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**Quarterly Report**
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***Project Title*: Low Temperature $SO_2$ Removal with Solid Sorbents in a Circulating Fluidized Bed Absorber**

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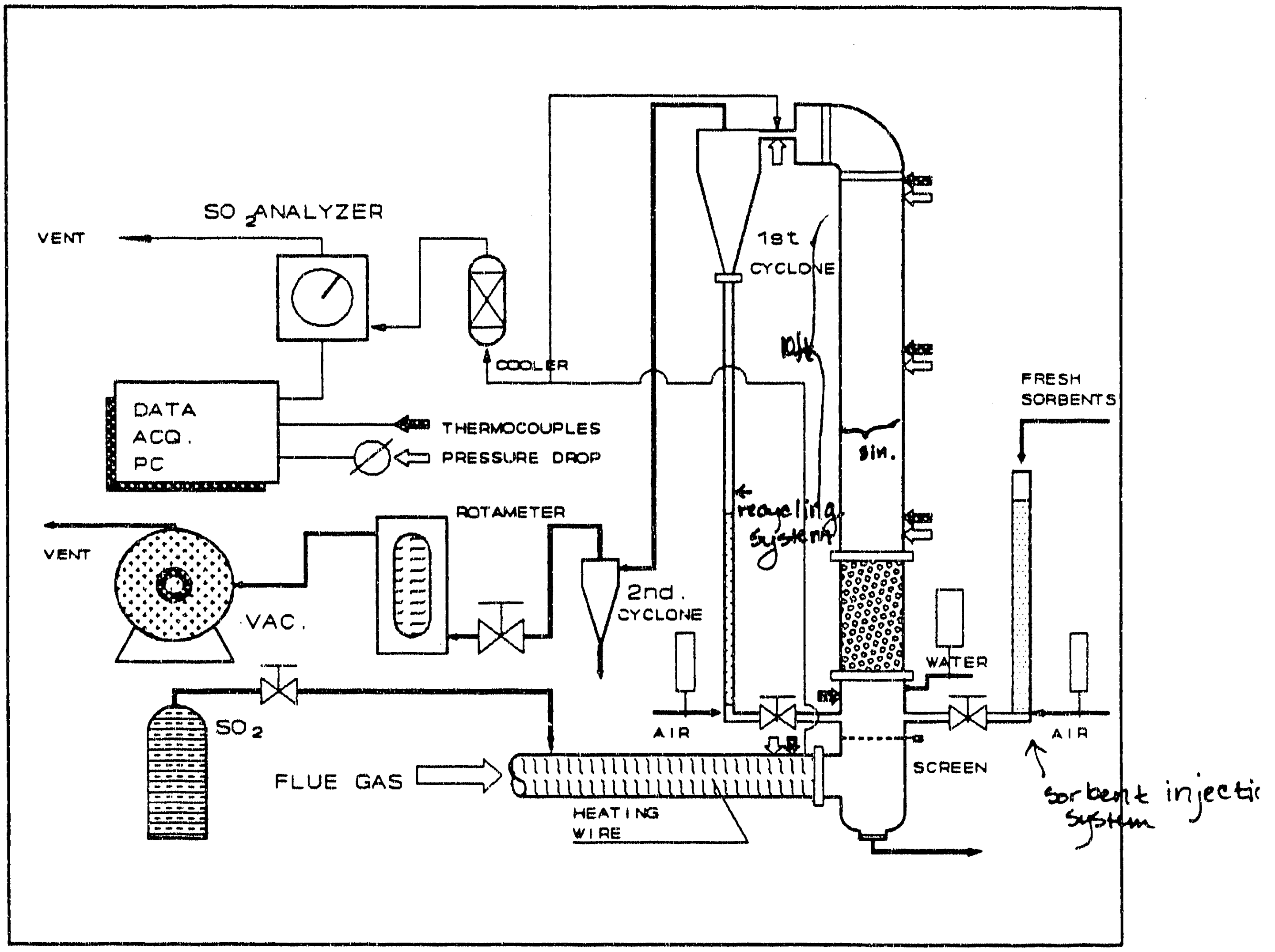
**Abstract**

