methods and places of limestone injection. To evaluate these variables, the Bureau is investigating all of them on a rational basis.

(3) *Improved combustion methods*

An entirely different approach to alleviate the sulfur problem involves the use of new combustion principles that theoretically develop electric power at considerably higher efficiencies than those presently used. The Bureau is investigating several of these principles, including magnetohydrodynamics, electrogasdynamics, and combined cycles. Also under investigation is the combustion of coal in a fluidized bed, a method that offers advantages from improved heat and mass transfer and from lower temperatures within the bed. Lower bed temperatures may lead to reduced emissions of sulfur and nitrogen oxides, as well as greater efficiency by reduction in corrosion and ash deposits.

(4) *Stack gas treatment*

The Bureau is studying the removal of sulfur oxides from the stack gases generated when fuel is burned. Some of these approaches depend on reacting and fixing the sulfur oxides with various chemicals which can be regenerated and reused after adsorption. The sulfur is recovered either as sulfuric acid or in elemental form, each of which can be marketed. Among the processes under investigation are:

(a) *Alkalized alumina process*

Oxides of sulfur are removed from hot stack gases by absorption on free-falling and entrained pellets of alkalized alumina. The pelleted absorbent is regenerated and released sulfur converted to hydrogen sulfide through application of heat and a reducing agent, such as producer gas. Subsequent treatment of the H_2S in a Claus reactor produces recoverable elemental sulfur.

Under the sponsorship of the Public Health Service, a small pilot plant (550 cubic feet per hour) was built at the Bureau's Pittsburgh Coal Research Center, Bruceton, Pa., in 1961 and operated for three years. A completely integrated unit handling 55,000 cfh is now being used at the center to investigate continuous operation of the absorption-regeneration cycle and other variables.

(b) *Rock-phosphate process*

Bench-scale tests have proved that, following catalytic oxidation of SO_2 to SO_3, the SO_3 is completely removed from stack gas at 400° C by contact with phosphate rock. Furthermore, the SO_3 and water vapor in the gas stream form sulfuric acid vapor and react with the calcium phosphate in the rock. This process presents the possibility of preparing a fertilizer or a fertilizer intermediate, while at the same time removing noxious sulfur oxides from flue gases. A considerable portion of the Nation's sulfuric acid is consumed at present in the preparation of superphosphate fertilizer.

(c) *Manganese-oxides process*

While manganese oxides were found in a preliminary screening investigation to be highly absorbents of SO_2 from combustion gases at 130° to 330° C., an improved, low-cost regeneration scheme is needed to reconvert the spent oxides to usable, active manganese oxides. Physical regenerating methods under study consist of thermal treatments at various pressures. Chemical methods involve use of the following gases at various temperatures and pressures: H_2, CO, CH_4, air, CO_2, steam, H_2S, and producer gas. Reducing solids, i.e., coal, coke, manganese matte, and iron pyrites, will be considered also for regeneration tests. To reduce attrition losses in the absorber development of a harder manganese oxide absorbent will be sought. This involves investigating methods such as coprecipitation with other oxides, impregnation on supports, and pelletizing.

(d) *Teller process*

Dr. A. J. Teller of Cooper Union University, New York City, has conducted laboratory studies of an absorption system using chromatographic-type base materials such as alumina or chromosorb, impregnated with an absorption agent. The absorbing compound may be organic; i.e., amines, amides, quinones; or inorganic, such as metal sulfites. The absorption product must be regenerable thermally.

Under a cooperative agreement with Cooper Union, additional research is being funded by the Bureau of Mines in order to study the process variables. Different aspects of this work is being conducted simultaneously at Cooper Union and at the Bureau's Pittsburgh Coal Research Center.