Louna Works - July 27, 1942.

STATUS OF CATALYTIC CRACKING, JUNE 1942

The following investigations were carried out prior to starting the first semi-commercial fixed-bed catalytic cracking unit. The moving-bed catalytic cracking reactor with a capacity of about 5 gallons of cracking catalyst has operated for 4 - 5 months without difficulty.

Figure 1 shows the amount of coke deposited at various space velocities as well as the cracking period corresponding to these space velocities. With decreasing space velocity and increasing length of the cracking period the amount of carbon deposited on the catalyst (based on the charge) decreases but it increases considerably when it is calculated as percentage of the catalyst. The data represented in Figure 2 have been obtained on the moving-bed unit but values for carbon formation obtained in experiments with the fixed-bed catalyst have been used. Shorter cracking periods in the fixed-bed process correspond to a larger quantity of catalyst moved through the unit, whereas a decrease in the amount of catalyst moved corresponds to shorter cracking periods. The conversion to aviation gasoline was assumed to be 28% by weight. It is to be expected that the amount of carbon formation will be smaller than in the fixed-bed process so that the values assumed in these calculations are rather too high.

Figure 3 shows the amount of aviation gasoline produced per hour in relation to the space velocity and the regeneration gas which has to be circulated per hour for regeneration of the catalyst.

In order to dissipate the amount of heat which is liberated during regeneration in order to keep the catalyst temperature below 1,022°F., it is necessary to circulate a definite amount of gas with a carefully controlled oxygen concentration. The larger the amount of gas which is circulated in the unit of time the shorter will be the unproductive regeneration time and the higher will be the amount of gasoline produced per catalyst volume and total time. The total time is made up of the cracking period, the regeneration period and the switching and purging periods which latter are assumed, in all cases, to be 9 minutes. The practical upper limit of gasoline production is dependent on the economics of the entire unit and is estimated to be 0.4 gallons per hour per cubic foot of catalyst.

At lower space velocities and longer cracking periods the amount of gasoline produced is higher because of the smaller amount of coke formed (calculated on the oil charge) which can be burned off in a shorter regeneration period.

Figure 4 shows the ratio of regenerating time to conversion time for the fixed-bed reactor for various space velocities. The optimum ratio from an economic standpoint will probably be 1.5 : 1 (for a space velocity of 0.4 and a cracking period of 3 hours).

Figure 5 shows the considerably higher efficiency of the moving-bed reactor as compared to the fixed-bed reactor and shows also the difference in behavior of the two processes when the space velocity is increased. Because of continuous operation of the moving-bed process, the amount of gasoline produced for the same reaction space is 2 - 6 times that of the solid-bed process.

Figure 6 shows the advantageous economics of the moving-bed reactor as compared to the fixed-bed reactor with respect to regeneration.

In the moving-bed reactor it is possible - 1) to regenerate with air only, and, 2) the regeneration is carried out in a special reactor and, therefore, the amount of air required for regeneration can be decreased by about 20 - 30% from the amount shown in the diagram. In the calculation of the amount of air required the reduction in air consumption has not been considered, which results when the regeneration is carried out in tubes cooled from the outside. The sensible heat of the catalyst which is available when the catalyst is cooled from the regeneration temperature (1,022°F.) to the cracking temperature (788°F.) can be used for the production of steam.

Description of the Moving-Bed Reactor.

The cracking zone is arranged below the regeneration zone. Both sections are separated by a pocket valve arrangement. The regenerating zone is composed of the catalyst preheater, the combustion zone proper and the catalyst cooling zone. In the latter the catalyst is cooled from 1,022°F. to 788°F. and the air is replaced in the tubes by means of inert gas. Immediately below the pocket valve arrangement is the cracking zone in which catalyst and oil vapors are contacted countercurrently. Below the cracking zone is a second cooling zone in which the catalyst is cooled from 788°F. to 176 - 392°F. In this zone the catalyst is also purged from oil vapors by means of inert gas. From the lower pocket valve arrangement the catalyst is continuously transported to the regenerating zone by means of a conveyor.

Description of the Fixed-Bed Reactor.

Only one reactor of the entire unit which consists of 6 - 8 reactors has been shown. Only a part of the 6 - 8 reactors cracks at any one time, whereas the other reactors are regenerated. In the drawing the reactor is shown as having 2 catalyst beds. The vaporized oil is passed at atmospheric pressure through both catalyst beds. Following the cracking period the oil vapors in the reactor are purged with dry gas which has been previously preheated to the cracking temperature. The dry gas is recycled, cooled and the oil is separated. The dry gas is subsequently purged by means of inert gas which is passed through the catalyst bed in parallel flow. In the regeneration period air is passed into the reactor together with inert gas and when the regeneration pressure has been reached an amount of regenerating gas corresponding to the amount of air added is drawn off. The regenerating gas is recycled and must be continuously cooled in order to separate the water which is formed by combustion of the coke; this is important because the catalyst is sensitive towards water vapor. After completion of the regeneration the regenerating gas, which now contains 12 - 18% oxygen, is removed by means of inert gas and the cracking period is started.

Advantages of the Moving Catalyst Process as Compared to the Fixed-Bed Process.

1. Investment costs are lower because of the 2- - 6-fold increase in gasoline production for the same cracking space.

2. Elimination of automatic switch-over controls and all other disadvantages inherent in the operation of several reactors or groups of reactors in the same unit.

