CHAPTER 5

SUMMARY AND CONCLUSION

5.1 GENERAL

The textile dyeing industry has long been one of the largest water users and polluters. The textile dyeing wastewaters are coloured by the release of unfixed dye and hence they are aesthetically objectionable. The removal of colour from the textile wastewater is achieved either by separation or oxidation techniques. The separation techniques viz., chemical coagulation and adsorption are not environment friendly, since they generate large amount of sludge that require disposal. The oxidative decolourisation techniques also have several limitations e.g. biological oxidation is not effective, oxidation with hydrogen peroxide requires long reaction time and oxidation with ozone is costly. Hence there is a need for a more suitable technology for decolourisation of textile dyeing wastewaters.

The semiconductor photocatalysis has proved to be a potential oxidation technique. It involves generation of hydroxyl radicals (powerful oxidants) by photoactivation of a semiconductor by the ultraviolet light radiation. The solar photocatalytic oxidation (PCO) involving solar light for activating a semiconductor (titanium dioxide (TiO$_2$)) is considered to be an alternative wastewater treatment technique.
A number of solar photocatalytic reactors have been investigated so as to facilitate the possible transfer of this technique to the industry. But, still solar PCO has not been sufficiently efficient for large-scale application. Hence, the scope of this study was to develop a new solar photoreactor and to demonstrate its applicability for the decolourisation of textile dyeing wastewaters, so as to facilitate the possible transfer of solar PCO technique to the industry.

5.2 SUMMARY

In this study, two ‘Water Fountain Solar Photoreactors’ of suspended catalyst system were developed. The fabrication of the reactors involved construction of water fountains in shallow ponds. The water fountain was used for keeping the photocatalyst in the form of thin films. Since the water fountain was transparent to solar light, the inexpensive and abundant solar UV light photons were exploited effectively for activating the photocatalysts.

A very detailed laboratory scale feasibility study was carried out on decolourisation of simulated rinse wastewaters (SRWWs), rinse wastewaters (RWWs) and dye bath wastewaters. The photoactivity of two catalysts viz., P25 TiO$_2$ and IS TiO$_2$ were studied under UV and solar light sources. The effects of operating variables viz., control conditions, pH, dye concentration and catalyst concentration were studied on decolourisation of SRWWs using both the catalysts under UV and solar light sources. In addition, effect of inorganic ions, solar ultraviolet light intensity and catalyst reuse were studied. SRWWs were prepared with dye concentration of 40 mg/L. Catalyst concentration of 0.1 g/L for indoor studies and 1.0 g/L for outdoor studies were adopted in general.
After successful completion of the studies on SRWWs, the studies were extended to RWWs collected from the industry. In this study, the effects of pH, catalyst concentration and catalyst reuse were studied. Finally, feasibility studies were extended to dye bath wastewaters and only the effects of pH and catalyst concentration were studied.

The detailed laboratory scale studies had shown the feasibility of decolourisation of RWWs. Hence, performance studies on solar photoreactors were restricted to only RWWs. During the performance studies, the photoreactors were operated in batch mode for three hours and in continuous flow mode for seven hours so as to study the influence of various operating variables of the photoreactors. The studies were carried out using SRWWs prepared with red dye of concentration 40 mg/L. Inorganic ions were also added in order to include their influence on the rate of decolourisation. A catalyst dosage of 1.0 g/L was adopted and the studies were carried out at the natural pH of the wastewaters. The samples were collected at 15 min interval for analysis of colour.

In batch mode, the influence of water fountain, liquid volume, constant liquid depth and solar ultraviolet light intensity were studied. The influence of flow rate was studied in continuous flow mode in the range of 1.5 – 12.0 L/h. Manual catalyst dosing was done at 15 min interval. Treatability studies on three batches of RWWs were carried out at their natural pH using IS TiO₂ in solar photoreactor of trapezoidal configuration at a flow rate of 6 L/h.

After successful completion of studies on bench-scale solar photoreactors, a pilot-scale solar photoreactor was designed for ninety percent decolourisation of rinse wastewaters for treating a flow of 11,760 L/day. Based
on reactor configuration, detention time and the amount of wastewater treated per day, the surface area of the reactor was determined. Based on the kinetic parameter arrived from the treatability studies of RWWs, the surface area of the water fountain was determined. The design light intensity was arrived by calculating the yearly average solar ultraviolet light intensity.

The capital cost and the operation and maintenance cost of the treatment system were estimated (the treatment system included the reactor and other accessories). The total cost was found by adding the capital cost and the present value of the operation and maintenance cost. The capital cost included reactor civil works, water-bell fountain with piping and circulation pump, settling tank with catalyst lifting, electrical controls and switchgears, contingency and installation. The operation and maintenance cost included energy costs of circulation pump of water fountain, inlet pump, and catalyst lifting pump and catalyst and labour costs. The costs were compared with the actual costs for an existing treatment plant that uses chemical precipitation and adsorption for wastewater treatment. The solar photocatalytic treatment system with indigenous titanium dioxide proved to be marginally economical. Thus, while overcoming the disadvantages associated with other methods of decolourisation of textile dyeing wastewaters, the present technology proved to be cost effective too.

5.3 CONCLUSION

- Two ‘Water Fountain’ solar photoreactors without any UV transparent walls were developed and the practical applicability of the reactors for solar photocatalytic decolourisation of textile dyeing wastewaters was proved for the first time.
The photocatalytic decolourisation of textile dyeing wastewaters was found to be first order. The rate of decolourisation under UV light was higher than the rate of decolourisation under solar light. This may be due to the higher intensity of UV light compared to solar light. A catalyst concentration of 1 g/L was found to be necessary for solar decolourisation studies, whereas only one tenth of 1 g/L was needed for UV decolourisation studies. Beyond the above catalyst concentrations, the rate of decolourisation increased only slightly or it remained constant.

