PHYSICO-CHEMICAL TREATMENT OF
BUKIT TAGAR SANITARY LANDFILL LEACHATE
USING P-FLOC775 AND FERRIC CHLORIDE

SAID NASSER ALI AL-ABDALI

FACULTY OF SCIENCE
UNIVERSITY MALAYA
KUALA LUMPUR
2008
PHYSICO-CHEMICAL TREATMENT OF
BUKIT TAGAR SANITARY LANDFILL LEACHATE
USING P-FLOC775 AND FERRIC CHLORIDE

SAID NASSER ALI AL-ABDALI

FACULTY OF SCIENCE
UNIVERSITY MALAYA
KUALA LUMPUR
2008
PHYSICO-CHEMICAL TREATMENT OF
BUKIT TAGAR SANITARY LANDFILL LEACHATE
USING P-FLOC775 AND FERRIC CHLORIDE

SAID NASSER ALI AL-ABDALI

FACULTY OF SCIENCE
UNIVERSITY MALAYA
KUALA LUMPUR
2008
PHYSICO-CHEMICAL TREATMENT OF BUKIT TAGAR SANITARY LANDFILL LEACHATE USING P-FLOC775 AND FERRIC CHLORIDE

SAID NASSER ALI AL-ABDALI

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMNENT FOR THE DEGREE OF MASTER OF TECHNOLOGY (ENVIRONMENTAL MANAGEMENT)

INSTITUTE OF BIOLOGICAL SCIENCE
FACULTY OF SCIENCE
UNIVERSITY MALAYA
KUALA LUMPUR
2008
UNIVERSITY MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: SAID NASSER ALI AL-ABDALI   Passport No.:00954798

Registration/Metric No.: SGH060010

Name of Degree: Master of Technology (Environmental Management)

Title of project/Research report/Dissertation/Thesis:- PHYSICO-CHEMICAL TREATMENT OF BUKIT TAGAR SANITARY LANDFILL LEACHATE USING P-FLOC775 AND FERRIC CHLORIDE

Field of study: Landfill Leachate Management

I do solemnly and sincerely declare that:-

1. I am the sole author / writer of this work;
2. This work is original;
3. Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any exert or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the work and its authorship have been acknowledgement in this work;
4. I don’t have any actual knowledge nor do I ought reasonable to know that the making of this work constitute an infringement of any copyright work;
5. I hereby assign all and every right in the copyright to this work to the university of Malaya(UM), who hence forth shall be the owner of the copyright in this work and that any production or use in any form or by any means what so ever is prohibited without the written consent of UM having been first had and obtained;
6. I am fully aware that if in the course of making this work I have infringed any copyright whether intentionally or otherwise, I may be subjected to legal action or any other action as may be determined by UM.

Candidates Signature  Date

Subscribed and solemnly declared before,

Witness’s Signature  Date

Name:
Designation:
ABSTRACT

Sanitary landfill leachate is considered a heavily polluted wastewater. It contains high concentration of organic matter, heavy metals and toxic components. To treat leachate a combination of physical, biological and chemical treatment are often required to enhance the treatment efficiency. Coagulation/flocculation is a commonly used process in water and wastewater treatment. In this study, the characteristics of municipal landfill leachate from Bukit Tagar Landfill leachate was analyzed. The pH of the leachate sample was 6.6 while the BOD and COD of leachate were 27000 mg/L, 59000 mg/L, respectively. The concentration of Cd, Pb, Zn and Cu in the leachate was 11.25mg/L, 15.15mg/L, 17.55mg/L and 10.95 mg/L, respectively. The leachate contained high concentrations of colour (15300 ADMI), TSS (13.5 mg/L), and ammonia at (4300 ml/L. All parameters analyzed were above the Environmental Quality (Sewage and Industrial Effluent) Regulation Standard B limits. Jar-test experiments were employed to determine the efficiency of coagulant and flocculent FeCl₃ and P-Floc775 at different concentrations, pH and mixing speed, in removing heavy metals, turbidity, colour and TSS from the leachate. After coagulation, the filtrates were digested and analyzed. Treatment with 2g/500mL of FeCl₃ (which was the optimum) produced the highest reduction in turbidity (75%), colour (82%), TSS (78%), Cd, Pb, and Cu (100%) and Zn (91%). The optimal reduction of all parameters was at pH 7. On the other hand the optimum mixing speed for FeCl₃ was 100 rpm and at 90 rpm for P-Floc775. At optimum coagulant dosage, pH and mixing speed Cd, Pb, and Cu were lower than the EQA Standard A and B limits, whereas the Zn remained above the Standard A and B. Mixing speed and pH improved the performance of FeCl₃ and P-Floc775, at optimum dosage. FeCl₃ and P-Floc775 were effective in the reduction of most parameters to below EQA 1979 limit.
Acknowledgement