The construction of a bench-scale Circulating Fluidized Bed Absorber (CFBA) unit has been completed, and system calibrations have already been performed. In addition, as a novel method injecting water into CFBA, a toroidal-shaped nozzle was designed and installed in a bed reactor to increase the wetting efficiency of solid sorbents. The experimental set up for low temperature $SO_2$ removals consists of a bed reactor of 3 inches in diameter and 10 feet in length, two high efficiency cyclones for gas/solid separation, sorbent injection and recycling system, water injection system, gas heating system, and gas flow, concentration, temperature and pressure monitoring system. The toroidal-shaped nozzle located at the base of the bed has 12 holes placed symmetrically around the ring at an angle of 50° with the horizontal, and is made of a copper tube.

## I. Work Performed/Results Obtained

***Construction of CFBA Unit :*** A bench scale CFBA unit has been constructed for the purpose of study on sulfur uptake of solid sorbents under low temperature conditions. The bench scale CFBA unit, which is similar with the pilot scale unit built earlier, consists of a bed reactor of 3 inches in diameter and 10 ft in length, two high efficiency cyclones for gas/solid separation, sorbent injection and recycling system, water injection system, gas heating system, and gas flow, concentration, temperature and pressure monitoring system. The bench scale CFBA system is schematically shown in Figure 1.

**Figure 1 : Scheme of Bench Scale CFBA Unit**



The bed reactor was built with 6 ft of steel pipe and 4 ft of pyrex glass, which allows for visible observation of the mixing and wetting phenomena during the fluidization. A woven stainless steel mesh (70 mesh) at the base of the bed serves to distribute the gas flow and support the sorbent materials.

The sorbent injection and recycling systems were also designed to be checked visibly for maintaining constant feeding and recycling rate for the case of continuous operation. The sorbent injection system consists of a pneumatically operated L-valve which is controlled by air flow. The coarse sorbents entrained from bed is captured by the two cyclones. Two high efficiency cyclones with diameters of 2.4" (1st. cyclone) and 1.5" (2nd. cyclone) collect solids greater than 32 microns with 99.9% of efficiency, and particles greater than 10 microns with 99.9% of efficiency, respectively. The collected sorbents are recirculated to the base of the reactor through another L-valve.

The gas heating system provides the simulated flue gas ranging from 300°F to 500°F through the heater located at the bottom of a reactor. Sulfur dioxide of 3000 ppm is injected to simulate the flue gas emitted from the combustion of high sulfur coal available in Ohio.

For the low temperature $SO_2$ removals with solid sorbents, a water injection system for water spraying to a bed reactor has been designed for use of a toroidal type of pressurized spray nozzles.

The sampling ports are positioned at both top and bottom of reactor, and pressure taps and thermocouples are installed at equal distance throughout the height of the fluidized bed. The particulate samples can be taken from 2 cyclones located at downstream of a bed reactor. The $SO_2$ concentrations of gas is determined with Horiba $SO_2$ analyzer (Model 2000) which uses the nodispersive infrared technique. Gas concentration, temperature, and pressure of the system are measured at selected locations along the bed, and a data acquisition system is also employed to monitor and record the data continuously.

***Calibrations of CFBA Unit :*** Calibrations of air flow rate and pressure drop for operations of the bench scale unit were also performed. This unit has three rotameters for controlling air flow through a bed reactor, feeding and circulating system, and five magnehelics for measurements of pressure drop along the bed reactor. The rotameter calibrations were carried out with a wet test meter, a bubble meter and a roots meter (Model 5M125TC, Dresser Systems, Inc.), and the magnehelics were adjusted by using a manometer.

The rotameters for feeding and circulating system were calibrated with a wet meter whose correction factor was determined by a bubble meter. The air flow rate and the correction factor of wet meter at standard conditions are calculated. The results are illustrated in Figure 2 for the rotameter I (feeding system), and Figure 3 for the rotameter II (circulating system), respectively. Their squared correlation coefficients ($R^2$) are larger than 0.99. Air flow of a bed reactor can be controlled with a large rotameter, which was already calibrated. Its calibration curve is verified by using a roots meter (Model 5M125TC, Dresser Systems, Inc.). Four tests are compared with the rotameter calibration curve (solid line) as shown in Figure 4.

