

The plant to be described is to produce 500 MW of electrical power. The flow rates, compositions, stream conditions, and other details to be given are representative of such installations. The key step in removing SO_2 from the stack gas is the reaction of SO_2 with CaO and oxygen to produce CaSO_4 , an insoluble stable compound. Four major components of the process will be traced: the coal-limestone-stack gas streams, the scrubber water, the cooling-heating water cycle, and the generated steam cycle.

The composition of coal can vary considerably, but that shown in Table CS 2.1 is typical of that used in this process. During coal combustion the sulfur in the coal reacts to form SO_2 and very small amounts of SO_3 . Eighty-five percent of the ash in the coal leaves the boiler in the stack gas as fly ash; nitrogen emerges as N_2 , and the carbon, hydrogen, and sulfur in the fuel are oxidized completely to CO_2 , H_2O , and SO_2 .

Table CS 2.1. Coal Properties

1. Composition (ultimate analysis)

Component	Dry Wt%
Ash	7.2
Sulfur	3.5
Hydrogen	5.0
Carbon	75.2
Nitrogen	1.6
Oxygen	7.5
Moisture: 4.58 lb _m /100 lb _m wet coal	

2. Heat capacities

$$\text{Dry coal: } C_p = 0.25 \text{ Btu/lb}_m \cdot \text{F}$$

$$\text{Ash: } C_p = 0.22 \text{ Btu/lb}_m \cdot \text{F}$$

3. Heating value of coal: 13,240 Btu/lb_m dry coal

Finely ground limestone, whose composition is given in Table CS 2.2, is injected directly into the furnace where complete calcination occurs.²

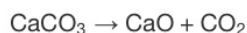


Table CS 2.2. Limestone Properties

1. Composition

Component	Dry Wt%
CaCO_3	91.8
Inerts	8.2
Moisture: 10 wt% water	

2. Heat capacity of inerts

$$C_p(\text{Btu} / \text{lb}_m \cdot \text{F}) = 0.180 + 6.00 \times 10^{-5} T(^{\circ}\text{F})$$

The limestone feed rate to the furnace is 10% in excess of that required for complete consumption of the generated SO_2 . Both limestone and coal enter the process at about 77°F. A waste stream consisting of 15% of the limestone inerts and coal ash is removed from the furnace at 1650°F.

Air at 110°F and 30% relative humidity is brought to 610°F in an air preheater, and the heated air is fed to the furnace. The air feed rate is 40% in excess of that required to burn the coal completely. Gases from the furnace containing fly ash, CaO , and CaSO_4 and at 890°F are cooled in the air preheater and then split into three trains. The gas in each train is cooled further to 177°F, and fed to a scrubber where it is contacted with an aqueous slurry of CaO and CaSO_4 . Sulfur dioxide is absorbed in the slurry and reacts with the CaO . The gas leaving each scrubber contains 3.333% of the SO_2 and 0.3% of the fly ash emitted from the boiler furnace. The effluent gas from the scrubber, which is at 120°F and saturated with water, is heated and mixed with the gas streams from the other trains. The combined gas stream is sent to a blower where its pressure is increased from 13.3 psia to 14.8 psia; it is then exhausted through a stack to the atmosphere.

The liquid feed enters the scrubber at 117°F and contains 10.00 wt% solids; it is fed at a rate such that there are 6.12 lb_m liquid per lb_m inlet gas. Liquid scrubber effluent at 120°F is sent to a holding tank where it is mixed with fresh makeup water and water recycled from a settling pond. From the holding tank, one stream is recycled to serve as liquid feed to the scrubber and another is pumped to the settling pond for solids removal.

Generation of steam and its utilization in the production of electricity in this plant is typical of many power cycles. Steam is generated in the boiler and leaves the boiler and superheater tubes at 1400°F and 2700 psia. It is expanded through a turbine where its pressure and temperature are reduced to 5 psia and 200°F. The low-pressure steam is then condensed at constant pressure and pumped isothermally to the inlet boiler tubes.

The temperature of the water used to cool the gas entering the scrubber is 148°F. The hot water at 425°F is then used to reheat the effluent gas stream from the scrubber. (The water thus undergoes a closed cycle.)

The power company for which you work is contemplating adding an SO_2 scrubber to one of its generation stations and has asked you to do the preliminary process evaluation. In solving the following problems, you may neglect the formation of SO_3 in the furnace, and assume that CaSO_4 and CaO are the only calcium compounds present in the slurry used in the scrubber (i.e., neglect the sulfite, bisulfite, and bisulfate compounds that are present to some extent in the real process).

Done



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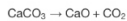


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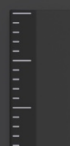
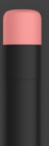
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CS 2.1 Construct a flowchart of the process, labeling all process streams. Show the details of only one train in the SO₂ scrubber operation.

CS 2.2 From the data on coal composition given in Table [CS 2.1](#), determine the molar flow rate of each element other than ash in the dry coal.

CS 2.3 Determine the feed rate of O₂ required for complete combustion.

CS 2.4 If 40% excess O₂ is fed to the boiler, calculate:

a The air feed in

- i.** lb-mole/min.
- ii.** Standard cubic feet/min.
- iii.** Actual cubic feet/min.

b The molar flow rate of water in the air stream.