3. Elimination of all expensive valves operating at high temperature.

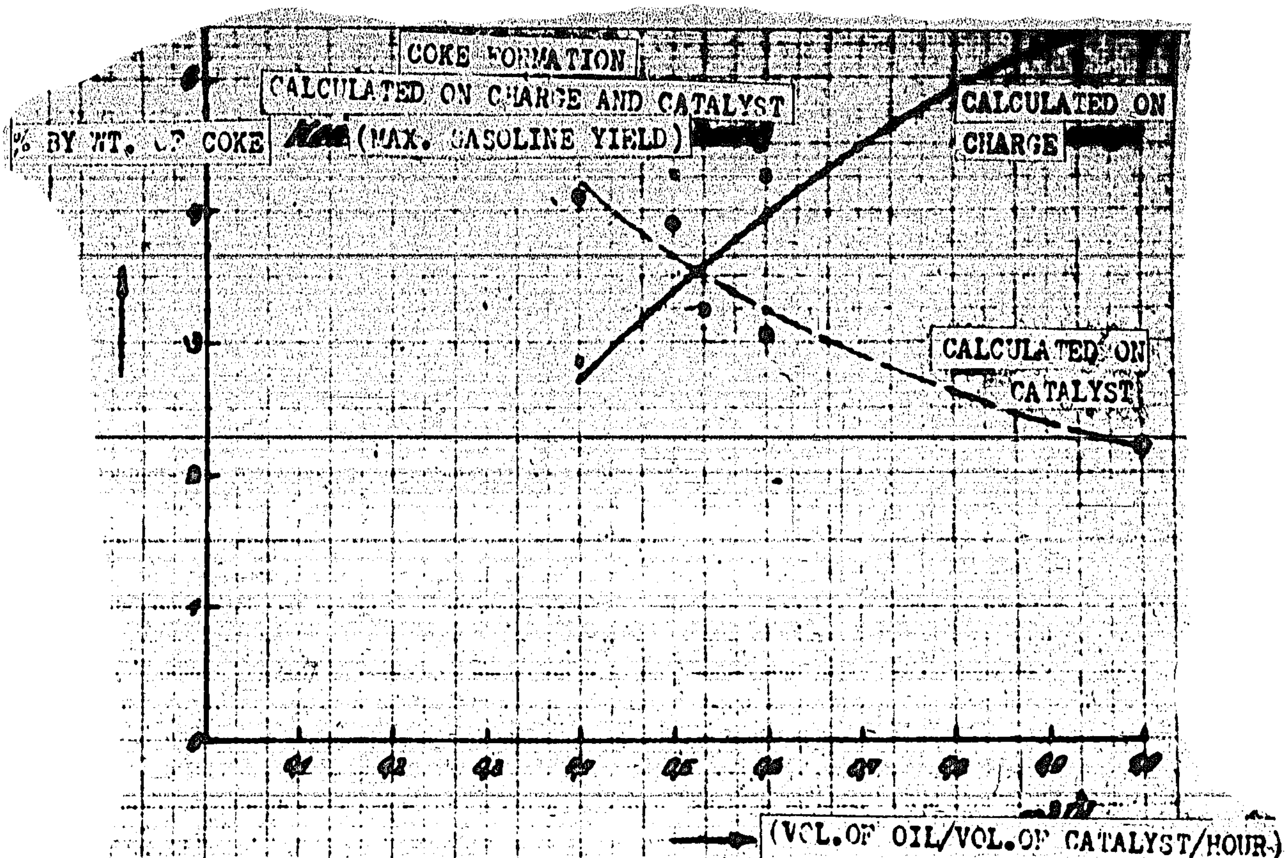
4. Simplification of the catalyst regeneration because air can be used. Superheating of the catalyst due to excessive oxygen concentration is no longer possible.

5. Reduction in the electrical energy required because of the considerably smaller quantities of regenerating gas (only 20 - 30% of the regenerating gas required in the fixed-bed process).

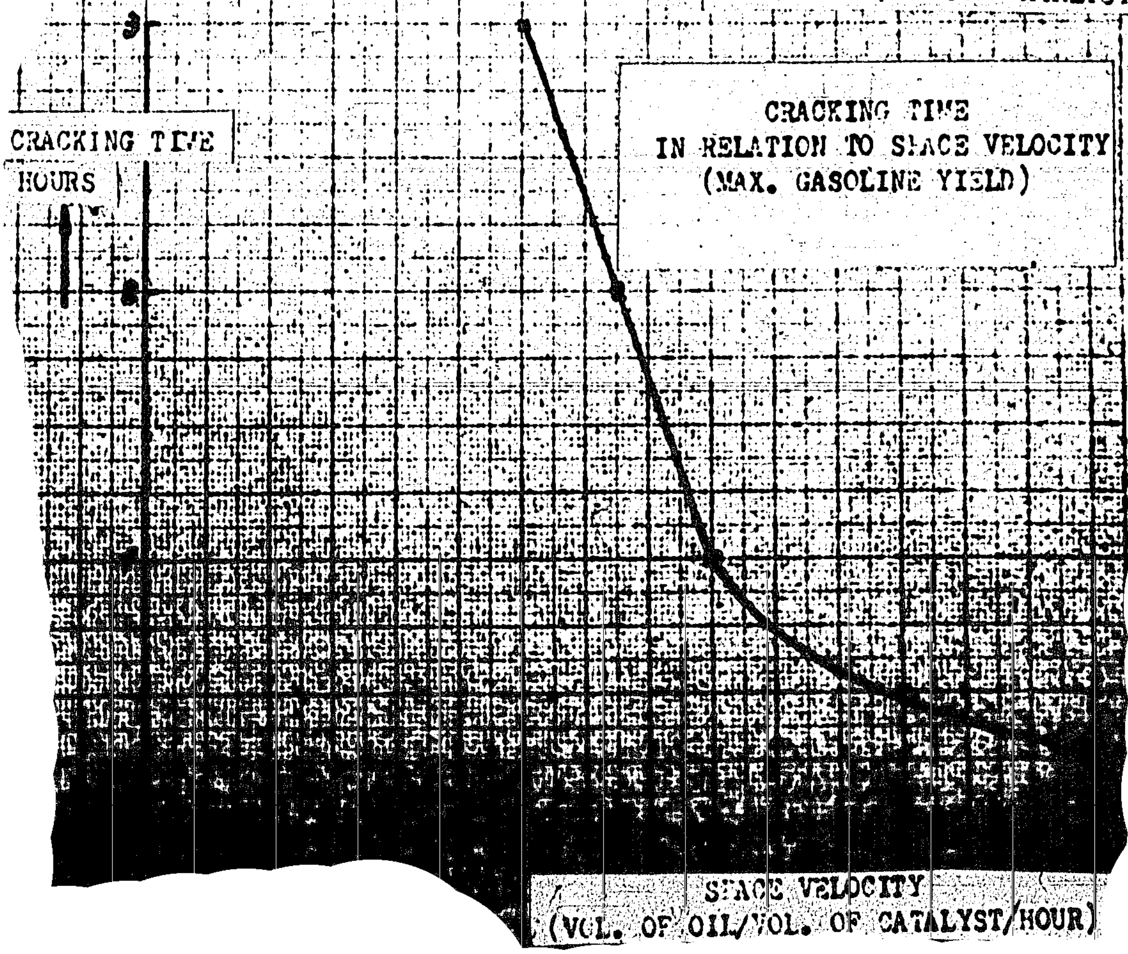
6. The moisture content of the regenerating air in the moving-bed process amounts to 1.5 - 2% as compared to 14% by volume in the operation of the fixed-bed process without water separation. The necessity for the separation of water in the fixed-bed process is the cause for the higher installation cost because of the large additional heat exchanger surfaces required.