First and foremost, I thank God for guiding me in this study and then I would like to express my sincere gratitude to my supervisors Professor P. Agamuthu (University of Malaya) for his guidance, assistance and support. He has been the main motivator for me to bring this report out on time.

I wish to thank the Ministry of the Environmental and Climates Affairs in Sultanate of Oman for giving me a good opportunity to continue my study. I also wish to thank my friends for their continued support and encouragement. My thanks also go to the stuff in the laboratory, namely Fauziah, Noorasikir, Khalil, Aiza for their assistance and advice.

My special and sincere gratitude goes to my family, especially my mother and my wife for providing me with support and inspiration to make the best use of the opportunities that were given to by country. Last but not least I am also thankful to my brothers for their inspiration and support.
CHAPTER ONE: INTRODUCTION

1.1 Municipal Solid Waste .......................................................... 1
  1.1.1 Solid waste generation ..................................................... 1
  1.1.2 Solid waste composition .................................................... 3
  1.1.3 Solid Waste Management ................................................... 4
  1.1.4 Challenges in Waste Management ......................................... 5

1.2 Issues in the landfill................................................................. 5
  1.2.1 Landfill Gas ................................................................. 5
  1.2.2 Leachate ................................................................. 6

1.3 Problem Statement ............................................................... 7

1.4 Research Site ........................................................................ 9

1.5 Project Objectives ............................................................... 11
CHAPTER TWO: LITERATURE REVIEW

2.1 Municipal Solid Waste ................................................................. 12
  2.1.1 Generation ................................................................. 13
  2.1.2 Composition .............................................................. 18
  2.1.3 Collection ................................................................. 23

2.2 An Integrated System of Solid Waste Management ......................... 25
  2.2.1 Open dump and landfill ................................................ 25
  2.2.2 Sanitary landfill ......................................................... 26
  2.2.3 Incineration ............................................................... 28
  2.2.4 Composting ............................................................... 28

2.3 Landfilling of Waste .................................................................. 29
  2.3.1 Leachate generation .................................................... 29
  2.3.2 Leachate formation ..................................................... 31
  2.3.3 Leachate composition and characteristics ....................... 35
  2.3.4 Leachate control ......................................................... 41
  2.3.5 Leachate treatment ..................................................... 42
    2.3.5.1 Biological treatment .............................................. 43
    2.3.5.2 Physio-Chemical treatment .................................. 44
      2.3.5.2.1 Coagulation and flocculation ......................... 46
      2.3.5.2.2 Chemical precipitation .................................. 48
      2.3.5.2.3 Adsorption using Activated carbon ............... 49
      2.3.5.2.4 Chemical oxidation ...................................... 50
      2.3.5.2.5 Air stripping .............................................. 50
      2.3.5.2.6 Membrane filtration .................................... 51

IV
CHAPTER THREE: MATERIALS AND METHODS

3.1 Research Site and Leachate Collection ........................................... 52

3.2 Materials .................................................................................. 52
   3.2.1 Coagulants and precipitant .................................................. 52
   3.2.2 Jar Test Instrument ............................................................... 52
   3.2.3 Inductively Coupled Plasma Emission Spectrometry .............. 52

