# SULFUR REMOVAL DURING COMBUSTION OF SOLID FUELS IN A FLUIDIZED BED OF DOLOMITE

C. W. Zielke, H. E. Lebowitz, R. T. Struck, and E. Gorin

Research Division
Consolidation Coal Company
Library, Pennsylvania 15129

## INTRODUCTION

The national concern over atmospheric pollution has led to extensive research and development on removal of sulfur oxide pollutants from flue gases. There has been considerable effort in this regard using limestone or dolomite to react with the sulfur oxides in dry, high-temperature processes. In these processes, $SO_2$ in the gases produced during combustion is fixed as $CaSO_4$ by reaction with CaO:

$$CaO + SO_2 + \tfrac{1}{2}O_2 = CaSO_4 \qquad (1)$$

Usually the raw stone (dolomite or limestone) is fed to the process and calcination immediately takes place by the following reaction:

$$CaCO_3 = CaO + CO_2 \qquad (2)$$

One method of operation has involved removal of sulfur oxides by direct injection of limestone dust above the burners of power plant boilers. A system such as this requires a minimum of new facilities and is readily adaptable to existing plants. However, the removal of sulfur in this case is carried out in a relatively inefficient and uncontrolled manner. Hence, utilization of limestone is poor and sulfur removal does not exceed 50 to 60%. An excellent article by the Tennessee Valley Authority reviews work done along this line.[1]

More efficient contact between gases and solid, as well as excellent temperature control, can be obtained by passing the combustion gases through a fluidized bed of lime or dolomite. The research reported here was aimed at the ultimate combination along this line: combustion of the fuel within a fluidized bed of lime or dolomite, which, in addition to pollution control, has great potential for reducing boiler size and cost by locating boiler tubes within the fluidized bed.[2,3,4,9]

## EXPERIMENTAL

The experimental unit consists of a continuous fluidized combustor, four inches in diameter, with a fluidized bed depth of 36 inches. The bed is supported on a perforated plate above a plenum chamber through which fluidizing gas is fed. Figure 1 shows the arrangement of equipment for feeding and recovering products. The combustor fits within an electric furnace for startup, and thereafter, cooling is provided by an air flow between reactor and furnace. The cyclone to recover coal ash and dolomite fines is operated at 350°F, and the filter at 150 to 200°F. The dolomite overflowing the bed via the weir is substantially free of ash. Argon is used for purges to facilitate accurate analysis of off-gases. Operating pressure was 8 psig, the pressure required to force the gases through the recovery train and give adequate control. All runs were preceded by a line-out period at conditions involving at least 3 changes of bed inventory.

In addition to combustion studies under various conditions with once-through use of dolomite, the re-use of dolomite was explored using $6\frac{1}{2}$ cycles of alternate regeneration and $SO_2$-absorption.

The $SO_2$ absorption runs were conducted in a manner similar to the normal combustion runs except that $SO_2$ gas was added with the fluidizing air as a major source of sulfur; coal was burned to supply heat and supply a minor amount of sulfur. The purpose of adding $SO_2$ was to produce large amounts of highly sulfated dolomite in a relatively short time. The activity of the regenerated product was measured in these runs by determining the CaO-to-S mol feed ratio required to produce a 20% sulfur breakthrough in the exit gas. The required ratio was reached by adjusting the amount of feed $SO_2$; the dolomite residence time was held essentially constant in all cycles. When the desired Ca-to-S ratio was reached, conditions were maintained constant and the usual line-out and balance were made.

The regeneration portion of each cycle was conducted at 1950°F with CO as the reducing gas according to the overall reaction

$$CO + CaSO_4 = CaO + SO_2 + CO_2 \qquad (3)$$

No solid fuel was used in the regeneration runs. However, excess CO, over that required to carry out the reduction reaction, was burned with air to supply the heat. The gas flows were first established with nitrogen being substituted for the CO carrier gas. A bed of dolomite was established with the bed held at about 1400°F. Sufficient CO was then substituted in place of an equal amount of $N_2$ such that the bed was heated to 1925°F under a slightly oxidizing atmosphere. The remaining CO was then introduced, the used dolomite feed restarted and the unit lined out at 1950°F. Frequent analyses of the off-gas were made by gas chromatography to determine the $CO/CO_2$ ratio. Frequent analyses of the $SO_2$ content of the gas were made by determining the sulfate obtained in hydrogen peroxide scrubbers.

Feedstocks

The solid fuels tested in the combustor were Ireland Mine Coal, Disco Char, and Cresap Char. Analyses of these feeds are given in Table I. Ireland mine coal is a highly caking, high volatile, bituminous coal from the Pittsburgh seam. It is typical of the product sold to power stations. Both chars are from low temperature carbonization processes. The Disco char was produced in a rotary kiln from a Pittsburgh seam coal. The Cresap char was derived from Ireland mine coal. It was produced by fluidized low temperature carbonization of the residue remaining after solvent extraction of the coal in the "Project Gasoline" pilot plant operated by Consol for the U. S. Office of Coal Research at Cresap, West Virginia.

The dolomite used is from the Tymochtee formation in western Ohio. This stone was chosen because it had shown good physical strength and good resistance to chemical deactivation in $CO_2$ acceptor gasification studies.[6] Its analyses are given in Table II. The dolomite typically contained 0.05 to 0.10 weight percent moisture as it was fed to the unit.

## RESULTS AND DISCUSSION

### A. Runs Using Dolomite On a Once-Through Basis

Table III gives results using Disco char and Cresap char. Disco char was used in the initial runs because it is non-caking, thus precluding the possibility of operability problems due to coking. Cresap char was of interest because of its unusually high sulfur and ash content. Table IV gives results with Ireland coal. Superficial velocity is defined as the velocity of the air feed at process conditions based on the empty reactor. Superficial residence time is based on the superficial velocity and fluidized bed depth. Stoichiometric air is defined as that required to completely burn carbon to $CO_2$, hydrogen to water, and sulfur to $SO_2$.

1. Sulfur Removal

Runs 1 through 4 of Table III using Disco char explored the effect of temperature in the range of 1700-1900°F and the effect of residence times of one and two seconds. A large excess of acceptor was used in these runs (Ca/S mol feed ratio of 7.3 to 8.3) while holding the air input substantially constant at 120±5% of stoichiometric. Neither the temperature nor time variation had a significant effect on sulfur absorption which was nearly complete in all runs.