7. Saving in alloys by reduction in the size of the unit and elimination of alloy steel valves.

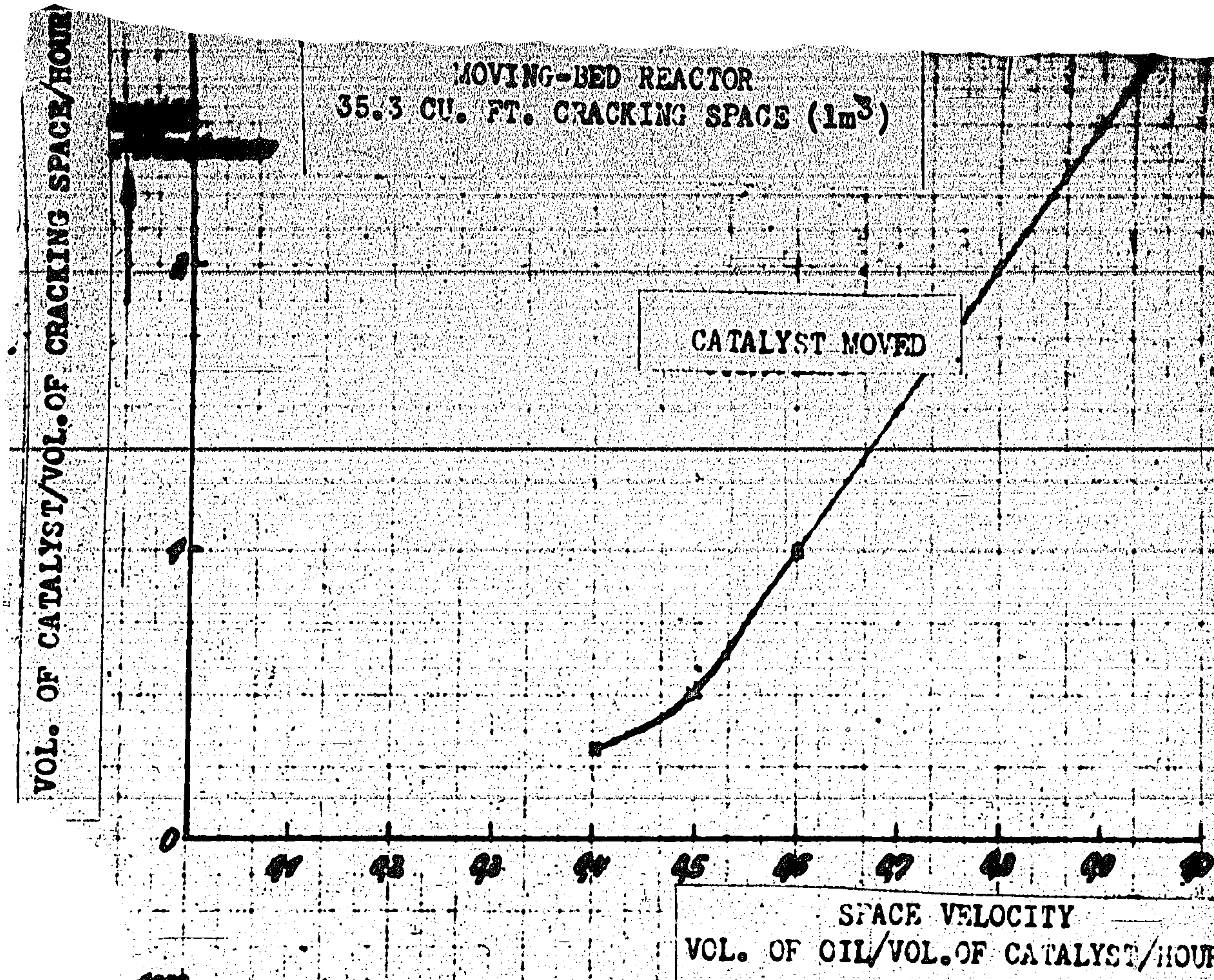
8. Reduction in the cost of most of the equipment since the moving-bed process can be operated almost entirely at atmospheric pressure.



