CHAPTER 6

IMPLEMENTATION OF FOCDM-PI$^{\lambda}$D$^{\mu}$ CONTROLLER FOR SO_2 EMISSION CONTROL PROCESS WITH MIXED GAS (SO_2 + NO_2)

In industrial flue gases, sulphur oxides (SO_x) and nitrogen oxides (NO_X) are very often present together in variable concentrations from 1000 to 5000 ppm, depending on the combustible composition and on combusting conditions (Liemans & Thomas 2010). Nitrogen oxides (NOx) are a very interesting and important family of air polluting chemical compounds blended with SO_2 especially in coal fired thermal power plants. Hence, the experiments need to be carried out with SO_2 and NO_X mixed gases since among most of the industrial flue gas emissions, SO_2 and NO_X are the gases that can react with the hydrogen peroxide absorbent. In this analysis, absorption of SO_2 into H_2O_2 is called as desulphurization process and absorption of NO_2 into H_2O_2 is termed as denitrification process and they take place to oxidize SO_2 and NO_2 into sulphuric and nitric acids respectively.

From the outcome of the previous chapter, it is clear that the performance of the proposed FOCDM-PI$^{\lambda}$D$^{\mu}$ controller in SO_2 emission control process furnishes superior results when the mixer of pure SO_2 gas with air is given as an input. Hence, an attempt is made with the proposed

FOCDM-$PI^{\lambda}D^{\mu}$ controller in SO_2 emission control set up by considering the gas mixture of SO_2 + NO_2 with H_2O_2 as an absorbent.

The experimental runs are carried out in a laboratory scale SO_2 emission control set up with the same procedure as detailed in section 4.1. In addition to this, the air inlet is the mixed gas which comprises calibrated SO_2 gas inlet from the SO_2 gas cylinder with the concentration of 5000 ppm, NO_2 gas inlet from the NO_2 gas cylinder with the concentration of 1000 ppm and air from the air compressor with the flow rate of 40 m^3/hr as shown in Figure 6.1. This mixed air is fed at the inlet of the packed column. The mixing tank comprises H_2SO_4 + externally added H_2O_2 sprayed at the top of the packed column as a scrubbing liquid. The SO_2 gas sensor mounted at the inlet and outlet of the packed column measures the concentration of SO_2. Thus the effect of NO_2 on the SO_2 absorption process is studied.

Figure 6.1 SO_2 emission control setup with mixed gas

6.1 PERFORMANCE OF FOCDM-PI$^{\lambda}$D$^{\mu}$ CONTROLLER AND CDM-PID CONTROLLER WITH MIXED GAS

The present study is carried out to analyse the performances of FOCDM-PI$^{\lambda}$D$^{\mu}$ and CDM-PID controllers at the operating point of 50 ppm when mixed gas is given as an input. The behaviour of the flow rate of externally added H_2O_2 with the variation of SO_2 outlet concentration is recorded for the time period of 0 to 14,000 sec with a step size of 5 sec as shown in Figure 6.2 and its performance measures are tabulated in Table 6.1.

To ensure the performance of the controller when there is an external disturbance, NO_2 is added into the inlet gas, (NO_2 externally affects the absorption of SO_2 into H_2O_2) and the controller settings are chosen similar to the settings of the pure SO_2 gas analysis. Since the present study is focused on the removal of SO_2 from the mixed (SO_2+NO_2) gas, the concentration of NO_2 at the outlet of the column is not measured.

From the results, it is clear that during the simultaneous absorption of SO_2 and NO_2 into H_2SO_4 + externally added H_2O_2 solutions, both sulphuric and nitric acids are produced. The formation of concentrated sulphuric acid seems to have more effect on the SO_2 removal efficiency, but the formation of nitric acid (HNO_3) does not have a kinetic effect on the oxidation reaction. The concentration of HNO_3 somehow modifies the absorption properties of the liquid solution, and thus the settling time of FOCDM- PI$^{\lambda}$D$^{\mu}$ is increased. An increase in nitric acid concentration decreases the SO_2 absorption performance but it is negligible when compared to the effect of sulphuric acid on the absorption performance. The negative effect of the sulphuric acid on the absorption process is well-known, but while considering the influence of nitric acid, it has a medium effect at low concentrations, almost up to 6000 secs. After 6000 secs, HNO_3 concentration becomes higher and makes the mass transfer more difficult. Thus the CDM-PID controller could not forecast the behaviour of the absorption process. Hence it provides an offset about the set point.