Runs 5 and 6 of Table III with Cresap char and Runs 7 through 10 of Table IV with Ireland coal explored the effect of Ca/S mol feed ratio at a constant temperature of 1800°F, one second gas residence time, and about 120% of stoichiometric air. Figure 2 shows the sulfur removal data for these runs plotted as a function of Ca/S mol feed ratio. Sulfur removal efficiency appears to be independent of the feed sulfur concentration which indicates the absorption reaction is first order with respect to $SO_2$ at a given Ca/S ratio. There is further evidence of this in the life study data which will be discussed later. Therefore, the data with Disco char were also plotted on Figure 2, although its sulfur content was lower than either the Cresap char or Ireland coal. It is apparent from Figure 2 that a desulfurization efficiency exceeding 90% can be achieved at Ca-to-S ratios of 2 or higher; at a Ca-to-S ratio of 1.0, sulfur removal efficiency was about 78%.

In general, these results with low Ca-to-S ratios (1.0 to 1.5) are superior to those reported in the literature by others for such a coarse dolomite (16 x 28 mesh). In scrubbing $SO_2$ from flue gases in a fluidized bed of dolomite at 1600°F, Skopp[4] found that a high CaO utilization of 75% or more required that the dolomite size be finer than 100 mesh; his results indicate CaO utilization of only 50% or less with 16 x 28 mesh material. Williams, of the National Coal Board of England, ground his limestone to -120 mesh before he got close to 100% sulfur removal at 1.5 Ca-to-S mol ratio. These results are some of the best reported.

Possible reasons for the superior results of this work would be the type of stone, the rapid, but controlled high temperature calcination, sufficient residence time, and good contacting of gas with the absorbent. The importance of good contact and good dispersion can be seen by comparing Run 7 of Table IV with Run 11. The baffle mounted above the feed port, shown in Figure 1, was employed in Run 11 but not in Run 7. With the baffle in place, 93.6% sulfur removal was achieved, but without it, only 66.5% sulfur removal was achieved.

Most workers blame the poor CaO utilization using coarse acceptor on an impervious shell of $CaSO_4$ which acts as a diffusion barrier preventing utilization of most of the CaO. Our results indicate that, under some conditions, the shell can be permeated reasonably well. For example, with 77% CaO utilization, penetration is at least 39% of the radius assuming spherical particles.

In all of this work, only the CaO fraction of the dolomite has been assumed to be active as a sulfur acceptor; the MgO has been assumed to have no ability for $SO_2$ removal because of equilibrium limitations.

2. Carbon Burnout

Carbon burnout efficiency at 1800°F with one second residence time using coal feed was 97%, as the data of Table IV show. The chars were somewhat less reactive, as would be expected. At conditions similar to the coal runs, Cresap char burnout was 93-94% (Runs 5 and 6 of Table III) and Disco char burnout was 94% (Run 3 of Table III). Increasing the temperature from 1800 to 1900°F, or increasing the residence time from one to two seconds at 1800°F, raised the burnout of Disco char from 94 to 98 or 97%, respectively.

3. Dolomite Fines Formation

A substantial amount of the feed dolomite is degraded to fines under some conditions. These fines are elutriated from the bed along with the large majority of the ash and unburned carbon. Figure 3 shows the rate of fines formation as a function of the Ca-to-S ratio in the bed. The ordinate of Figure 3 is defined as follows:

$$\text{Attrition Rate } \%/\text{hr} = \frac{\text{lbs(Ca + Mg) in Overhead Fines from Dolomite x 100}}{\text{lbs(Ca + Mg) in Dolomite Feed x Dolomite Res. Time in hrs.}}$$

It is apparent that the highly sulfated dolomite is much more resistant to size degradation than the lightly sulfated dolomite. At low Ca-to-S ratios, the rate of degradation is very low, that is, about 0.5% per hour. The rate of fines formation is also much higher using coal feed than with char feed for some unknown reason. Perhaps the higher reactivity of the coal causes greater thermal stresses in the particles.

4. Nitrogen Oxides in the Gases

The nitrogen oxides content of the gases vary considerably from run to run, i.e., 60 to 340 ppm. There is no apparent pattern to the variation. Perhaps this is due to variation in the rate of quenching of the off-gases which was not carefully controlled.

B. Dolomite Life Study

Potentially, the amount of new acceptor required per ton of coal can be reduced substantially by regenerating the acceptor and recycling the used acceptor back to the combustion process. One advantage of combustion in a bed of coarse acceptor is that the ash and fines are separated naturally by elutriation during combustion leaving substantially pure acceptor for regeneration treatment. To help assess the possibilities of regeneration, a series of cyclical combustion-regeneration runs was made. Results of the combustion runs with sulfur absorption are given in Table V; results of the regeneration runs are given in Table VI.

1. Regeneration

Regeneration comprises converting the $CaSO_4$ in the acceptor to CaO. In the present work, this was done using CO as the reducing gas at 1950°F. It is first of all necessary to reduce a portion of the $CaSO_4$ to CaS by the reaction

$$1/4\ CaSO_4 + CO = 1/4\ CaS + CO_2 \qquad (4)$$

The ratio of $CO_2$ to CO in the exit gas needs to be near that which corresponds to equilibrium for the above reaction so as to provide for the co-existence of $CaSO_4$ and CaS. The concentration of $SO_2$ in the off-gas from regeneration in cycle 1 was about 23 times greater than that in a flue gas from burning a 4% sulfur fuel, making its recovery much easier. Sulfur rejection then occurs by the reaction

$$1/4\ CaS + 3/4\ CaSO_4 = CaO + SO_2 \qquad (5)$$

The overall reaction can be represented by the equation

$$CaSO_4 + CO = CaO + CO_2 + SO_2 \qquad (6)$$

$$\Delta H = +59.2 \text{ Kcal/mol}$$

Since the overall reaction is endothermic, excess CO over that required to carry out the reduction of $CaSO_4$ was burned to provide the heat to conduct the regeneration at

1950°F. At 1950°F and 1.5 atmospheric pressure, the equilibrium concentration of $SO_2$ in the gas is 12 mol %. This provided adequate driving force since the maximum concentration of $SO_2$ in the gases produced was 7.10%.