3.3 Leachate Sampling ..................................................................... 52

3.4 Raw Leachate Analysis .............................................................. 54
   3.4.1 Chemical characteristics ...................................................... 54
      3.4.1.1 pH ........................................................................... 54
      3.4.1.2 Total Suspended Solid (TSS) ........................................ 54
      3.4.1.3 Biochemical Oxygen Demand (BOD₅) .......................... 54
      3.4.1.4 Ammonia - N, Nessler Method (0-2 500mg/l NH₃-N) ...... 56
      3.4.1.5 Heavy Metals .............................................................. 57
      3.4.1.6 Chemical Oxygen Demand (COD) ................................. 57
   3.4.2 Physical characteristics ......................................................... 59
      3.4.2.1 Total Solid ................................................................. 59
      3.4.2.2 Turbidity .................................................................. 60
      3.4.2.3 Colour ..................................................................... 60
      3.4.2.4 Total Dissolved Solid (TDS), Salinity and Conductivity .... 60

3.4. 3 Coagulation – flocculation studies ......................................... 60
   3.4.3.1 Coagulation and flocculation .......................................... 60
CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Leachate Study ............................................................................................................. 62

4.2 Physico-Chemical treatment......................................................................................... 70
   4.2.1 Treatment with FeCl₃ ............................................................................................... 70
      4.2.1.1 Treatment with FeCl₃ at different concentrations ........................................ 70
      4.2.1.2 pH effect on coagulant with (FeCl₃) ............................................................... 75
      4.2.1.3 Effect of Various Mixing speed using Ferric chloride FeCl₃ ......................... 81
   4.2.2 Treatment with P-Floc775 ...................................................................................... 85
      4.2.2.1 Treatment with P-Floc775 at different concentration ................................. 85
      4.2.2.2 pH effect on coagulant with P-Floc775 ....................................................... 89
      4.2.2.3 Effect of mixing speed using P-Floc775 ..................................................... 93

4.3 General Discussion ....................................................................................................... 98
   4.3.1 Characteristics of Bukit Tagar landfill ................................................................. 98
   4.3.2 Leachate Treatment .............................................................................................. 100
      4.3.2.1 Treatment with FeCl₃ .................................................................................. 100
      4.3.2.2 Treatment with P-Floc775 ................................................................. 102

CHAPTER FIVE: CONCLUSION

5.1 Conclusion .................................................................................................................. 105

REFERENCES ............................................................................................................... 106