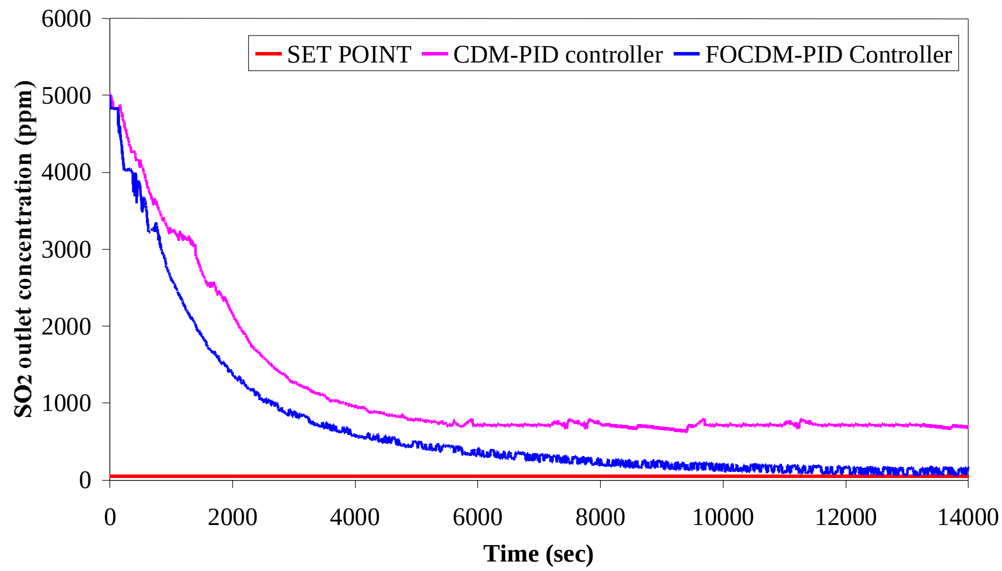

Figure 6.2 Performance of FOCDM-$PI^{\lambda}D^{\mu}$ and CDM-PID controllers with mixed (SO_2+NO_2) gases at 50 ppm SO_2 outlet concentration

Table 6.1 Performance measures of FOCDM-$PI^{\lambda}D^{\mu}$ and CDM-PID controllers with mixed (SO_2+NO_2) gases at 50 ppm SO_2 outlet concentration

Performance Measures	**CDM-PID**	**FOCDM-$PI^{\lambda}D^{\mu}$**
ISE	3.92E+09	3.23E+06
IAE	1.83E+10	1.47E+06
ITAE	4.60E+09	2.66E+05
t_s	NIL	11705

As shown in Figure 6.2, the response of the proposed FOCDM-PI$^{\lambda}$D$^{\mu}$ controller provides no offset with minimum sustained oscillations and gets settled at the operating point 50 ppm SO_2 outlet concentration with 2% tolerance error at 11705 sec. Whereas the performance of CDM-PID controller provides an offset of almost 700 ppm SO_2 outlet concentration throughout the measuring period since the CDM-PID controller could not predict the behaviour of the absorption process when SO_2 and NO_2 blended together. The proposed FOCDM-PI$^{\lambda}$D$^{\mu}$ controller provides the closed loop stability and achieves the desired specification at the interested gain crossover frequency. This signifies the potential benefit of using a fractional order controller over an integer order CDM-PID controller. It is also clear that the control action of the fractional FOCDM-PI$^{\lambda}$D$^{\mu}$ controller is significantly faster than that of the classical PID controller tuned by the CDM tuning method. As presented in Table 6.1, the error indices show that the performance of FOCDM-PI$^{\lambda}$D$^{\mu}$ controller is far better when compared to the CDM-PID controller. Thus the FOCDM-PI$^{\lambda}$D$^{\mu}$ controller outperforms CDM-PID controller in the mixed gas analysis also.