It was found that best results were obtained with the effluent gas slightly richer in CO than the equilibrium $CO_2$-to-CO ratio of 46, i.e., 23 to 30. Higher or lower ratios gave lower sulfur rejection. When the appropriate $CO_2/CO$ ratio was established, rejection of 93% or more of the sulfur was achieved. In Runs 3 and 4, an erroneously low CO concentration was used and sulfur rejection was poorer.

A small amount of COS is produced as shown in the gas analyses. The concentration corresponds roughly to that at equilibrium for the reaction

$$CaS + CO_2 = CaO + COS \qquad (7)$$

$$Kp = \frac{(COS)}{(CO_2)} = .00037 \text{ at } 1950°F^{(6)}$$

In principle, the regeneration could be carried out in a similar fashion in a single stage by burning coal or char with a deficiency of air according to the overall equation

$$CaSO_4 + C + \tfrac{1}{2}O_2 = CaO + SO_2 + CO_2 \qquad (8)$$

Fusion of ash, of course, may be a problem if the reaction is to be carried out at 1900°F or more since the ash fusion temperature is lowered under the reducing conditions necessary to carry out the sulfur rejection.

2. Sulfation

The results of the sulfation ($SO_2$ absorption) runs are given in Table V. These runs were conducted in much the same way as the once-through combustion runs except that $SO_2$ gas was added in order to rapidly produce large amounts of treated dolomite for the cyclical life study. The $SO_2$ content of the gas was adjusted to give 20% breakthrough of sulfur in the gas, i.e., 80% absorption. The Ca/S ratio obtained then was the measure of dolomite activity. It is apparent from the results that ~80% absorption was obtained in all cycles. In cycle 1, with fresh dolomite, a 0.95 Ca/S mol feed ratio gave 79% sulfur absorption. This point falls approximately on the curve of Figure 2, again showing that the absorption reaction is first order.

The acceptor activity as listed is based only on the CaO in the feed and not the $CaSO_4$ since, in cycles 3 and 4, regeneration wasn't as complete as desired.

3. Dolomite Life

The activity, a, of the dolomite sulfur-acceptor from cycle to cycle was measured as the fraction of available calcium which would absorb sulfur while maintaining 20% breakthrough of $SO_2$. This is calculated from the spent acceptor analysis on a mol basis: $CaSO_4/(CaO + CaSO_4)$. Figure 4 shows how the capacity (activity) of the dolomite decreased with the number of cycles, n, of absorption and regeneration.

Using the composite activity for a perfectly-mixed bed as described by Curran,[6] the effect of recycling dolomite has been calculated as a function of the rate of recirculation. Figure 5 shows this relationship. The ordinate of Figure 5 is the ratio of the pounds of fresh dolomite feed in the once-through process to that in the regenerative process, with the amount and efficiency of sulfur dioxide pick-up held constant. By going to high recirculation rates of regenerated acceptor, the makeup rate of fresh acceptor can be kept quite low.

Fresh dolomite makeup rate is usually controlled by activity loss since decrepitation loss is generally small. Total loss as fines overhead in $6\frac{1}{2}$ cycles was 9.43% or about 1.5% per cycle. The average rate of decrepitation was 0.39%/hr during regeneration and 0.67%/hr during combustion. Discarding the attrition results from cycles 3 and 4, which look erroneously high, the rate during combustion was 0.42%/hr. Thus, it is apparent that makeup requirements due to attrition are probably not more than 1%/cycle.

## COMMERCIAL IMPLICATIONS

The results of this work suggest two basic processes: 1) a process where dolomite is used on a once-through basis and discarded, or 2) a process in which the dolomite is regenerated and reused. The first process would require at least 0.25 ton of dolomite/ton of coal feed of 4% S. The second process could require 0.05 ton or less of dolomite per ton of coal feed. The cost of regeneration could be partially offset by recovering elementary sulfur from the sulfur-rich regeneration off-gas. If a relatively pure limestone could be found that has the same activity as the dolomite, the stone requirements could be cut substantially because of the greater CaO content in a limestone as compared with a dolomite.

## REFERENCES


(1) "Sulfur Oxide Removal from Power Plant Stack Gas", PB-178972, Tennessee Valley Authority, 1968.

(2) Bishop, J.W., Robinson, E.B., Ehrlich, Shelton, Jain, A.K., Chen, P.M., "Status of the Direct Contact Heat Transferring Fluidized Bed Boiler", ASME Publication 68-WA/FU-4, 1968.

(3) Moss, G., Paper presented at the "First International Conference on Fluidized Bed Combustion" at Hueston Woods State Park, Oxford, Ohio, Nov. 18-22, 1968.

(4) Skopp, A.P., Work published in the "Proceedings of the First International Conference on Fluidized Bed Combustion" at Hueston Woods State Park, Oxford, Ohio, Nov. 18-22, 1968.

(5) Kruel, M., and Juntgen, H., Chemie-Ingenieur-Technik 39, No. 9/10, 607, 1967.

(6) Curran, G.P., Fink, C.E., and Gorin, E., Fuel Gasification, Advances in Chemistry Series, 69, 141, 1967.

(7) Barney, J.C. and Bertolacini, Anal. Chem., 29, 283, 1957.

(8) Standard Methods for the Examination of Water and Waste Water; American Public Health Association, Inc., 11th ed. 175, 1960.

(9) Williams, D.F., Work published in the "Proceedings of the First International Conference on Fluidized Combustion" at Hueston Woods State Park, Oxford, Ohio, Nov. 18-22, 1968.

(10) Zawadski, J., Ztschr. Anorg. Chem., 205, 180, 1932.

(11) Marchal, G., Compt. rend., 175, 270, 1922.

