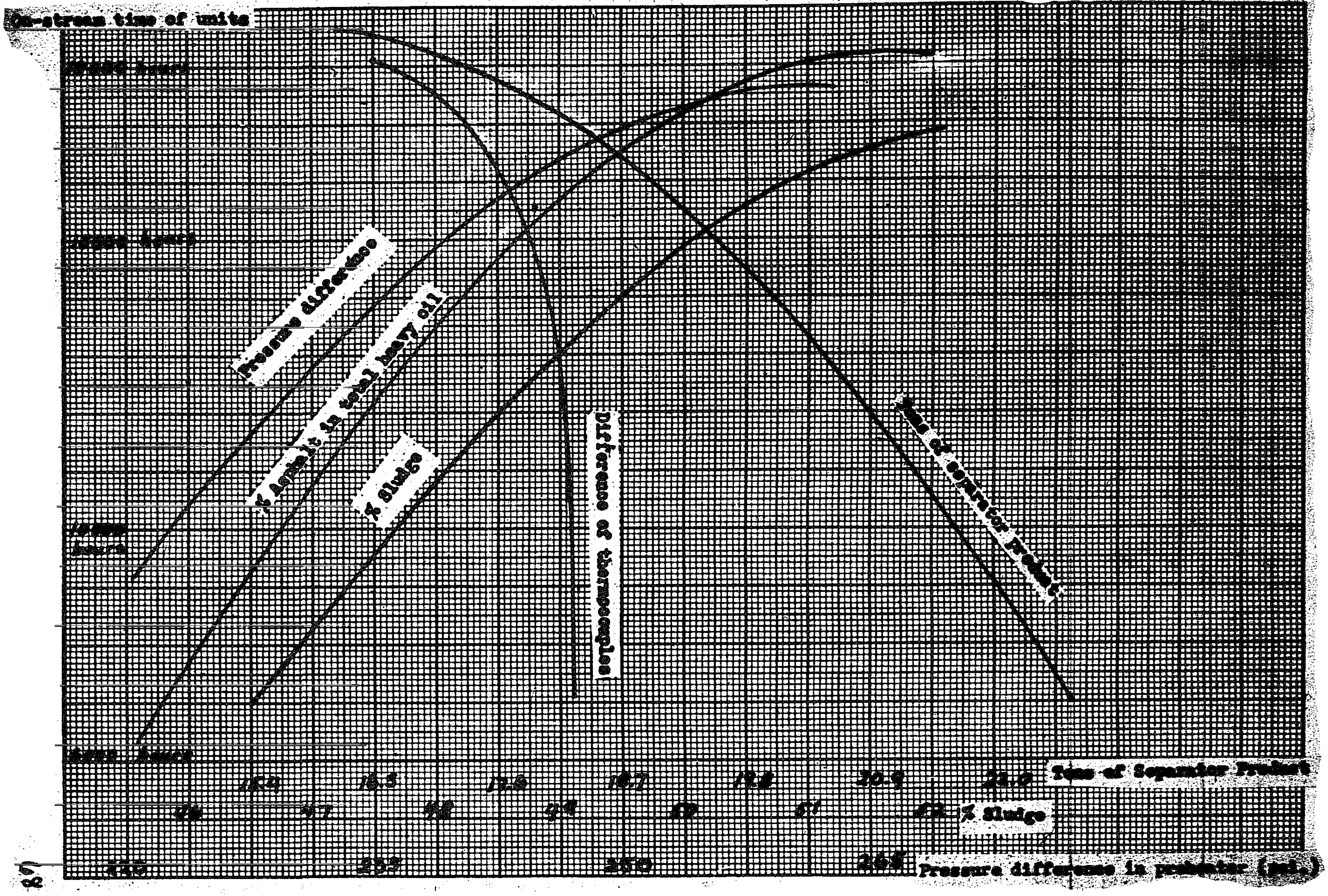
Heating gas requirements: 2,000,000 B.t.u./hour.

Efficiency of preheater: 84%


Paste Mixt.
Inlet Gas
Paste - Gas Mixture
2 Mixing Hairpin Tubes
Present design of preheater
5 paste hairpin tubes
6 gas hairpin tubes, countercurrent flow
16 gas hairpin tubes, parallel flow
5,300,000 cu.ft./hour circulating gas
To Converter I
New design of preheater
6.5 paste hairpin tubes
7 gas hairpin tubes, countercurrent flow
16.5 gas hairpin tubes, parallel flow
5,300,000 cu.ft./hour circulating gas
To Converter I



1112°F
932°F
752°F
572°F
392°F
212°F
104°F
Flue Gas
Inlet Gas
Paste - Gas Mixture
Paste Mixture
calculated
experimentally found


On-stream time of units
Pressure difference
% Asphalt in total heavy oil
% Sludge
Difference of thermocouples
16.5
16.7
20.9
22.0
% Sludge
203
250
265
Pressure difference in preheater