6.2 ROBUSTNESS TEST OF FOCDM-PI$^{\lambda}$D$^{\mu}$ CONTROLLER AND CDM-PID CONTROLLERS WITH MIXED GAS

The performance of the proposed FOCDM- PI$^{\lambda}$D$^{\mu}$ controller is ensured by conducting the robustness test. The robustness of the FOCDM-PI$^{\lambda}$D$^{\mu}$ controller is tested by conducting an experimental run at another operating point of 500 ppm SO_2 outlet concentration. The robustness metrics obtained using CDM-PID and FOCDM-PI$^{\lambda}$D$^{\mu}$ controllers and the performance measures are illustrated in Figure 6.3 and Table 6.2 respectively.

From the Figure 6.3, it is evident that the proposed FOCDM-PI$^{\lambda}$D$^{\mu}$ controller follows the set point from t= 6355 sec with minium 2% tolerance error. The performance of CDM-PID controller introduced an offset of around 400 ppm about the set point. As shown in Table 6.2, the minimum error indices are offered by the FOCDM-PI$^{\lambda}$D$^{\mu}$ controller compared to CDM-PID controller.

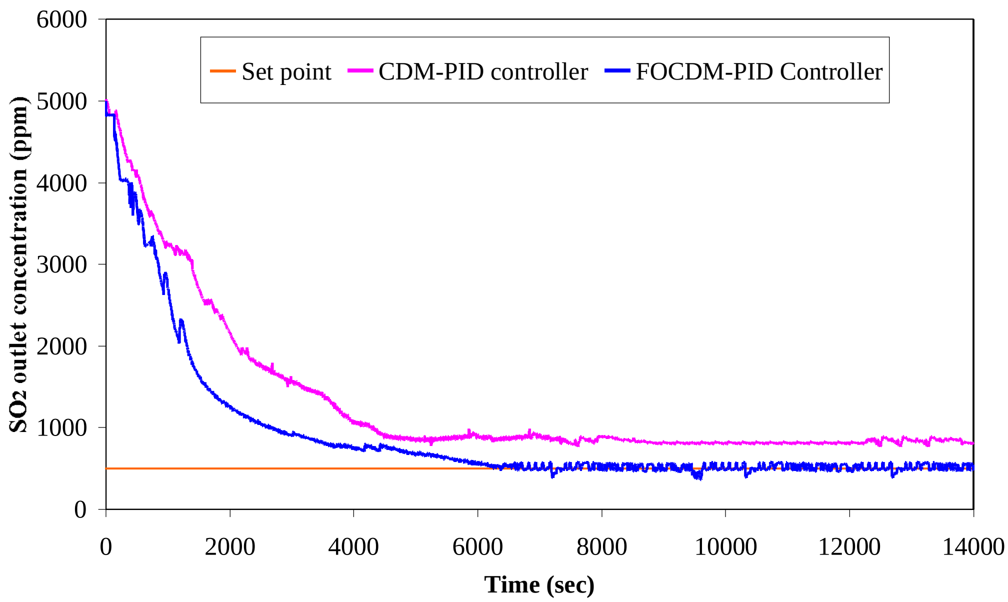

Figure 6.3 **Performance of FOCDM-PI$^{\lambda}$D$^{\mu}$ and CDM-PID controllers with mixed (SO_2+NO_2) gases at 500 ppm SO_2 outlet concentration**

Table 6.2 **Performance measures of FOCDM-PI$^{\lambda}$D$^{\mu}$ and CDM-PID controllers with mixed (SO_2+NO_2) gases at 500 ppm SO_2 outlet concentration**

Performance Measures	**CDM-PID**	**FOCDM-PI$^{\lambda}$D$^{\mu}$**
ISE	4.463E+09	2.616E+09
IAE	2.33E+06	1.2E+06
ITAE	8.49E+09	2.05E+09
t_s	7055	NIL

Thus the robustness test ensures a better performance of the proposed FOCDM-$PI^{\lambda}D^{\mu}$ controller than the CDM-PID controller during the mixed gas analysis. The results already have proved in pure gas analysis that ZN-PID classical controller has less performance than the CDM-PID controllers. Hence for this mixed gas analysis, CDM-PID controller alone is considered for comparative studies.