TABLE I

ANALYSES OF CHAR AND COAL FEEDS

| | Disco Char | Cresap Char | Ireland Coal |
|---|---|---|---|
| Moisture, Wt.% | 3.65 | 1.15 | 1.30 |
| Proximate Analysis, Dry Basis, Wt.% | | | |
| Volatile Matter | 20.77 | 14.34 | 39.84 |
| Fixed Carbon | 66.24 | 60.99 | 52.60 |
| Ash (Ex. mineral sulfur) | 12.99 | 24.67 | 12.67 |
| Elemental Analysis, Dry Basis, Wt.% | | | |
| H | 3.28 | 1.65 | 4.81 |
| C | 70.81 | 63.08 | 69.25 |
| N | 1.42 | 1.55 | 1.37 |
| O (Diff.) | 10.53 | 4.60 | 8.94 |
| S | 1.72 | 6.20 | 4.15 |
| Btu/lb MF Fuel, Net | 11845 | 10350 | 12840 |
| Ash Fusion Temp., °F (Oxid. Atm.) | | | |
| Initial Deformation | 2040 | 1920 | 1950 |
| Softening | 2120 | 2020 | 2020 |
| Hemispheric | 2270 | 2200 | 2140 |
| Fluid | 2360 | 2360 | 2320 |
| Screen Size, Tyler Mesh | 28 x 150 | 28 x 200 | 28 x 150 |

TABLE II

ANALYSIS OF TYMOCHTEE FEED DOLOMITE

| | Weight, % |
|---|---|
| CaO | 27.93 |
| MgO | 18.56 |
| $Fe_2O_3$ | .41 |
| $SiO_2$ | 1.40 |
| $Al_2O_3$ | 1.64 |
| $CO_2$ | 44.87 |
| Unaccounted for | 5.19 |

SCREEN ANALYSIS, TYLER MESH

| | |
|---|---|
| On 14 | 0 |
| 16 | 1.0 |
| 20 | 39.1 |
| 24 | 33.9 |
| 28 | 24.7 |
| 35 | 1.2 |
| -35 | 0.1 |

Raw dry stone/fully calcined stone, wt. ratio = 1.814

Ca/Mg, mol ratio - 1.08

## TABLE III

### RESULTS WITH CHAR FEEDSTOCKS AND ONCE-THROUGH DOLOMITE

Acceptor: 16 x 28 mesh raw Tymochtee dolomite

Inlet Gas: 100% air

Pressure 8 psig.

| Run No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Fuel | ← Disco Char → | | | | ← Cresap Char → | |
| Bed Temperature, °F | 1700 | 1800 | 1800 | 1900 | 1800 | 1800 |
| Ca/S mol feed ratio | 7.3 | 7.9 | 8.3 | 8.0 | 4.2 | 2.0 |
| Superficial velocity, fps | 1.5 | 1.5 | ← 3.0 → | | | |
| Stoichiometric air, % | 116 | 118 | 120 | 121 | 125 | 118 |
| Fuel feed rate, lb/hr | 1.27 | 1.19 | 2.34 | 2.23 | 2.46 | 2.62 |
| Raw dolomite feed rate, lb/hr | 1.00 | 1.01 | 2.09 | 1.90 | 4.05 | 1.99 |
| Run length, hr. | 30 | 28 | 32 | 29 | 38 | 33 |
| Gas residence time, sec. | 2.0 | 2.0 | ← 1.0 → | | | |
| **Results** | | | | | | |
| Feed sulfur removed, % | 100.0 | 97.9 | 98.2 | 99.0 | 94.5 | 90.7 |
| Sulfur in effluent acceptor, Wt.% | 3.12 | 2.70 | 2.51 | 3.39 | 5.27 | 9.40 |
| Carbon burnout, % | 95.8 | 98.3 | 94.4 | 97.1 | 93.8 | 93.2 |
| Lb. dust overhead/lb. fuel fed | 0.165 | 0.159 | 0.284 | 0.267 | 0.304 | 0.278 |
| Dolomite overhead as dust, % | 7.3 | 9.4 | 23.6 | 24.5 | 3.8 | 1.8 |
| **Dry Exit Gas, Mol %** | | | | | | |
| $CO_2$ | 16.3 | 16.8 | 19.2 | 20.6 | 16.5 | 16.1 |
| CO | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| $O_2$ | 4.1 | 3.7 | 5.0 | 4.1 | 5.2 | 4.7 |
| $N_2$ + A | 79.6 | 79.5 | 75.8 | 75.3 | 78.3 | 79.1 |
| $SO_2$ | 0.0000 | 0.0031 | 0.0026 | 0.0015 | 0.0290 | 0.0536 |
| $NO_x$ | 0.024 | 0.027 | 0.013 | 0.027 | 0.0060 | 0.0103 |

## TABLE IV

### RESULTS WITH COAL FEEDSTOCKS AND ONCE-THROUGH DOLOMITE

| | |
|---|---|
| Acceptor: | 16 x 28 mesh raw Tymochtee dolomite |
| Inlet Gas | 100% air |
| Pressure, psig | 8.0 |
| Superficial velocity, fps | 3.0 |
| Temperature, °F | 1800 |
| Superficial gas residence time, sec. | 1.0 |

| Run No. | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|
| Ca/S, mol feed ratio | 4.03 | 1.89 | 1.45 | .95 | 3.68 |
| Stoichiometric air, % | 122 | 115 | 119 | 120 | 120 |
| Coal feed rate, lb/hr | 2.15 | 2.27 | 2.20 | 2.18 | 2.19 |
| Raw dolomite feed rate, lb/hr | 2.25 | .94 | .70 | .46 | 2.09 |
| Run length, hr | 36 | 53 | 85 | 113 | 38 |
| **Results** | | | | | |
| Feed sulfur removed, % | 93.6 | 88.5 | 87.0 | 74.1 | 66.5 |
| Sulfur in effluent acceptor, wt.% | 5.00 | 8.62 | 10.93 | 12.59 | 2.99 |
| Carbon burnout, % | 97.5 | 96.7 | 96.9 | 97.1 | 97.5 |
| Lb total dust overhead/lb feed coal | .254 | .162 | .157 | .136 | .258 |
| Dolomite overhead as dust, % | 20.9 | 21.6 | 14.7 | 11.4 | 17.6 |
| **Dry Exit Gas, Mol %** | | | | | |
| $CO_2$ | 15.5 | 14.8 | 13.9 | 14.2 | 14.8 |
| CO | .02 | .01 | .00 | .00 | .08 |
| $O_2$ | 4.3 | 4.0 | 4.7 | 4.6 | 4.3 |
| $N_2$ + A | 80.2 | 81.2 | 81.4 | 81.1 | 80.7 |
| $SO_2$ | .0205 | .0334 | .0370 | .0726 | .110 |
| $NO_x$ | .0116 | .0044 | .0152 | .0090 | .034 |