APPENDIXES .................................................................................................................. 121
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1.1</td>
<td>Components of landfill leachate</td>
<td>8</td>
</tr>
<tr>
<td>Table 2.1</td>
<td>MSW generated by the high, medium and low socio-economic areas in Petaling Jaya</td>
<td>15</td>
</tr>
<tr>
<td>Table 2.2</td>
<td>Household solid waste (SW) generation (tonne per year) in Tehran in different seasons of 2005</td>
<td>18</td>
</tr>
<tr>
<td>Table 2.3</td>
<td>Composition of MSW for Malaysia and USA (% dry weight)</td>
<td>19</td>
</tr>
<tr>
<td>Table 2.4</td>
<td>Solid waste composition (% dry weight) of selected urban localities</td>
<td>20</td>
</tr>
<tr>
<td>Table 2.5</td>
<td>Composition of Municipal Solid Waste in selected countries (% dry weight)</td>
<td>21</td>
</tr>
<tr>
<td>Table 2.6</td>
<td>Composition of household solid waste in Tehran (% dry weight) in different seasons of 2005.</td>
<td>22</td>
</tr>
<tr>
<td>Table 2.7</td>
<td>Solid waste composition in Singapore.</td>
<td>23</td>
</tr>
<tr>
<td>Table 2.8</td>
<td>Consortium responsible for the management of solid waste in Malaysia.</td>
<td>24</td>
</tr>
<tr>
<td>Table 2.9</td>
<td>Types of landfill in each state in Malaysia in 2000.</td>
<td>25</td>
</tr>
<tr>
<td>Table 2.10</td>
<td>Characteristics of different types of landfill leachate</td>
<td>36</td>
</tr>
<tr>
<td>Table 2.11</td>
<td>Characteristics of landfill leachate from Kundang and Sungai Sedu landfill</td>
<td>37</td>
</tr>
<tr>
<td>Table 2.12</td>
<td>Characteristics of the Vancouver landfill leachate of 27 years old.</td>
<td>38</td>
</tr>
<tr>
<td>Table 2.13</td>
<td>Physical and chemical characteristics of Sanitary Landfill leachate from two Malaysian landfills compared with leachate from other countries.</td>
<td>39</td>
</tr>
<tr>
<td>Table 2.14</td>
<td>Maximum discharge standard for landfill leachate from selected countries.</td>
<td>40</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Characteristics of raw leachate from Bukit Tagar sanitary landfill.</td>
<td>63</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Characteristics of raw leachate from Taman Beringin Landfill and Ampang landfill compared to Environmental Quality Act (EQA) 1974 Standard A and B</td>
<td>67</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Characteristics of leachate from China – Hong Kong and Italy</td>
<td>69</td>
</tr>
<tr>
<td>Table 4.4</td>
<td>Comparison between the performance of P-Floc775 and alum</td>
<td>95</td>
</tr>
<tr>
<td>Table 4.5</td>
<td>Comparative removal (%) of pollutant by each chemical at optimum conditions.</td>
<td>99</td>
</tr>
<tr>
<td>Table 4.6</td>
<td>Summary of the optimum conditions for FeCl₃ and P-Floc775</td>
<td>100</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2.1</td>
<td>Waste generation in Malaysia.</td>
<td>13</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Waste generation sources in Malaysia .</td>
<td>15</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>Per capita generation rate of municipal solid waste for developing countries.</td>
<td>16</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>Per capita waste generation rate for municipal solid waste in Indian cities.</td>
<td>17</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>Composition of MSW in Malaysia.</td>
<td>20</td>
</tr>
<tr>
<td>Figure 2.6</td>
<td>Pattern of leachate generation.</td>
<td>30</td>
</tr>
<tr>
<td>Figure 2.7</td>
<td>Development of gas and leachate in a landfill.</td>
<td>32</td>
</tr>
<tr>
<td>Figure 2.8</td>
<td>Illustration showing the amount of pollutants in the leachate.</td>
<td>34</td>
</tr>
<tr>
<td>Figure 2.9</td>
<td>Schematic diagram showing a cross section of typical LCS.</td>
<td>41</td>
</tr>
<tr>
<td>Figure 2.10</td>
<td>Scheme of often used methods and combinations for leachate treatment.</td>
<td>42</td>
</tr>
<tr>
<td>Figure 2.11</td>
<td>Coagulation process.</td>
<td>47</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Effect of concentration of ferric chloride (FeCl₃) on the removal of pollution parameters (turbidity, colour, and TSS) in the leachate.</td>
<td>71</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Effect of concentration of FeCl₃ on the leachate colour removal</td>
<td>72</td>
</tr>
<tr>
<td>Figure 4.2a</td>
<td>Regression analyses for removing colour from landfill leachate using FeCl₃ at various doses until the optimum.</td>
<td>72</td>
</tr>
<tr>
<td>Figure 4.2b</td>
<td>Regression coefficient for removing colour from landfill leachate using FeCl₃ at various doses after the optimum removal.</td>
<td>72</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Effect of concentration of ferric chloride (FeCl₃) in the removal of heavy metals (Cd, Pb, Zn, and Cu) in the leachate.</td>
<td>73</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>Effect of concentration of ferric chloride (FeCl₃) in the removal of Cd in the leachate.</td>
<td>74</td>
</tr>
</tbody>
</table>

