towards the operating point. Among the two controllers, FOCDM-$PI^{\lambda}D^{\mu}$ controller outperforms and reaches the set point with minimum error indices as compared to the CDM-PID controller and it is shown in Table 6.3. Thus the proposed FOCDM-$PI^{\lambda}D^{\mu}$ controller tolerates the disturbance in a shorter time period and provides enhanced performance in disturbance rejection during the mixed gas analysis.

CHAPTER 7

CONCLUSION AND SCOPE FOR FUTURE WORK

The present research work has been undertaken with a vision to develop a simple and robust control strategy for SO_2 emission control process. It is done by designing the experimental set up with the packed column along with the effective absorbent combination and concentration for obtaining maximum SO_2 removal efficiency. In this work, 0.01 M of H_2SO_4 + 0.1 M of externally added H_2O_2 was considered as an absorbent. To regulate the flow rate of externally added H_2O_2 into the packed column, a new fractional order based CDM-PID (FOCDM-PI$^{\lambda}$D$^{\mu}$) controller was designed by combining the concepts of fractional calculus and Coefficient Diagram Method (CDM). More over, the literature surveys reveal that so far no real time implementation has been carried out with the above said controllers in the SO_2 emission control process.

The performance, robustness and load rejection characteristics of the proposed FOCDM-PI$^{\lambda}$D$^{\mu}$ controller have been investigated by conducting experimental works with operating points of 50 ppm and 500 ppm SO_2 outlet concentrations. The performance of the controllers was evaluated in terms of performance measures such as Error indices (ISE, IAE, and ITAE) and Quality indices (t_s) of the output signal. The results of the proposed control strategy have been compared with the other classical PID control techniques such as ZN-PID and CDM-PID controllers.

7.1 CONCLUSION

1. The physical modelling was carried out to determine various parameters of the packed column and the calculated specifications are diameter (150 mm), total height (2500 mm), packed height (1000 mm), minimum inlet liquid flow rate (150 lph) and minimum inlet gas flow rate (40 m^3/hr). Based on these designed parameters of the packed column, CFD analysis was carried out to determine the maximum SO_2 removal efficiency by conducting investigations with the absorbents such as water and hydrogen peroxide.From the CFD simulation results, the SO_2 removal efficiency was obtained as 46% for water absorbent and 94.33% for 0.1M hydrogen peroxide absorbent. Hence, the computed packed column parameters

were used to fabricate the packed column in lab scale SO_2 emission control set up.

2. The experiments were carried out in the lab scale experimental set up to confirm the type and concentration of the absorbent used for the controller studies. For this purpose, the absorbents such as water, NaOH, H_2SO_4 with different combinations and concentrations and H_2O_2 with different combinations and concentrations were analysed.

   Based on the experimental results, it is confirmed that for flue gas desulphurization process, 0.01M sulphuric acid with 0.1M externally added hydrogen peroxide was an attractive alternative to increase the SO_2 removal efficiency.

   Though 0.01M sulphuric acid with 0.1M externally added hydrogen peroxide produced 98.5% SO_2 removal efficiency, the experimental results conclude that the increase in sulphuric acid concentration reduces the SO_2 removal efficiency. Hence to maintain the removal efficiency to the operating point, externally added H_2O_2 is regulated based on the SO_2 outlet concentration. A better control action is essential to regulate the flow rate of externally added H_2O_2, since it has the direct influence on the SO_2 removal efficiency.

3. To design the controller, the SO_2 emission control system was modelled as FOPTD transfer function using experimental step test method. The model parameters (process gain K_p and process time constant τ_p, time delay θ) of the process were determined at different nominal operating points of SO_2 outlet concentration.

The average value of process gain and time constant were chosen as model parameters to compute PID controller settings. The identified model is represented as

$$G_p(S)=\frac{1.5616}{13.58S+1}e^{-23.48S}$$

Concurrence Based on the above model parameters, the classical controllers such as ZN-PID controller parameters (**K_c = 0.4444; T_i = 46.96 min; T_D = 11.74 min)** and CDM-PID controller parameters (**K_c= 0.3357; T_i = 18.0715 min; T_D = 0.2918 min)** were computed.

4. The performances of classical ZN-PID and CDM-PID controllers were implemented in a lab scale SO_2 emission control setup. By using the above controller settings, experimental studies were conducted at different operating points with set point tracking as mentioned above.

   Experimental studies revealed that the responses obtained by the ZN-PID controller provided transient behavior and never settled at the tracking period, since it failed to tackle the variation in process gain (nonlinearity). On the other hand, the results made by CDM-PID controller follows the set point at short duration of time and maintained the oscillation with low percent (±2%) throughout the measuring period.

   Since the CDM-PID controller have a feed forward controller in the reference input, it has the potential to adapt its parameters according to the process gain (nonlinearity) in the current working point. Similarly, the robustness metrics and disturbance rejection analysis obtained with the CDM-PID controllers provided superior performance with the same settings. Thus, CDM-PID controller provided better performance than the ZN-PID controller.

5. However, to further enhance the performance of the CDM-PID controller, the fractional calculus was incorporated with the concept of CDM and it was named as Fractional Order based CDM-PID (FOCDM-$PI^{\lambda}D^{\mu}$) controller.

   This new conception method of the FOCDM-$PI^{\lambda}D^{\mu}$ controller was proposed in this work to improve system control quality and performance. The tuning parameters of FOCDM-$PI^{\lambda}D^{\mu}$ controller such as Kp, T_i, and T_d were determined based on CDM design strategy (K_c = 0.3357; T_i = 18.0715 min; T_D = 0.2918 min).

   The optimum values of fractional integral order (λ) and fractional differentiation order (μ) were computed based on PSO optimisation criterion and its objective function was formulated using minimum ISE criterion in a given frequency band of [0.00992, 0.992] rad/sec. The computed parameters of FOCDM-$PI^{\lambda}D^{\mu}$ controller were **K_c = 0.3357; T_i = 18.0715min; T_D = 0.2918 min; λ = 0.1176 and μ = 0.9033.**

6. By using the above controller settings, the experiments were carried out in a lab scale SO_2 emission control set up. The performance of the FOCDM-$PI^{\lambda}D^{\mu}$ controller has been analysed and compared with CDM-PID controller through experimental runs with pure SO_2 gas at the operating points of 50 ppm and 500 ppm.

7. The results established that the response made by FOCDM-$PI^{\lambda}D^{\mu}$ controller maintained the set point at a short duration of time with minimum error when compared to the CDM-PID controller. The additional tuning parameters λ and μ in the fractional order controller signified the potential benefit in reducing the settling time and error.

   Tuning parameters λ and μ of the FOCDM-$PI^{\lambda}D^{\mu}$ controller are in fraction which increases the robustness of the system and gives an optimal control over the process. The FOCDM-$PI^{\lambda}D^{\mu}$ controller is more flexible and gives an opportunity to adjust the dynamics of the control system.

   These conclusions were obtained by the experiments which were conducted in the SO_2 emission control system with 5000 ppm pure SO_2 gas. In addition, the performance of the FOCDM-$PI^{\lambda}D^{\mu}$ controller was tested with the mixed (SO_2+NO_2) gas.

7.2 SCOPE FOR FUTURE WORK

The suggestions for further work are as follows:

- Experimental investigation may be carried out by regulating the flow rate of liquid inlet to the packed column.
- Controller study may be carried out by considering the concentration of inlet SO_2 as a measurement variable.
- A detailed study may be carried out for the determination of the interaction effects of SO_2 and NO_x absorption simultaneously in mixed solutions HNO_3+H_2SO_4+H_2O_2.