TABLE V

CONDITIONS AND RESULTS
OF COMBUSTION RUNS WITH $SO_2$ ABSORPTION
IN DOLOMITE LIFE STUDY

| | |
|---|---|
| Bed temperature, °F | 1800 |
| Pressure, psig | 8 |
| Fuel | -28 mesh Ireland coal |
| Fuel feed rate, lb/hr | 1.79 |
| Dolomite feed | To first cycle: raw, 16 x 28 mesh<br>To succeeding cycles: regenerated material from previous cycle |
| Superficial inlet gas velocity, fps | 3.0 |
| Superficial gas residence time, sec. | 1.0 |
| Nominal percent of stoichiometric air | 120 |

| Cycle Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Dolomite feed rate, lb/hr | 10.2 | 5.8 | 5.7 | 6.0 | 6.0 | 5.7 | 5.6 |
| Dolomite residence time, hr | 1.09 | 1.15 | 1.14 | 1.11 | 1.25 | 1.21 | 1.11 |
| Inlet gas composition | | | | | | | |
| Air, SCFH | | | | 3.34 | | | |
| $SO_2$, lb/hr | 3.29 | 2.19 | 1.56 | 1.56 | 1.24 | 1.26 | 1.08 |
| CaO/S mol feed ratio | .953 | 1.38 | 1.86 | 1.86 | 2.25 | 2.27 | 2.62 |
| **Results** | | | | | | | |
| Feed S absorbed, % | 79.3 | 80.4 | 80.2 | 78.7 | 77.6 | 79.3 | 80.6 |
| S in effluent acceptor, Wt.% | 14.27 | 11.41 | 9.02 | 9.70 | 8.43 | 7.64 | 7.13 |
| Carbon burnout, % | 97.1 | 97.5 | 96.4 | 97.1 | 96.4 | 96.4 | 97.0 |
| Acceptor activity, $CaSO_4/(CaO+ CaSO_4)$ | .770 | .540 | .382 | .400 | .306 | .313 | .284 |
| Feed dolomite overhead as dust, % | 1.02 | .71 | 1.50 | 1.42 | .25 | .25 | .21 |
| **Dry Exit Gas, Mol%** | | | | | | | |
| $CO_2$ | 18.4 | 12.6 | 12.7 | 12.5 | 12.2 | 12.3 | 13.1 |
| CO | 0.40 | .16 | .29 | .35 | .10 | .14 | .18 |
| $O_2$ | 4.4 | 5.0 | 5.6 | 5.7 | 5.9 | 5.8 | 5.2 |
| $N_2$ + A | 75.7 | 81.2 | 81.1 | 80.9 | 81.2 | 81.2 | 81.1 |
| $SO_2$ | 1.21 | .89 | .66 | .70 | .61 | .57 | .44 |
| **Balance Closures** | | | | | | | |
| Mass | 96.7 | 97.2 | 97.2 | 96.6 | 97.2 | 96.6 | 98.4 |
| S | 95.5 | 94.3 | 92.0 | 91.1 | 93.3 | 95.6 | 96.2 |
| CaO | 109.0 | 100.0 | 102.5 | 103.2 | 116.6 | 104.7 | 109.5 |

## TABLE VI

### CONDITIONS AND RESULTS OF REGENERATION RUNS IN DOLOMITE LIFE STUDY

| | |
|---|---|
| Bed temperature, °F | 1950 |
| Pressure, psig | 8 |
| Superficial inlet gas velocity, fps | 2 |
| Superficial gas residence time, sec. | 1.5 |

| Cycle Number | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Spent dolomite feed rate, lb/hr | 8.82 | 8.20 | 7.23 | 6.83 | 6.98 | 7.12 |
| Dolomite bed residence time, hr | 1.62 | 1.70 | 1.78 | 1.79 | 1.83 | 1.78 |
| Inlet gas composition, mol % | | | | | | |
| Air | 44.6 | 44.6 | 44.2 | 44.2 | 44.2 | 44.2 |
| Added $N_2$ | 30.3 | 31.6 | 34.3 | 35.2 | 34.0 | 33.9 |
| CO | 25.1 | 23.8 | 21.5 | 20.6 | 21.8 | 21.9 |
| Excess CO after combustion, mol ratio Feed S | .98 | .94 | .75 | .58 | .97 | 1.08 |
| **Results** | | | | | | |
| Fraction of $CaSO_4$ converted to CaO | .966 | .932 | .816 | .695 | .932 | .940 |
| Sulfate S in effluent acceptor, Wt.% | .95 | .68 | 2.28 | 3.53 | .56 | .51 |
| Sulfide S in effluent acceptor, Wt.% | .03 | .40 | .00 | .00 | .20 | .07 |
| Feed dolomite overhead as dust, Wt.% | 1.86 | .75 | .33 | .25 | .38 | .50 |
| **Dry Exit Gas, Mol %** | | | | | | |
| $CO_2$ | 23.4 | 22.2 | 20.5 | 19.9 | 20.9 | 21.0 |
| CO | .78 | .78 | .56 | .50 | .91 | .90 |
| $O_2$ | .09 | .13 | .15 | .42 | .27 | .33 |
| $N_2$ + A | 68.6 | 71.6 | 75.0 | 76.4 | 74.3 | 74.7 |
| $SO_2$ | 7.10 | 5.12 | 3.78 | 2.84 | 3.53 | 3.03 |
| COS | .02 | .03 | .01 | .01 | .03 | .03 |
| **Balance Closures, (Out)(100)/In** | | | | | | |
| Mass | 98.1 | 98.8 | 99.9 | 100.1 | 96.3 | 101.2 |
| S | 104.4 | 97.5 | 108.9 | 105.3 | 102.2 | 98.5 |
| CaO | 97.6 | 91.6 | 100.2 | 95.0 | 95.3 | 99.0 |