6.3 LOAD REJECTION ANALYSIS OF FOCDM-$PI^{\lambda}D^{\mu}$ CONTROLLER AND CDM-PID CONTROLLERS WITH MIXED GAS

The load rejection analysis for FOCDM-$PI^{\lambda}D^{\mu}$ controller and CDM-PID controller is investigated at the operating point of 500 ppm outlet SO_2 concentration with mixed gas as an input. The Figure 6.4 demonstrated that the FOCDM-$PI^{\lambda}D^{\mu}$ controller tried to settle almost at 6,000 sec. A step disturbance is introduced from the actual output data after 6000 sec into the system by way of introducing the water flow rate from 0-1 lph as shown in Figure 6.4.

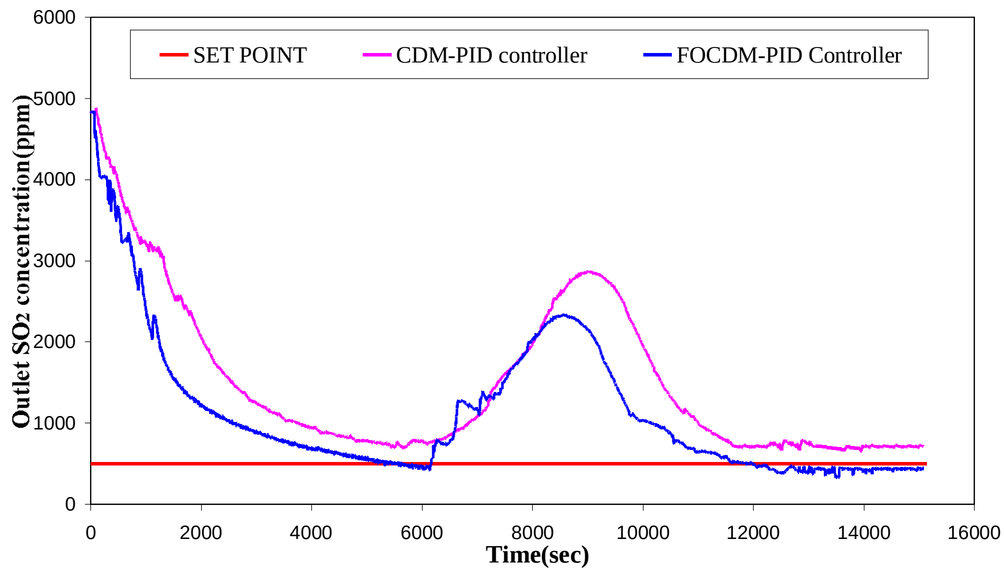

Figure 6.4 Performance of FOCDM-PI$^{\lambda}$D$^{\mu}$ and CDM-PID controllers with mixed (SO_2+NO_2) gas at 500 ppm operating point during disturbance analysis

Table 6.3 Performance measures of FOCDM-PI$^{\lambda}$D$^{\mu}$ and CDM-PID controllers with mixed (SO_2+NO_2) gas at 500 ppm operating point during load rejection analysis

Performance Measures	CDM-PID	FOCDM- PI$^{\lambda}$D$^{\mu}$
ISE	9.66E+09	5.97E+09
IAE	4.47E+06	3.27E+06
ITAE	2.67E+10	1.86E+10

After the step disturbance is introduced after 6000 sec, the SO_2 outlet concentration is increased upto 2500 ppm for FOCDM-PI$^{\lambda}$D$^{\mu}$ controller and 3000 ppm for CDM-PID controller. During the water disturbance, the concentration of mixed solution increases rapidly towards the maximum value of 3000 ppm (at 8000 sec) and 2500 ppm (at 9000 sec) by CDM-PID controller and FOCDM-PI$^{\lambda}$D$^{\mu}$ controller respectively. From the maximum peak value, due to the controller action, the concentration of SO_2 decreases