**Figure 2. Calibration curve of rotameter I**

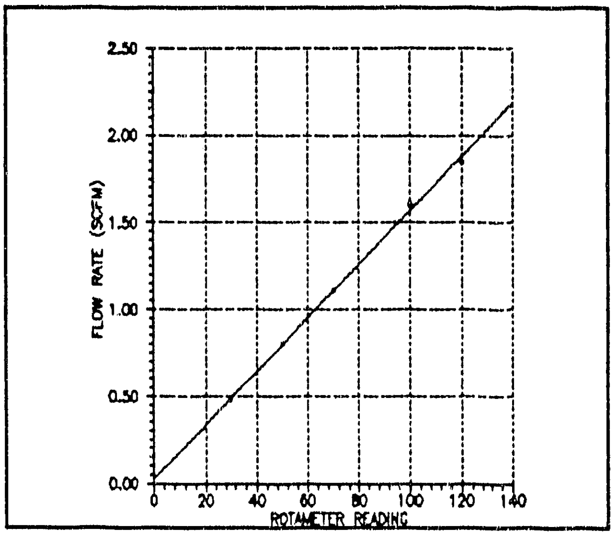



**Figure 3. Calibration curve of rotameter II.**

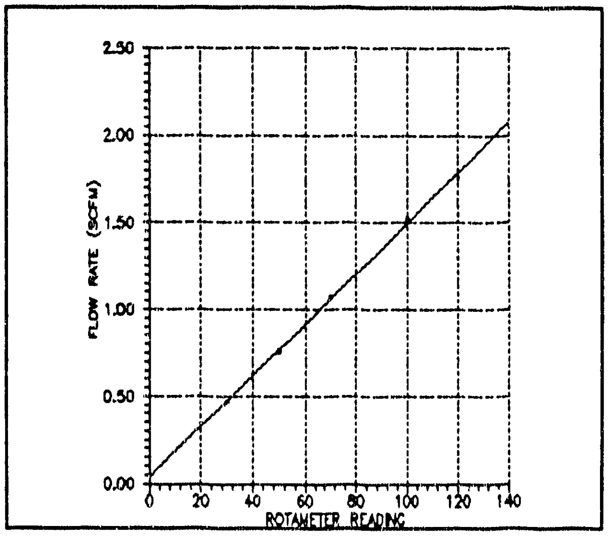
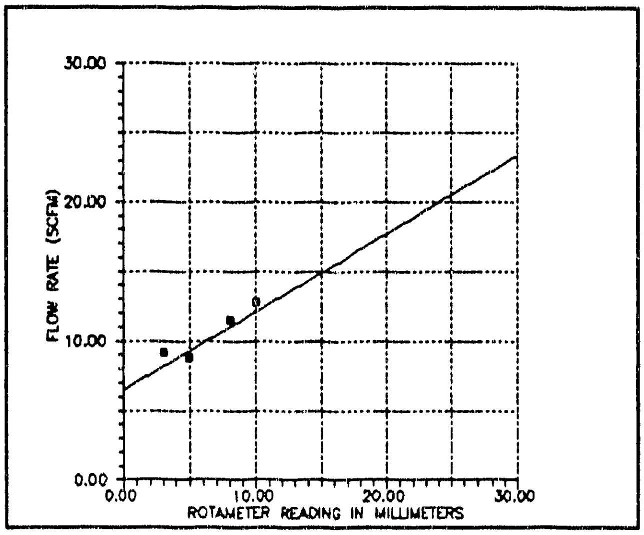



**Figure 4. Verification of main rotameter**



***Nozzle Construction and Installation :*** As mentioned previously, particle wetting in the CFBA system is very important to the overall $SO_2$ removal efficiency for a given bed material. Because of the physical limitations imposed by the commercial nozzles on the degree of particle wetting, a novel method injecting the water to the CFBA was constructed and installed to increase the degree of particle wetting while minimizing wall wetting.

The installed nozzle is shown in Figure 5. It consists of a toroidal ring placed at the base of the bed. As illustrated in Figure 6, the ring has water injection orifices placed symmetrically around the ring at an angle, $\alpha$, with the horizontal. The angle will be chosen to optimize the flight of the water drops with respect to the solid beds so as to maximize the probability of a drop-solid collision. For this study, the toroidal ring nozzle was made of 1/4 inches of copper tube for the CFBA unit, and has 12 holes and 50° angle based on droplet trajectories. The diameter of hole punctured by a laser technique is about 100 $\mu$m. Water is injected by a high pressure pump to insure good atomization and a high droplet initial velocity. A filter is placed before pump to prevent the contaminants from clogging the small holes.