IX
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4a</td>
<td>Regression coefficients for removal of Cd from landfill leachate using FeCl₃ at various doses until the optimum removal.</td>
<td>74</td>
</tr>
<tr>
<td>4.4b</td>
<td>Regression coefficients for removal of Cd from landfill leachate using FeCl₃ at various doses after the optimum removal.</td>
<td>74</td>
</tr>
<tr>
<td>4.5</td>
<td>Effect of pH on removal of turbidity, colour, and TSS in the leachate using FeCl₃ at (2 g / 500 mL).</td>
<td>76</td>
</tr>
<tr>
<td>4.6</td>
<td>Effect of pH on removal of turbidity using FeCl₃ at (2 g / 500 mL).</td>
<td>77</td>
</tr>
<tr>
<td>4.6a</td>
<td>Regression coefficient for pH range 4-7 for removing turbidity using FeCl₃ toward optimum pH.</td>
<td>77</td>
</tr>
<tr>
<td>4.6b</td>
<td>Regression coefficients for pH range 7-10 for removing turbidity using FeCl₃ after optimum pH.</td>
<td>77</td>
</tr>
<tr>
<td>4.7</td>
<td>Effect of pH on removal of heavy metals (Cd, Pb, Zn, and Cu) in the leachate using FeCl₃.</td>
<td>79</td>
</tr>
<tr>
<td>4.8</td>
<td>Effect of pH on removal of Pb in the leachate using FeCl₃.</td>
<td>80</td>
</tr>
<tr>
<td>4.8a</td>
<td>Regression coefficients for pH range 4-7 for removing Pb using Ferric chloride toward optimum pH.</td>
<td>80</td>
</tr>
<tr>
<td>4.8b</td>
<td>Regression coefficient for pH range 7-10 for removing Pb using FeCl₃ after optimum pH.</td>
<td>80</td>
</tr>
<tr>
<td>4.9</td>
<td>Effect of mixing speed on the removal of turbidity, colour, and TSS in the leachate using FeCl₃.</td>
<td>81</td>
</tr>
<tr>
<td>4.10</td>
<td>Effect of mixing speed on the removal of Cd, Pb, Zn, and Cu in the leachate using Ferric chloride.</td>
<td>82</td>
</tr>
<tr>
<td>4.11</td>
<td>Effect of mixing speed on the removal of Zn in the leachate using Ferric chloride.</td>
<td>83</td>
</tr>
<tr>
<td>4.11a</td>
<td>Regression coefficient toward the optimum mixing speed (at 2g/500ml, pH 7) for removing Zn using FeCl₃.</td>
<td>83</td>
</tr>
<tr>
<td>4.11b</td>
<td>Regression coefficient after the optimum mixing speed (at 2g/500ml, pH 7) for removing Zn using FeCl₃.</td>
<td>83</td>
</tr>
<tr>
<td>4.12</td>
<td>Effect of mixing speed on the removal of Pb in the leachate using Ferric chloride.</td>
<td>84</td>
</tr>
<tr>
<td>4.12a</td>
<td>Regression coefficient toward the optimum mixing speed (at 2g/500ml, pH 7) for removing Pb using FeCl₃.</td>
<td>84</td>
</tr>
<tr>
<td>4.12b</td>
<td>Regression coefficients after the optimum mixing speed (at 2g/500ml, pH 7) for removing Pb using FeCl₃.</td>
<td>84</td>
</tr>
</tbody>
</table>
Figure 4.13 Effect of concentration of P-Floc775 on the removal of pollution parameters (turbidity, colour, and TSS) in the leachate.

Figure 4.14 Effect of concentration of P-Floc775 on the removal colour in the leachate.

Figure 4.14a Regression coefficient for removing colour from landfill leachate using P-Floc775 at various doses until the optimum reduction.

Figure 4.14b Regression coefficient for removing colour from landfill leachate using P-Floc775 at various doses after the optimum reduction.

Figure 4.15 Effect of concentration P-Floc775 on the removal of heavy metals (Cd, Pb, Zn, and Cu) in the leachate.

Figure 4.16 Effect of concentration P-Floc775 on the removal of Zn in the leachate.

Figure 4.16a Regression coefficient for removing Zn from landfill leachate using P-Floc775) at various doses until the optimum removal.

Figure 4.16b Regression coefficients for removing Zn from landfill leachate using P-Floc775 at various doses after the optimum removal.

Figure 4.17 Effect of pH on the removal of turbidity, colour, and TSS in the leachate using P-Floc775.

Figure 4.18 Effect of pH on the removal of turbidity in the leachate using P-Floc775.

Figure 4.18a Regression coefficient for various pH for removing turbidity using P-Floc775 toward optimum pH.