The effect of pH on decolourisation of rinse and dye bath wastewaters was not of much practical significance. The rate of decolourisation was affected by the presence of carbonate ion, whereas it was not affected by the chloride and sulphates ions for both the catalysts.

The rate of decolourisation of rinse wastewater was found to be higher than that of the dye bath wastewater. The presence of carbonate ion at concentrations more than 0.5 g/L was found to inhibit the rate of decolourisation of dye bath wastewater. Even at catalyst concentration of 4.0 g/L, the reaction time of dye bath wastewater was greater than seven hours. As effective solar irradiation in a day would not be more than seven hours for the study location, the solar photocatalytic decolourisation of dye bath wastewater was not feasible.

The rate of decolourisation increased with increase of solar UV light intensity. As the light intensity increased from 20.8 to 39.1 W/m², the reaction time decreased from 72 to 35 min for P25 TiO₂ and 175 to 106 min for IS TiO₂. When the intensity of solar UV light was less than 20 W/m², the reaction time increased several times. During early morning
and late evenings, when the solar light intensity varied in the range of 6 to 20 W/m², there was either no decolourisation or the rate of decolourisation was very less. Hence, it could be concluded that solar light intensity of 20 W/m² was necessary for photocatalytic decolourisation of the dyes. For the study location, the useful time of operation for solar photocatalysis was considered as seven hours i.e. from 9:00 to 16:00 hours.

- The photoactivity of both P25 and IS TiO₂ catalysts were not affected by the reuse of the catalysts for 20 cycles. The variation in the rate of decolourisation observed during the study was mainly due to the variation in the solar light intensity.

- The effective area of solar insolation in which the photocatalytic reactions occur was found to be the surface area of the fountain. The photocatalytic reactions occur almost exclusively on the surface of the photocatalyst in the presence of oxygen.

- Since the water fountain is transparent to solar light and keeps the photocatalyst in the form of thin films, the most effective use of photocatalyst and solar UV light photons are achieved in this new reactor design. The increase in surface area of the water fountain from 0 to 0.111 m² decreased the reaction time by 83 – 85 % for P25 TiO₂ and 91 – 92 % for IS TiO₂ when the reactors were operated with 16 L liquid volume.

- The reaction time was observed to be less than three hours up to 16 L liquid volume and thereafter, it increased up to seven hours. The kinetic parameter derived from reactor analysis was also found to be maximum at 16 L liquid volume. Hence, it is concluded that the reactors could be operated with a maximum liquid volume of 16 L.
The performance of Reactor 1 (trapezoidal configuration) was always better than performance of Reactor 2 (Circular configuration), even when the reactors were operated under similar operating conditions (e.g. same liquid volume, same surface area of the fountain, same catalyst and same catalyst concentration). The kinetic parameter of Reactor 1 was always higher than the kinetic parameter of Reactor 2. This might be due to differences in the configuration of the reactors. The performance of the Reactors was not found to be equal even when they were operated under same liquid depths.

The influence of solar UV light intensity on the performance of the reactor was found to be significant. In the performance studies using P25 TiO₂, as the light intensity increased from 15.3 to 33.1 W/m², the reaction time decreased from 405 to 96 min for Reactor 1 and from 455 to 108 min for Reactor 2. In the performance studies using IS TiO₂, as the light intensity increased from 19.6 to 35.6 W/m², the reaction time decreased from 231 to 112 min and from 248 to 121 min for Reactors 1 and 2 respectively.

The kinetic parameter \( k_3 \) increased with increase in light intensity. In the performance studies using P25 TiO₂, the \( k_3 \) at the maximum light intensity of 33.1 W/m² was 1.95 greater higher than \( k_3 \) at the minimum light intensity of 15.3 W/m² and only 1.01 - 1.05 time greater than \( k_3 \) at light intensity greater than 20 W/m². In the performance studies using IS TiO₂, the \( k_3 \) at the maximum light intensity of 35.6 W/m² was 1.005 to 1.12 times greater than \( k_3 \) at light intensities greater than 20 W/m².
• A flow rate of 6.0 L/h was considered as the optimum flow rate for
decolourisation of RWWs. Only up to a flow rate of 6.0 L/h, the
decolourisation was greater than 90 % at light intensities greater than
20 W/m². When the flow rate was greater than 6 L/h, the decolourisation
varied in the range of 60.2 to 95.7 %.

• In the treatability studies on three batches of RWWs using 1 g/L of
IS TiO₂ at a flow rate of 6 L/h, more than 90 % decolourisation was
observed at light intensities greater than 20 W/m². However, only
40 to 50 % COD reduction was observed.

• The scale-up of the water fountain solar photoreactor is simple, since
there is no sun tracking system necessary. Also, it is economical, since
costly and fragile UV transparent walls are not necessary. In addition,
this reactor has no problem of clogging either by the catalyst or by the
impurities in wastewater. As there is absorption of oxygen from the
atmosphere, this reactor does not require any aerator devices.

• A pilot plant solar photoreactor for 90 percent decolourisation was
designed for a flow of 11,760 litres per day. The total cost of the
photoreactor was compared with that of an existing plant that uses
conventional chemical treatment technology. It was found that the solar
photocatalytic treatment system with indigenous titanium dioxide proved
to be marginally economical.