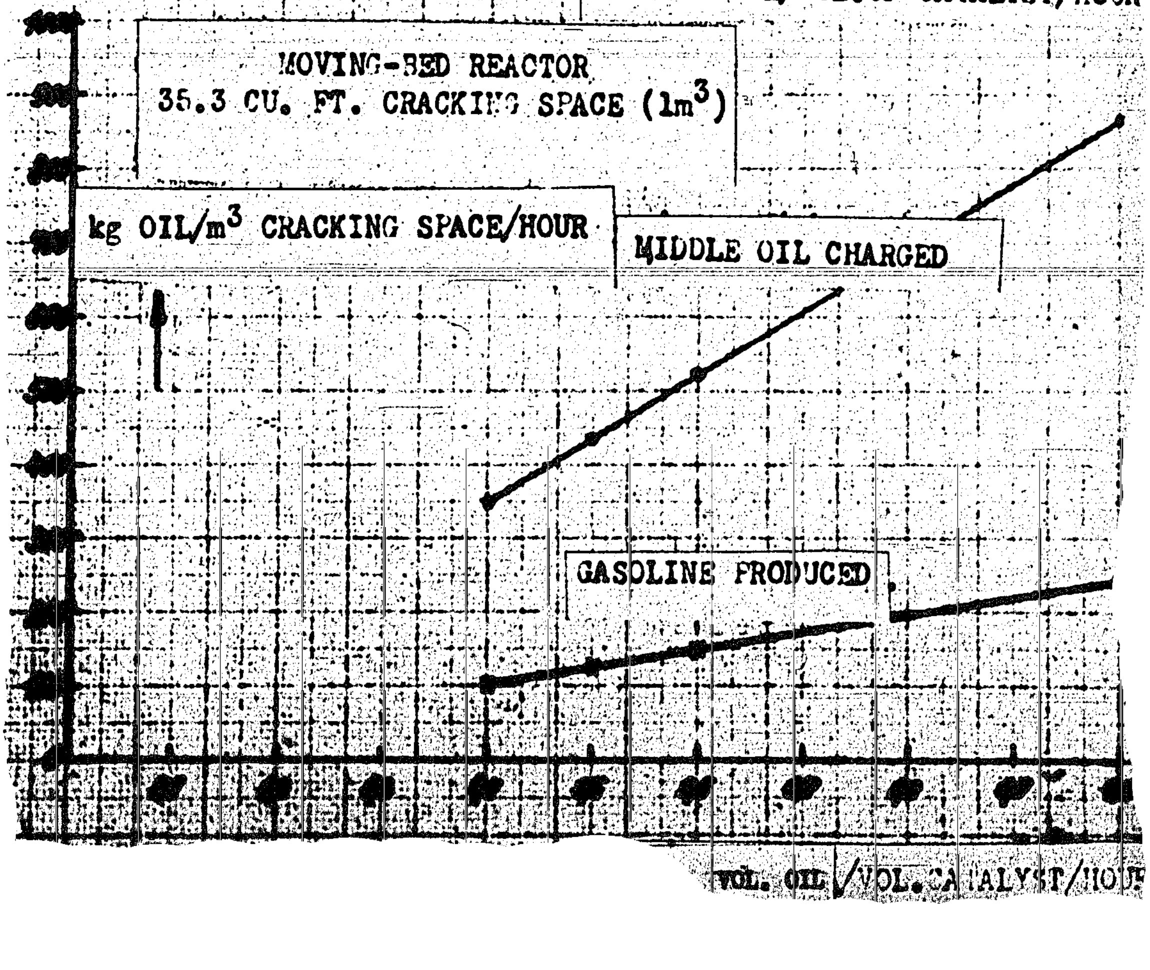
COKE FORMATION
CALCULATED ON CHARGE AND CATALYST
% BY WT. OF COKE
[redacted] (MAX. GASOLINE YIELD) [redacted]
CALCULATED ON CHARGE [redacted]
CALCULATED ON CATALYST
(VOL.OF OIL/VOL.OF CATALYST/HOUR)



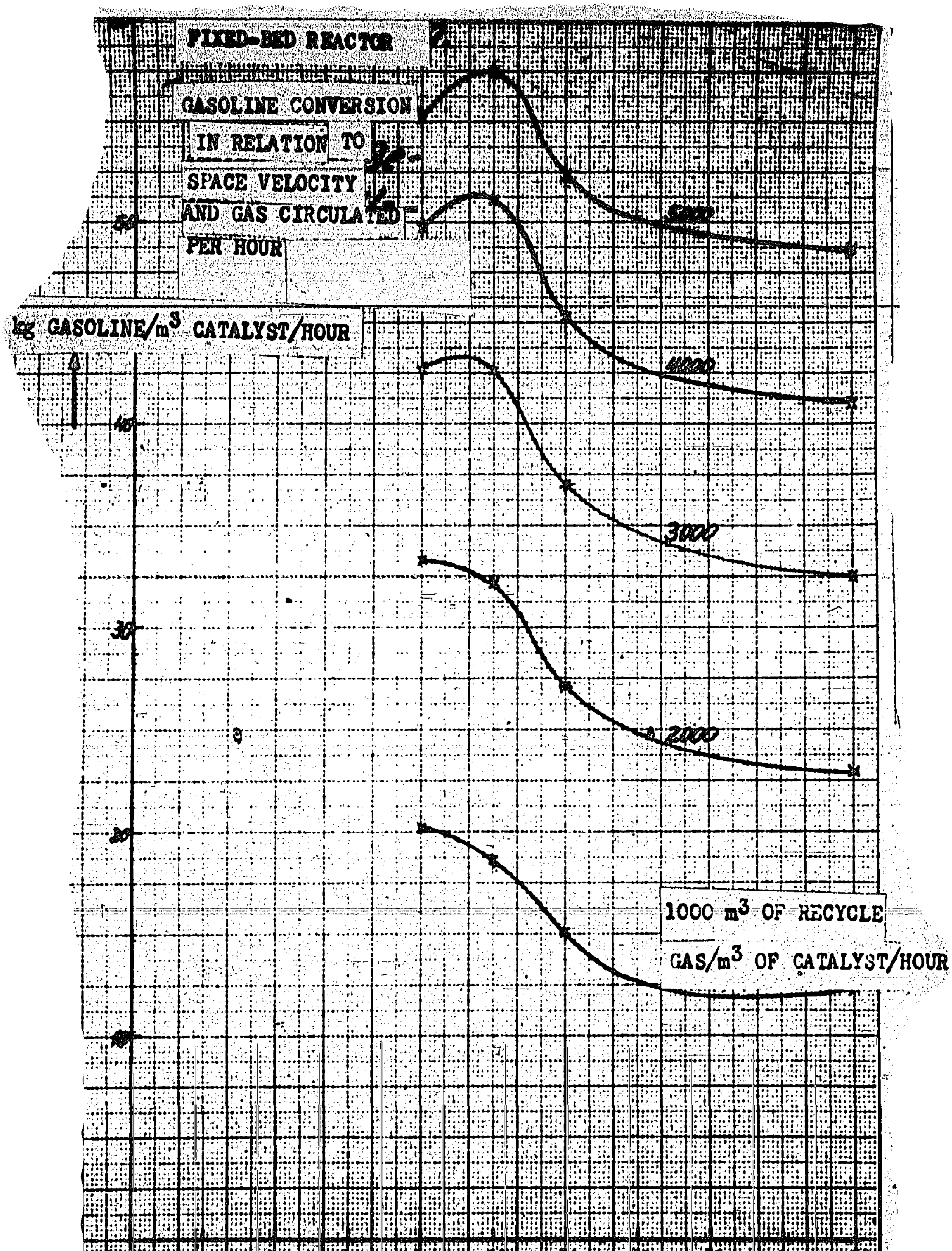
CRACKING TIME
IN RELATION TO SPACE VELOCITY
(MAX. GASOLINE YIELD)
CRACKING TIME
HOURS
SPACE VELOCITY
(VOL. OF OIL/VOL. OF CATALYST/HOUR)