Figure 4.18b Regression coefficient for various pH for removing turbidity using P-Floc775 after optimum pH.

Figure 4.19 Effect of pH on the removal of heavy metals (Cd, Pb, Zn, and Cu) in the leachate using P-Floc775.

Figure 4.20 Effect of pH on the removal of Cu in the leachate using P-Floc775.

Figure 4.20a Regression coefficient for various pH for removing Cu using P-Floc775 toward optimum pH.

Figure 4.20b Regression coefficient through adjusting pH for removing Cu using P-Floc775 (2ml/500ml) after optimum pH.
Figure 4.21 Effect of mixing speed on the removal of turbidity, colour, and TSS in the leachate using P-Floc775, at pH 7.

Figure 4.22 Effect of mixing speed on the removal of Cd, Pb, Zn, and Cu in the leachate using P-Floc775, at pH 7.

Figure 4.23 Effect of mixing speed on the removal of Cd in the leachate using P-Floc775, at pH 7.

Figure 4.23a Regression coefficients toward the optimum mixing speed, pH7 for removing Cd using P-Floc775 at (2ml/500ml).

Figure 4.23b Regression coefficients after the optimum mixing speed, pH7 for removing Cd using P-Floc775 at (2ml/500ml).

Figure 4.24 Effect of mixing speed on the removal of Pb in the leachate using P-Floc775, at pH 7.

Figure 4.24a Regression coefficients toward the optimum mixing speed, pH7 for removing Pb using P-Floc775 at (2ml/500ml).

Figure 4.24b Regression coefficients ($R^2$) after the optimum mixing speed, pH7 for removing Pb using P-Floc775 at (2ml/500ml).

Figure 4.25 Heavy metal concentration in Bukit Tagar landfill leachate compared to EQA Standard A and Standard B.

Figure 4.26 Effect of FeCl₃ on the removal of Cd in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.

Figure 4.27 Effect of FeCl₃ on the removal of Pb in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.

Figure 4.28 Effect of FeCl₃ on the removal of Cu in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.

Figure 4.29 Effect of FeCl₃ on the removal of Zn in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.

Figure 4.30 Effect of P-Floc775 on the removal of Cd in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.

Figure 4.31 Effect of P-Floc775 on the removal of Cu in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.
Figure 4.32  Effect of P-Floc775 on the removal of Pb in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.

Figure 4.33  Effect of P-Floc775 on the removal of Zn in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.
# LIST OF PLATES

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate 1.1</td>
<td>Location of landfill</td>
<td>10</td>
</tr>
<tr>
<td>Plate 3.1</td>
<td>Shows the Bukit Tagar Sanitary Landfill in Selangor, Malaysia</td>
<td>53</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>ADMI</td>
<td>American Dye Manufactures Institute</td>
<td></td>
</tr>
<tr>
<td>AOP</td>
<td>Advance Oxidation Process</td>
<td></td>
</tr>
<tr>
<td>BOD</td>
<td>Biochemical Oxygen Demand</td>
<td></td>
</tr>
<tr>
<td>BTSL</td>
<td>Bukit Tagar Sanitary Landfill</td>
<td></td>
</tr>
<tr>
<td>C&amp;D</td>
<td>Construction and Demolition waste</td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>Chemical oxygen demand</td>
<td></td>
</tr>
<tr>
<td>DO</td>
<td>Dissolve Oxygen</td>
<td></td>
</tr>
<tr>
<td>FAU</td>
<td>Formazine Attenuation Units</td>
<td></td>
</tr>
<tr>
<td>HHSW</td>
<td>Household solid waste</td>
<td></td>
</tr>
<tr>
<td>ICP</td>
<td>Inductively coupled Plasma Optical Emission Spectrometry</td>
<td></td>
</tr>
<tr>
<td>LCS</td>
<td>Leachate collection system</td>
<td></td>
</tr>
<tr>
<td>MCP</td>
<td>Moisture contents placement</td>
<td></td>
</tr>
<tr>
<td>MF</td>
<td>Micro filtration</td>
<td></td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal solid waste</td>
<td></td>
</tr>
<tr>
<td>PAC</td>
<td>Powder activated carbon</td>
<td></td>
</tr>
<tr>
<td>RBC</td>
<td>Rotating Biological Contractor</td>
<td></td>
</tr>
<tr>
<td>RO</td>
<td>Reverse Osmosis</td>
<td></td>
</tr>
<tr>
<td>TDS</td>
<td>Total dissolved solid</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td>Total suspended solid</td>
<td></td>
</tr>
<tr>
<td>UASB</td>
<td>Up flow Anaerobic Sludge Blanket</td>
<td></td>
</tr>
<tr>
<td>UF</td>
<td>Ultrfiltration</td>
<td></td>
</tr>
<tr>
<td>UFC</td>
<td>Unified Facilities criteria</td>
<td></td>
</tr>
<tr>
<td>UV</td>
<td>Ultraviolet.</td>
<td></td>
</tr>
</tbody>
</table>
# LIST OF APPENDICES