FIGURE 1

# SIMPLIFIED FLOW DIAGRAM OF CONTINUOUS FLUIDIZED COMBUSTOR

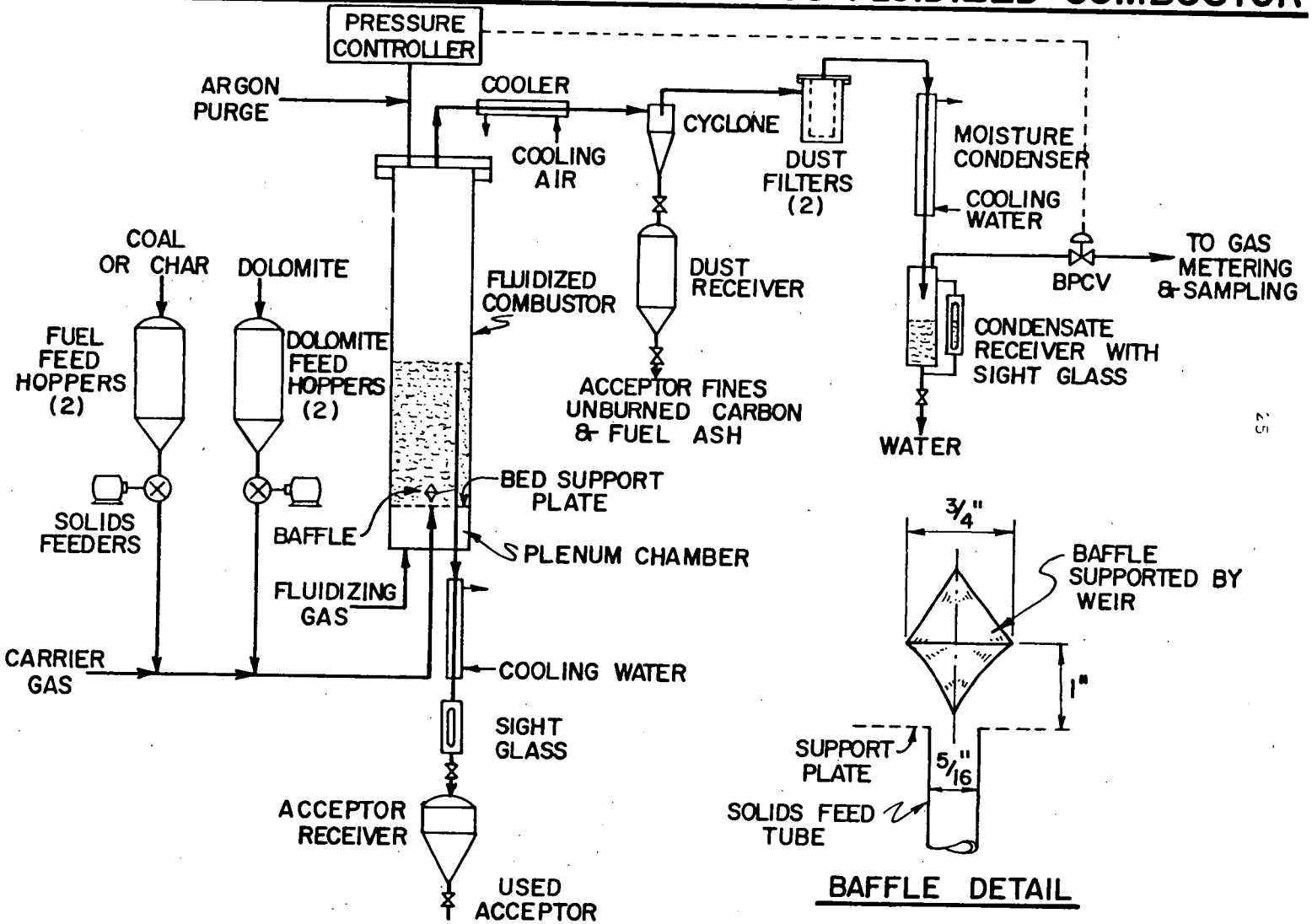


*FIGURE 2*

## SULFUR REMOVAL EFFICIENCY vs Ca/S MOL FEED RATIO