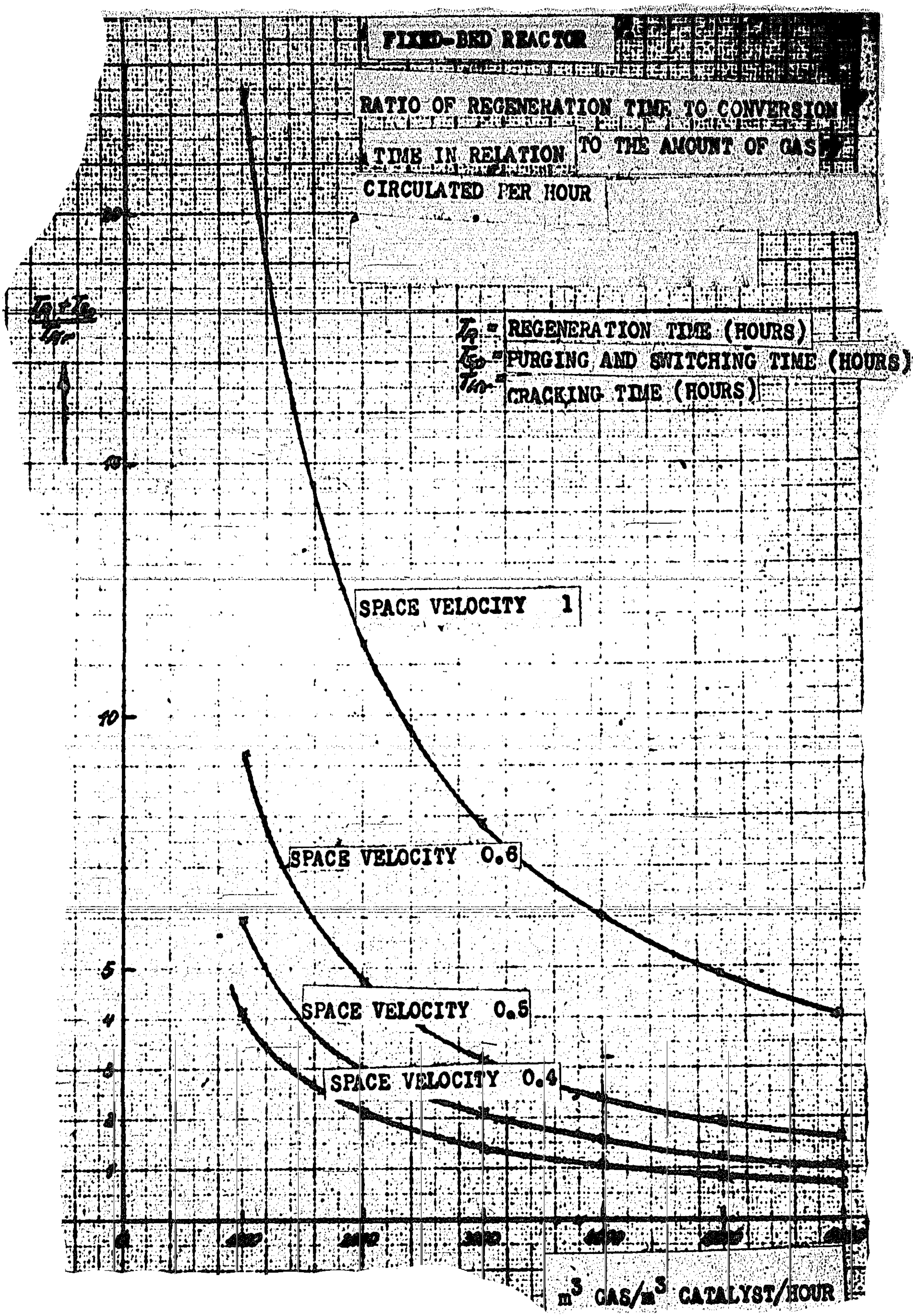


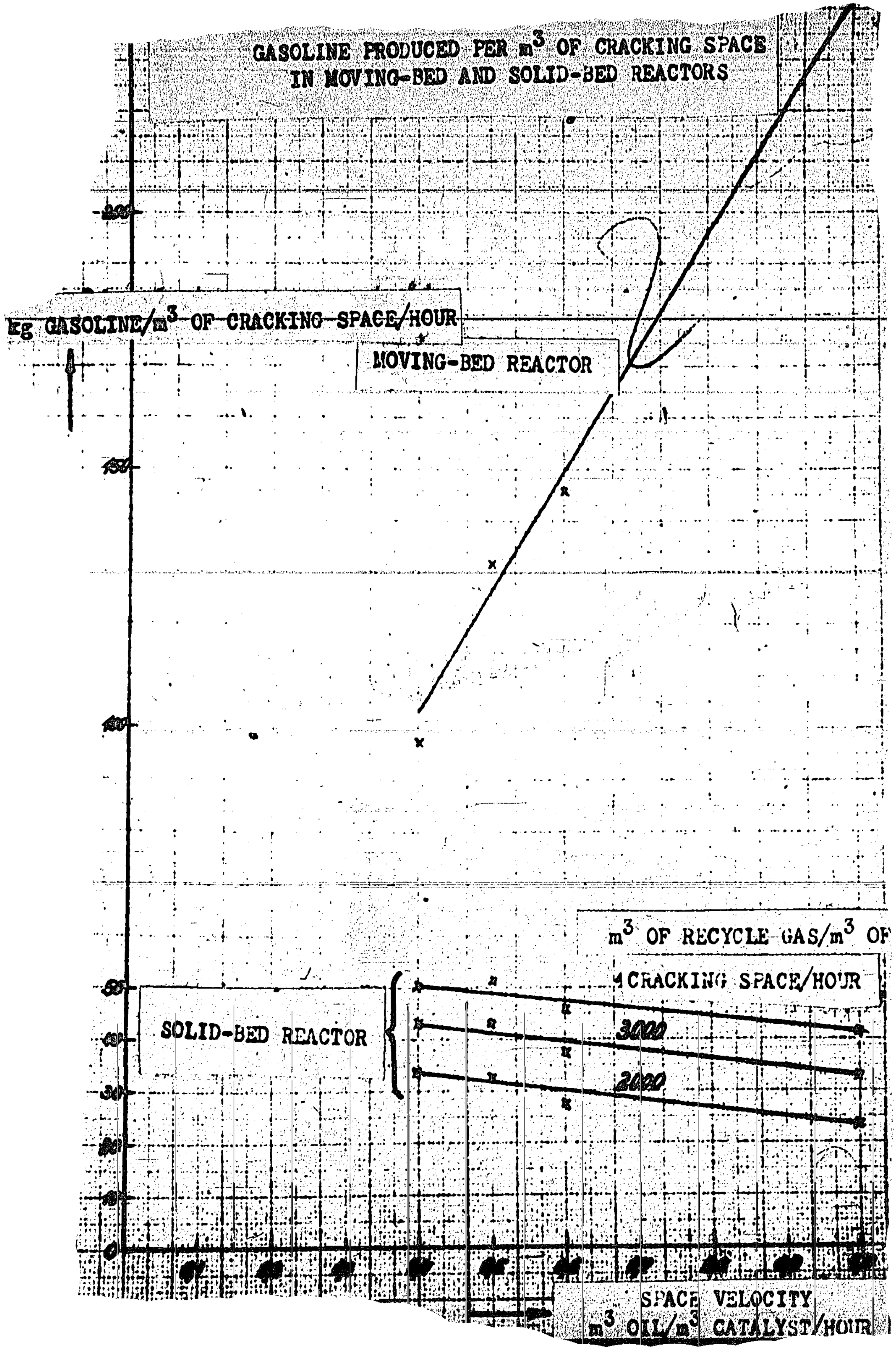
MOVING-BED REACTOR
35.3 CU. FT. CRACKING SPACE (1m³)
CATALYST MOVED
VOL. OF CATALYST/VOL.OF CRACKING SPACE/HOUR
0
SPACE VELOCITY