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Regulatory Standards for industrial wastewater as specified in the Environmental Quality (Sewage and Industrial Effluents) Regulation, 1979; EQA, 1974</td>
<td>121</td>
</tr>
<tr>
<td>B</td>
<td>Results of concentration dosage for treating leachate using Ferric chloride FeCl₃ and P-Floc775</td>
<td>122</td>
</tr>
<tr>
<td>C</td>
<td>Results of leachate treatment with various pH value at optimum concentration using Ferric chloride FeCl₃ and P-Floc775</td>
<td>123</td>
</tr>
<tr>
<td>D</td>
<td>Results of leachate treatment with various mixing speed at pH 7 and optimum concentration (2g/500ml using Ferric chloride (FeCl₃) and (2ml/500ml for P-Floc775).</td>
<td>124</td>
</tr>
<tr>
<td>E</td>
<td>The regression coefficient for different pollutants parameters removing from landfill leachate with different concentration using Ferric chloride.</td>
<td>125</td>
</tr>
<tr>
<td>F</td>
<td>The regression coefficient for different pollutants parameters removing from landfill leachate at different pH using Ferric chloride.</td>
<td>129</td>
</tr>
<tr>
<td>G</td>
<td>The regression coefficient for different pollutants parameters removing from landfill leachate at different mixing speed using Ferric chloride.</td>
<td>133</td>
</tr>
<tr>
<td>H</td>
<td>The regression coefficient for different pollutants parameters removing from landfill leachate with different concentration using P-Floc775.</td>
<td>137</td>
</tr>
<tr>
<td>I</td>
<td>The regression coefficient for different pollutants parameters removing from landfill leachate at different pH using P-Floc775.</td>
<td>141</td>
</tr>
<tr>
<td>J</td>
<td>The regression coefficient for different pollutants parameters removing from landfill leachate at different mixing speed using P-Floc775.</td>
<td>145</td>
</tr>
</tbody>
</table>
CHAPTER ONE: INTRODUCTION

1.1 Municipal Solid Waste

Rapid economic growth in Malaysia over the last fifteen years has enhanced the development process of the country. Many changes have taken place due to urbanization including increase in the population. The rate of consumption has risen and the lifestyle of the people, too, has changed. This rapid development, the increase in population and the rate of consumption have brought about an increase in waste generation and pollution which have badly affected human beings and the environment. The ethnological society produces waste which can be classified into different types, which affect the air, land, and water. Several studies have shown how increasing waste has affected society and the environment (nature) (Narisa, 2004).

The amount of waste production is a sign of the level of industrialization or a degree of development of a country or a city. This means that the higher the amount of waste, the more industrialized the country is. Waste generation increased with the growth of Gross Domestic product (GDP). In the same way, it is observed that an increase in composition of paper in the waste is associated with the development trend (Grover, 2002).