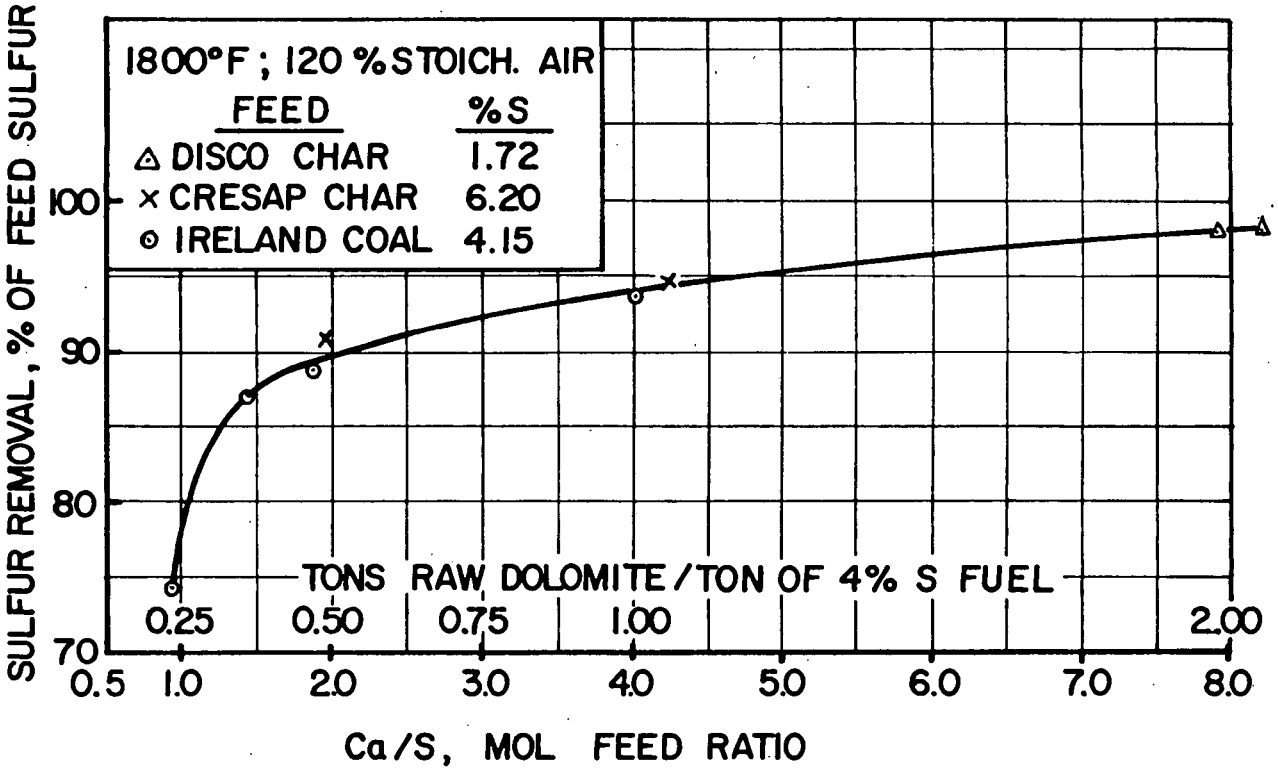


*FIGURE 3*

## DOLOMITE ATTRITION RATE vs SULFUR CONTENT OF EFFLUENT ACCEPTOR

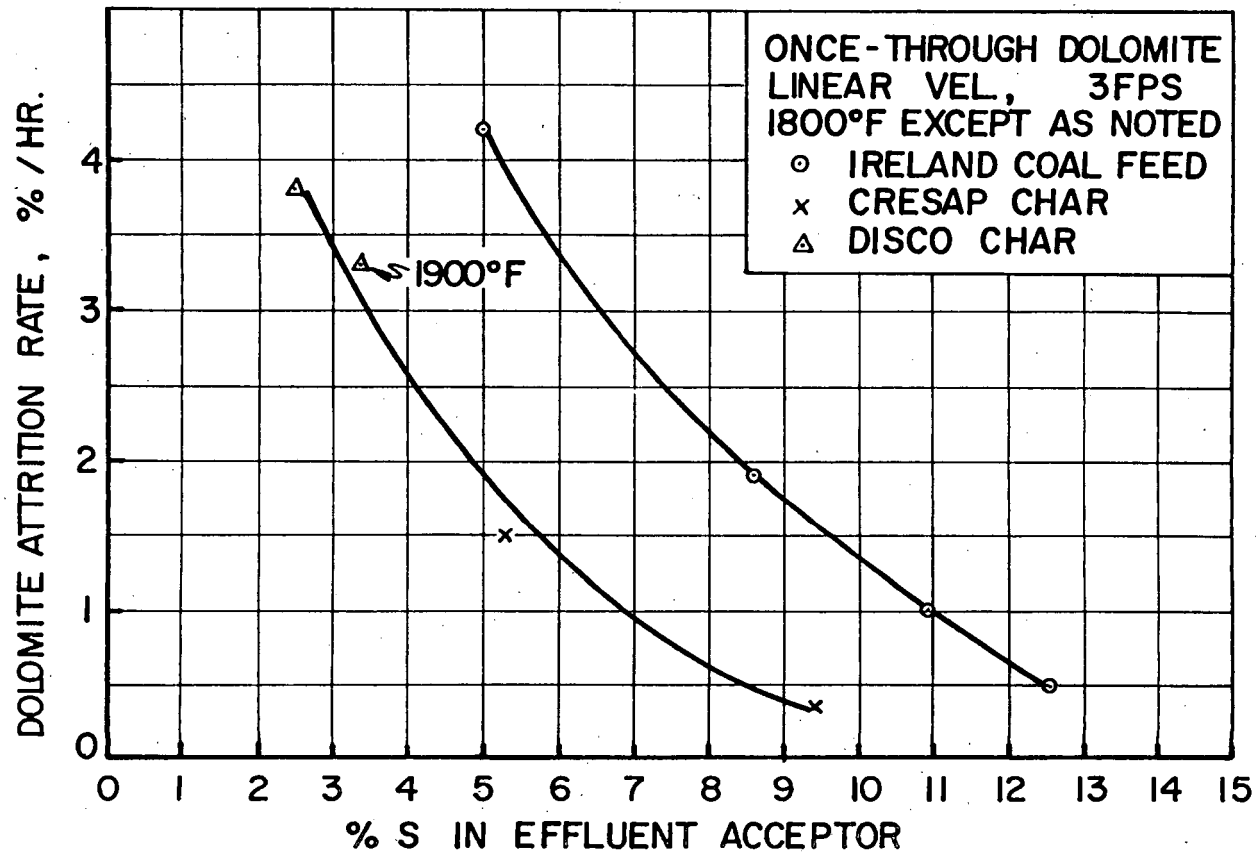


*FIGURE 4*