VOL. OF OIL/VOL.OF CATALYST/HOUR



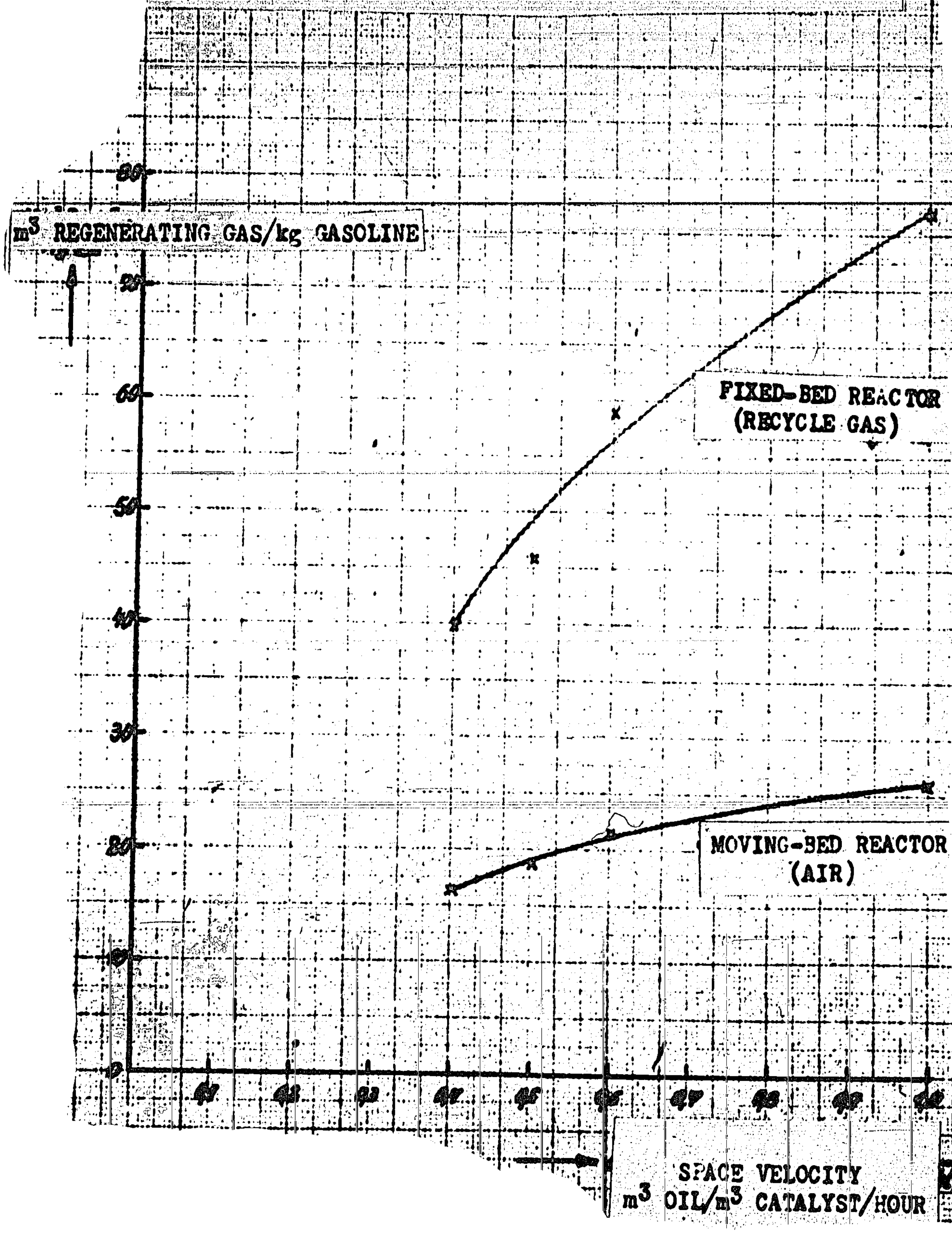
MOVING-BED REACTOR
35.3 CU. FT. CRACKING SPACE (1m³)
kg OIL/m³ CRACKING SPACE/HOUR
MIDDLE OIL CHARGED
GASOLINE PRODUCED
VOL. OIL /VOL. CATALYST/HOUR