**Figure 5. Toroidal Shaped Nozzle Installed for High Wetting Efficiency of Sorbents**

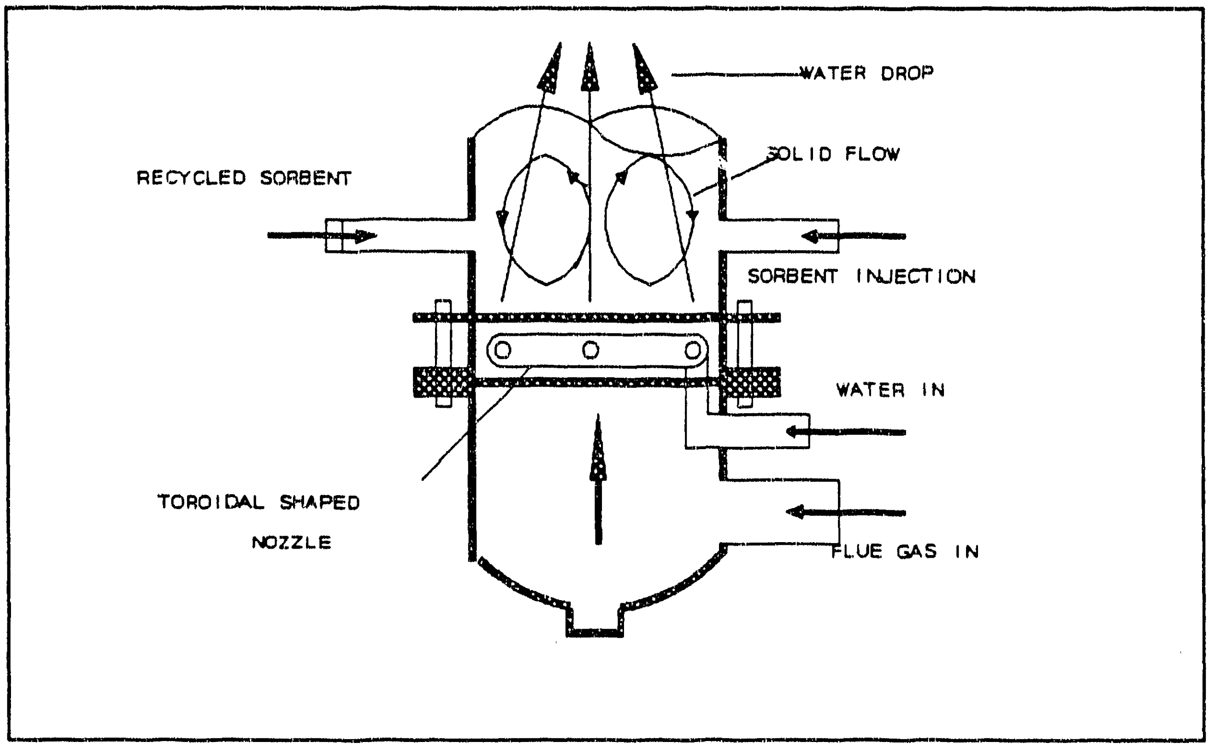
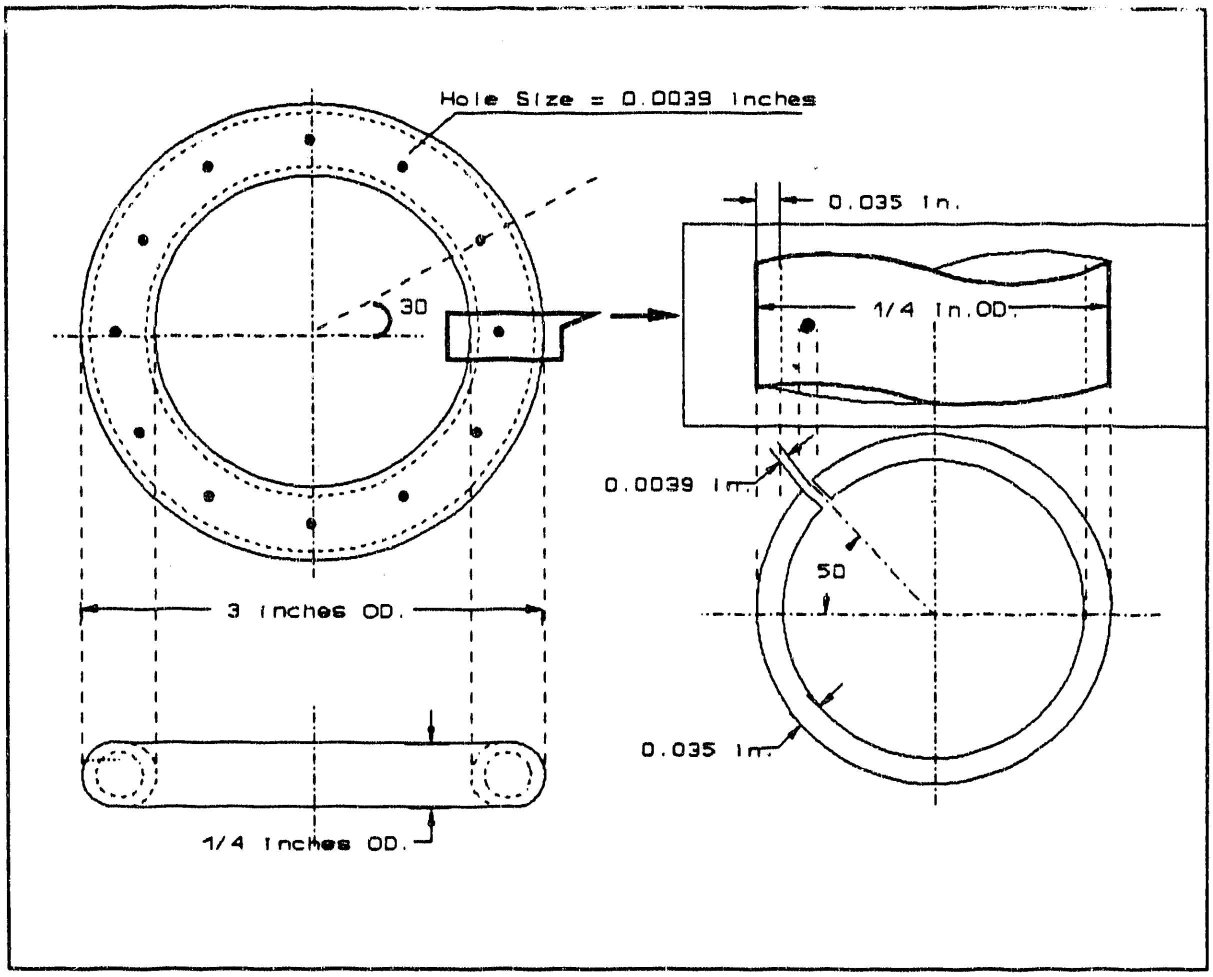


**Figure 6. Design of Toroidal Shaped Nozzle**




## II. Unusual Problems/Circumstances

The CFBA system was moved to another laboratory, which is more spacious and much more equipped than before. Such movement, however, caused the proposed phase to be slow. Another unusual problem came from nozzle clogged by contaminants, and a method to clean the blocked holes or prevent it from clogging should be established.

## III. Tasks/Work to be Performed

A series of experiments in the bench scale CFBA unit will be conducted with sized CaO to test the effectiveness of the new particle wetting system. These tests will be similar to those conducted with the commercial nozzle used previously, and the results will be compared. In addition, other tests will be performed with other toroidal nozzles with a different number of holes and at different angles. The variables to be tested will be ***the approach to saturation*** (from +15°F up), ***moisture content in the sorbents, bed pressure drop*** (4 in-$H_2O$ and greater), ***attrition under water injection, sulfation rates at different water injection rate, simultaneous hydration and sulfation of CaO, solid residence time distribution in the bed, geometry of spray nozzle, and CaO particle and water droplet size distribution, etc.***

Respectfully submitted by,

Tim C. Keener, PhD

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