## ACTIVITY OF REGENERATED ACCEPTOR

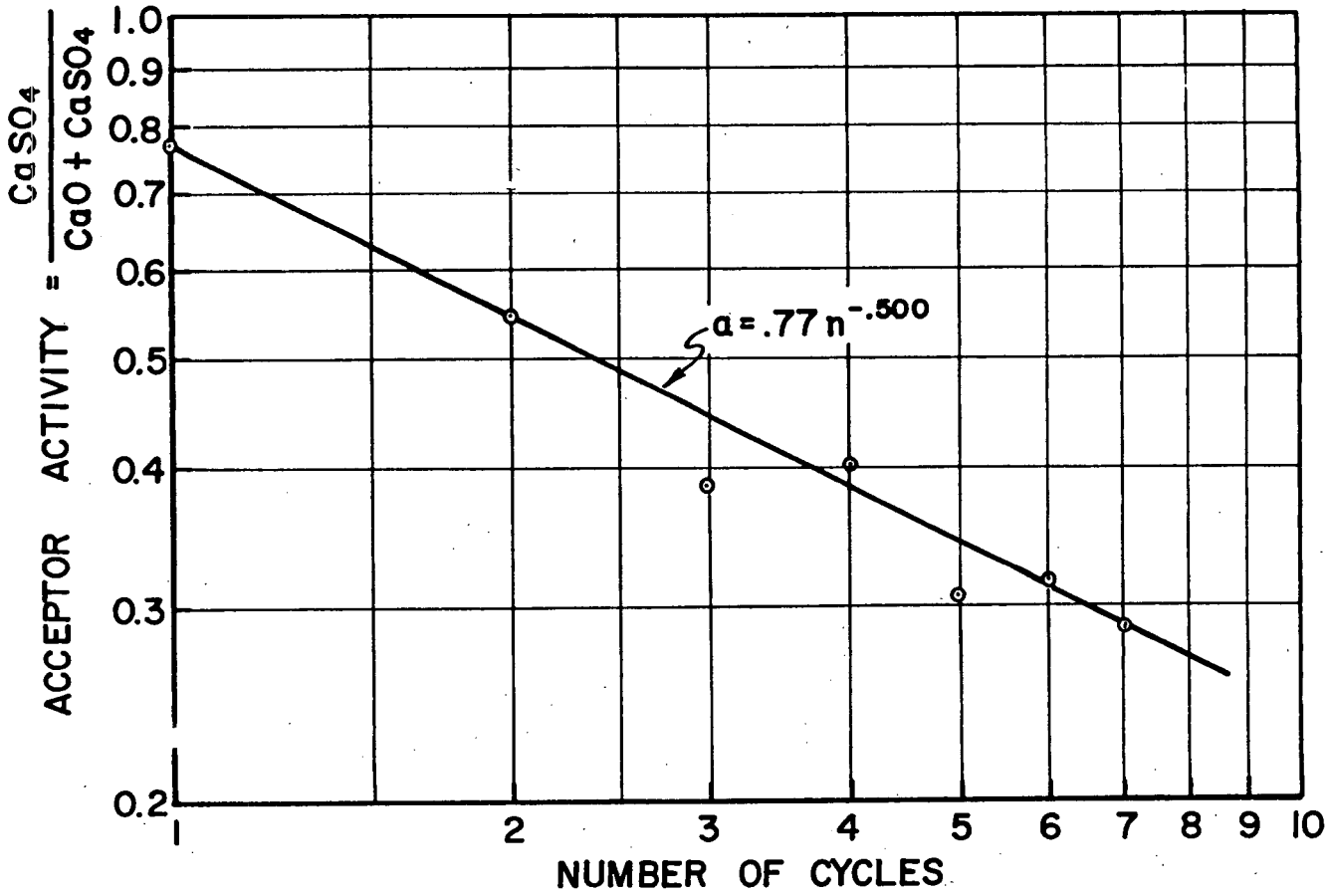
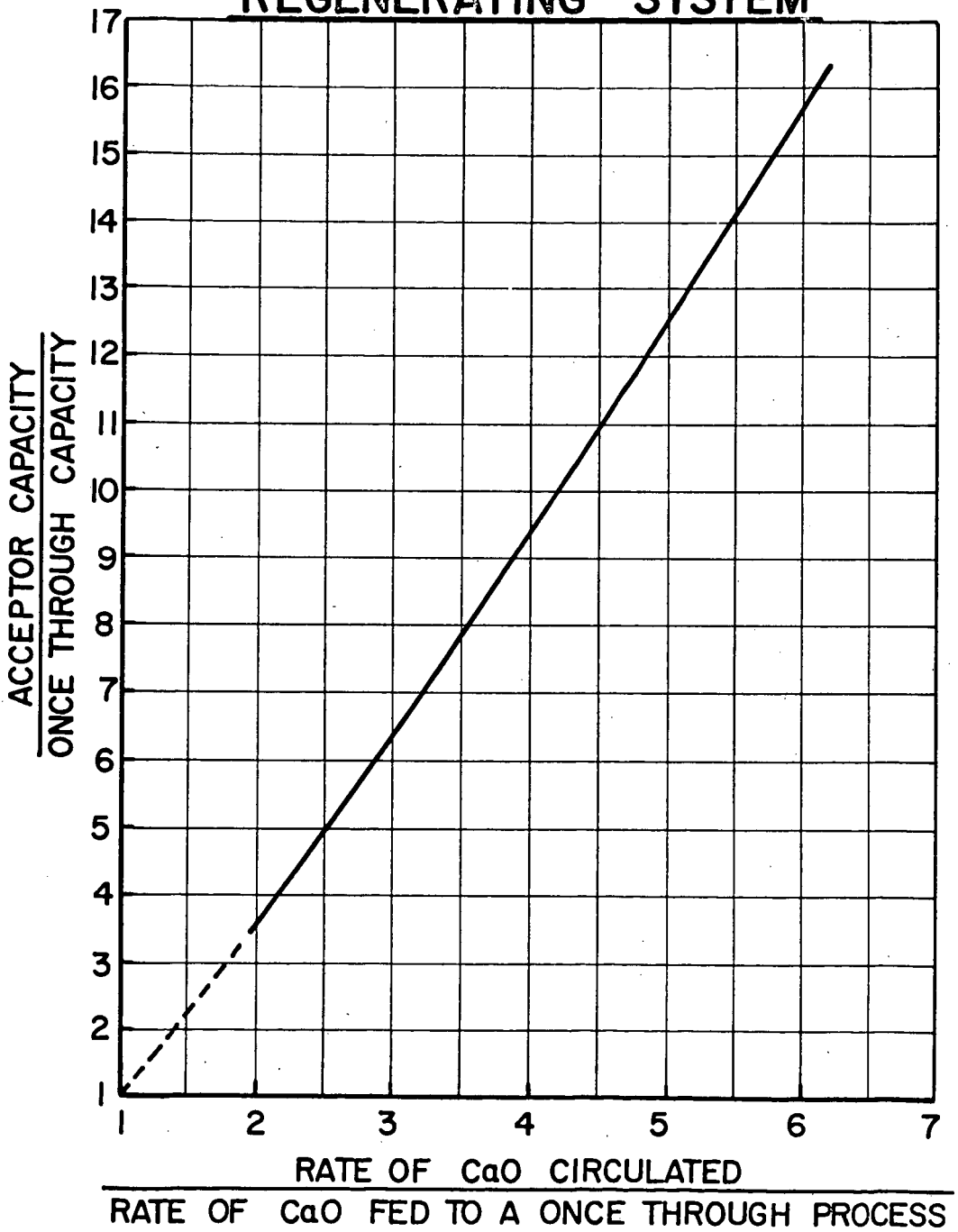


FIGURE 5

ACCEPTOR LIFETIME IN A CONTINUOUS REGENERATING SYSTEM