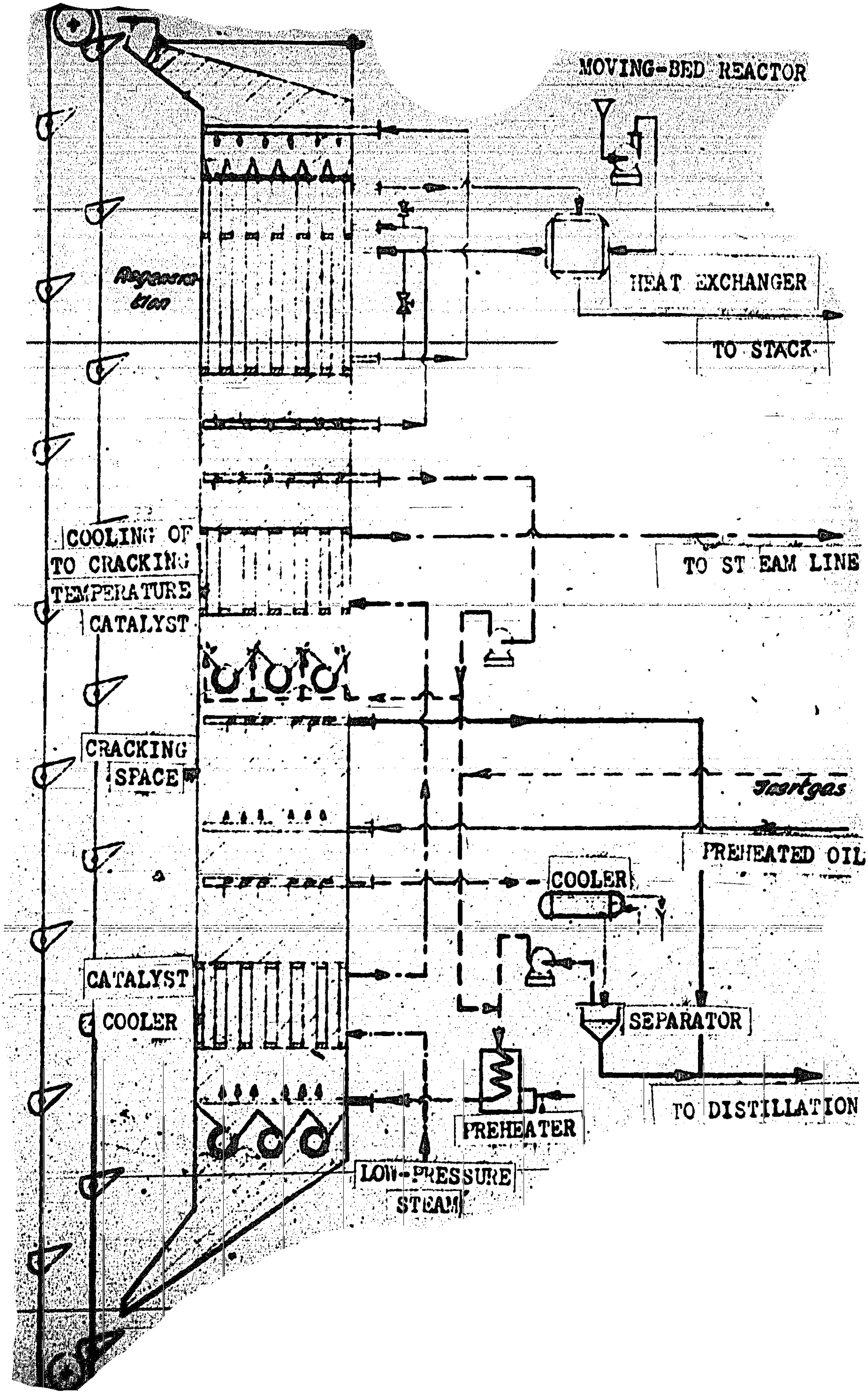

FIXED-BED REACTOR
GASOLINE CONVERSION
IN RELATION TO
SPACE VELOCITY
AND GAS CIRCULATED
PER HOUR
log GASOLINE/m3 CATALYST/HOUR
5000
4000
3000
2000
1000 m3 OF RECYCLE
GAS/m3 OF CATALYST/HOUR


