CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

In this work, the photocatalytic activity of TiO_2 was improved by adding graphene (GR), graphene/Fe^{3+} (GR/Fe^{3+}) and graphene/Ag_2S sensitizer (GR/Ag_2S). Generally, GR–TiO_2, GR/Fe^{3+}–TiO_2 and GR/Ag_2S–TiO_2 exhibited larger photocatalytic activity than that of TiO_2. Furthermore, it was obvious that GR/Fe^{3+}–TiO_2 had the highest photocatalytic activity than any other catalyst (see Table 7.1). The increase in photocatalytic degradation of modified TiO_2 by adding graphene, graphene–Fe^{3+} and graphene–Ag_2S sensitizer can be briefly explained as shown in Table 8.1.

Table 8.1 Major role of graphene, Fe^{3+} and Ag_2S dopants.

Material	Component	Major role
Graphene–TiO_2	Graphene (carbon)	Adsorbent, Charge separation and reduced band gap of TiO_2
	TiO_2	Catalyst
Graphene/Fe^{3+}–TiO_2	Graphene (carbon)	Adsorbent, Charge separation and reduced band gap of TiO_2
	TiO_2	Catalyst
	Fe^{3+}	Reducing band gap energy of TiO_2 and Charge transfer
Graphene/Ag_2S–TiO_2	Graphene (carbon)	Adsorbent and Charge separation
	TiO_2	Catalyst
	Ag_2S	Sensitizer

It was noted that the excessive graphene and Ag_2S added to TiO_2 had led to a decrease in photocatalytic activity. This phenomenon is attributed to the light obstruction that is defined as a main drawback of this method. In the case of GR/Fe^{3+}–TiO_2 photocatalyst, the excessive Fe^{3+} dopant in GR/Fe^{3+}–TiO_2 leads to precipitate of photocatalyst. Under UV irradiation, the degradation efficiency (%) of TiO_2, GR–TiO_2 (1:50), GR/Fe^{3+}–TiO_2 (0.12 wt% Fe^{3+}) and GR/Ag_2S–TiO_2 (5.6 wt% Ag_2S) was about 21.50, 26.76, 50.31 and

27.26%, respectively. In the case of visible light irradiation, the degradation efficiency (%) of TiO_2, GR–TiO_2 (1:50), GR/Fe^{3+}–TiO_2 (0.12 wt% Fe^{3+}) and GR/Ag_2S–TiO_2 (5.6 wt% Ag_2S) was about 12.52, 12.56, 49.95 and 15.20%, respectively. The decrease in photocatalytic activity of GR–TiO_2 and GR/Ag_2S–TiO_2 is attributed to the light obstruction because of excessive graphene and/or Ag_2S content in photocatalyst.

For GR/Fe^{3+}–TiO_2 photocatalyst, the excessive Fe^{3+} dopant that was added to photocatalyst acts as a charge recombination center. This phenomenon leads to the decrease in electron–hole pairs that effect to the photocatalytic activity of photocatalyst. Therefore, the appropriated amount of dopant material that was loaded to TiO_2 photocatalyst needs to be examined. GR/Fe^{3+}–TiO_2 (0.12 wt% Fe^{3+}) photocatalyst is considered as a good photocatalyst for HCHO removal application because of high photocatalytic degradation efficiency under UV and visible light irradiation. The prevention of charge of charge recombination, reduced band gap energy and increase in adsorption property by adding graphene and Fe^{3+} to TiO_2 photocatalyst were defined as important effect on photocatalytic activity of GR/Fe^{3+}–TiO_2.

The effects of environmental conditions on photocatalytic activity of GR/Fe^{3+}–TiO_2 films were examined by using glass chamber. The photocatalytic activity and degradation rate constant of GR/Fe^{3+}–TiO_2 (0.12 wt% Fe^{3+}) film increase with increasing initial concentration of HCHO and visible light intensity. However, GR/Fe^{3+}–TiO_2 (0.12 wt% Fe^{3+}) shows a decrease in photocatalytic activity including degradation rate constant under high relative humidity (%RH) condition because of the competitive adsorption between H_2O and HCHO molecules. The practical use of GR/Fe^{3+}–TiO_2 film for car interior HCHO removal was simulated and examined by using glass chamber using real environmental parameters (temperature, visible light intensity, intensity of UV and relative humidity) of outdoors conditions (sunshade). The results showed that the degradation efficiency of GR/Fe^{3+}–TiO_2 (0.12 wt% Fe^{3+}) film for HCHO removal is around 20–80 % under real environmental conditions as shown in Table 8.2.

Table 8.2 Summary of environmental parameters for the practical use of GR/Fe^{3+}–TiO_2 (0.12 wt% Fe^{3+}) film for HCHO removal (outdoor sunshade).

Environmental Parameter			
Temperature (°C)	Visible light intensity (W cm^{-2})	Intensity of UV (μW cm^{-2})	Relative humidity (%RH)
29.00–33.00	1.37–3.43	14.63–44.00	34.15–45.43

Therefore, GR/Fe^{3+}–TiO_2 (0.12 wt% Fe^{3+}) photocatalyst film can be used as an effective photocatalyst for HCHO removal because of the synergetic effect of graphene and Fe^{3+} dopants. The application of GR/Fe^{3+}–TiO_2 is not limited to car interior HCHO removal but also adapted for indoor air pollution control.

8.2 Recommendations

In the refluxed PTA solution method, the PTA solution was continuously converted into turbid solution and further precipitated when heated for more than 12 h. Therefore, TiO_2 prepared from refluxed method can be used as TiO_2 powder for other environmental remediation technique. Furthermore, the optimal amount of graphene, Fe^{3+} and Ag_2S dopants added to TiO_2 photocatalyst should be investigated for other organic pollutants removal. The application of a glass chamber reactor as a simulation of inside vehicle environment is limited due to high temperature. The glass chamber reactor is cracked and broken when the temperature in glass chamber reactor rises normally up to 50–60 °C. This phenomenon is attributed to the increase in air pressure inside glass chamber reactor. The effect of light obstruction of graphene and Ag_2S on photocatalytic activity of TiO_2 was considered as main limitation of the application of graphene and Ag_2S. In order to reduce the effect of light obstruction on photocatalytic activity, the photoexcitation and photooxidation processes of photocatalyst should be enhanced by other environmental conditions control such as relative humidity, UV and visible light intensity. As the result in this research work, redox reactions of Fe^{3+} can be used to reduce the effect of light obstruction because Fe^{3+} redox reactions also produce $^{\bullet}OH$ and $^{\bullet}O_2^-$ radicals that further degrade volatile organic compounds (VOCs) molecules that are adsorbed on the surface of photocatalyst.