FIXED-BED REACTOR
RATIO OF REGENERATION TIME TO CONVERSION TIME IN RELATION TO THE AMOUNT OF GAS CIRCULATED PER HOUR
T_R = REGENERATION TIME (HOURS)
T_{SP} = PURGING AND SWITCHING TIME (HOURS)
T_{KR} = CRACKING TIME (HOURS)
SPACE VELOCITY 1
SPACE VELOCITY 0.6
SPACE VELOCITY 0.5
SPACE VELOCITY 0.4
10
5
4
m³ GAS/m³ CATALYST/HOUR

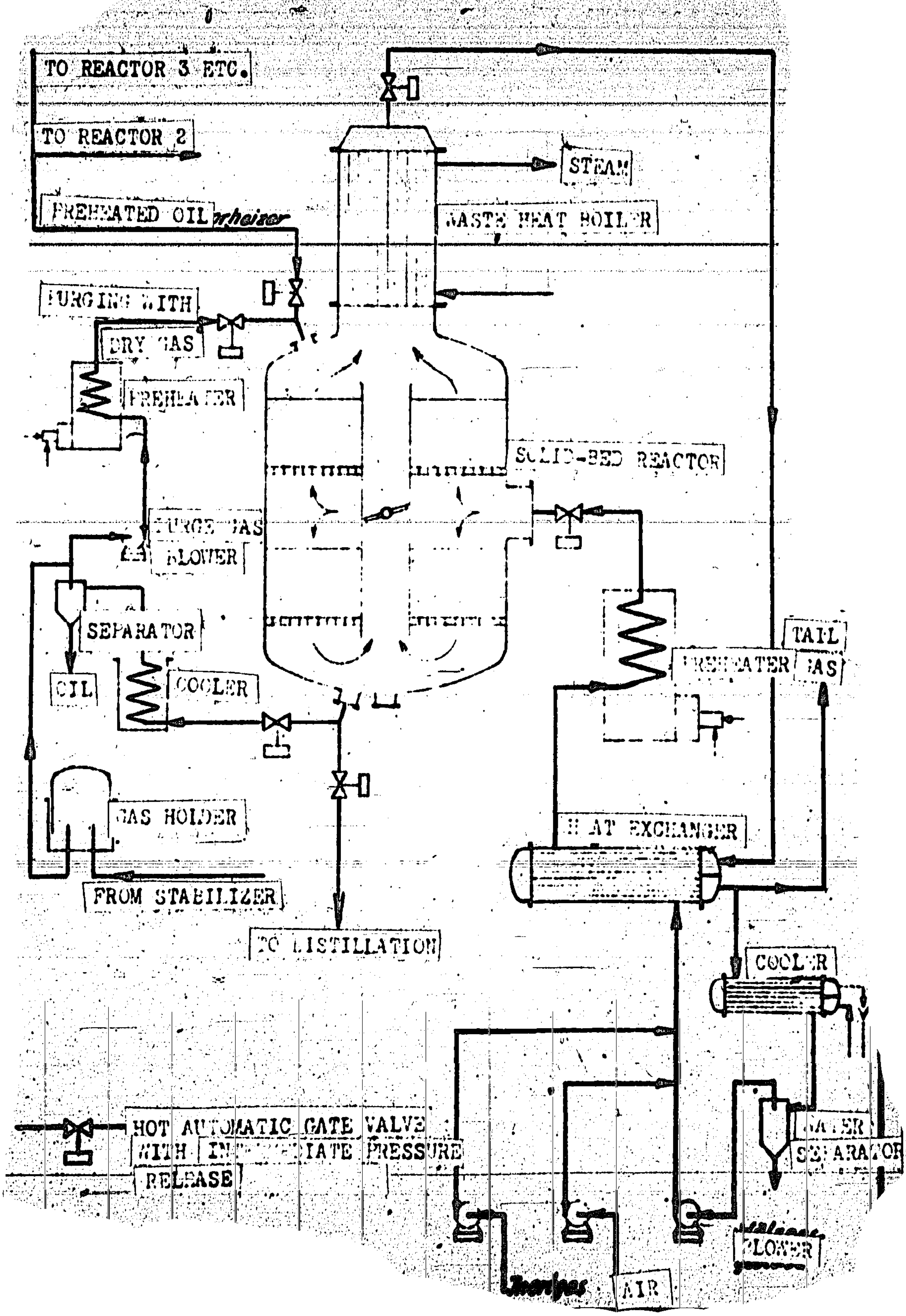

GASOLINE PRODUCED PER m3 OF CRACKING SPACE
IN MOVING-BED AND SOLID-BED REACTORS
kg GASOLINE/m3 OF CRACKING SPACE/HOUR
MOVING-BED REACTOR
m3 OF RECYCLE GAS/m3 OF
CRACKING SPACE/HOUR
SOLID-BED REACTOR
3000
2000
SPACE VELOCITY
m3 OIL/m3 CATALYST/HOUR

REGENERATING GAS OR AIR REQUIRED FOR 1 kg GASOLINE




MOVING-BED REACTOR
HEAT EXCHANGER
TO STACK
Regeneration
COOLING OF
TO CRACKING
TEMPERATURE
CATALYST
TO ST EAM LINE
CRACKING
SPACE
PREHEATED OIL
COOLER
CATALYST
COOLER
SEPARATOR
TO DISTILLATION
PREHEATER
LOW-PRESSURE
STEAM

FIXED-BED REACTOR WITH 2 CATALYST BEDS



WEIGHT RATIO OF REGENERATED CATALYST TO GASOLINE
PRODUCED IN RELATION TO SPACE VELOCITY
(MAX. GASOLINE YIELD)