1.1.1 Solid waste generation

The generation of solid waste depends on many factors such as the economic status of the area, level of education and awareness. Currently, the per capita generation of solid waste in Malaysia ranged between 0.7 to 1.2 kg/day (Fauziah and Agamuthu, 2005). Generation of solid waste is expected to reach 30,000 tonnes per day in 2020; and it is estimated that about 45% of the waste is made up of food waste, 24% of plastic, 7% is paper, 6% of iron and glass and others (Abdul Nasir, 2007). Solid waste in
Malaysia is mostly of very high organic waste and high moisture content with the density at 200 kg/m³. Most of the Asian countries exhibited an increase in municipal solid waste (MSW) generation at 3 to 7% yearly (Jayabala, 2005). Malaysia has an increase of 2% to 3% per year (Jayabala, 2004). The average amount of garbage produced by residents in the Klang Valley is estimated at around 1.56 kg every day per person in 1998. That amount of garbage in Klang Valley is enough to fill the entire twin tower in just a day (Masri, 2005).

The generation of solid waste, which results from human activities, varies according to the types of dwellings, as well as socio-economic groups. The type produced depends upon various factors such as the standard of living, occupation and habits of the contributing population, which in turn are affected by climate and diet. A very important factor which is useful in planning the collection and disposal system is the data of generation and variation of MSW (Mufeed et al., 2007).

Physical and chemical characteristics of MSW within the same geographic location vary according to seasons. Knowledge about the characteristics of the refuse is essential in order to decide the type of disposal method to be adopted and the desired frequency of the collection system. The method and capacity of storage, the correct type of collection vehicle, the optimum size of crew and the frequency of collection depend mainly on the volume, density of the waste and also the climate of the area. The disposal method may be influenced by the proportion of saleable materials that could be recycled and the vegetable content which could be a source of energy (Agamuthu, 2001). Although man has produced solid wastes ever since the beginning of civilization, in recent years the problem has been aggravated by rapid industrialization of many
developing countries. As the industries become more and more sophisticated the solid wastes produced require specialized treatment and disposal (Agamuthu, 2001).

1.1.2 Solid waste composition

Most of the countries, in the world have a national aim to decrease the quantity of solid waste in different ways such as by recycling, recovery and diversion from landfill. In order to achieve those aims, information about the composition of solid waste is required (Burnley et al., 2007). The successful planning of solid waste management requires the availability of reliable information about the quantity and the type of material being generated (Gidarakos et al., 2006).

In Malaysia, waste characteristics and composition were found to differ with the level of affluence and urbanization of the area served by a particular landfill. The waste received by the landfills in Malaysia was extremely mixed, which made extraction of recyclable material extremely uneconomical. In the year 2002, the local authorities and waste management consortia have to handle roughly 17,000 tonnes of MSW each day (Abdul Nasir, 2007). The highest percentage of MSW consisted of organic waste, approximately 46%, followed by paper and plastic at 14% and 10%, respectively. The rubber, textile, metal, and glass all of them have the same percentage which is at 3% while the others are at 7%. In addition, MSW composition depends on the level and economic standard and it also varies between states (Agamuthu, 2008). For example in Selangor state the highest percentage of MSW contained putrecible waste of around 46%, after that followed plastic and paper at 15 and 14%, respectively (Fauziah and Agamuthu, 2005).
1.1.3 Solid Waste Management

The main aims of solid waste management are to save and protect the human health, help to promote the quality of the environment and develop sustainability. Hence, in order to achieve the sustainable targets of solid waste management systems, different sectors in society, both government and public, need to co-operate (Renbi et al., 2002).

In Malaysia, the private sector collects most of the solid waste and disposes it into landfills which seem to be the best disposal option for municipal solid waste because of economic considerations. The solid waste managers and town and country planners face great difficulty in the disposal of solid waste, due to several reasons such as

- Shortage of space for landfills,
- Availability of site for landfills, and
- Increase in the quantity of solid waste over time.

The present landfills may be losing the ability to accept the solid waste due to the continued increase of waste over time as waste generation has reached about 8.0 million metric tonne/year (Agumuthu, 2001). Malaysia has around 161 official municipal solid waste dumping sites as of March, 2002. They are as follows:-

- 48% open dumps
- 30% controlled tipping
- 22% sanitary landfills
- 4% not included in the above but is covered by leachate treatment plans (Ministry of Housing and Local Government, 2002).
1.1.4 Challenges in Waste Management

A measure of success can be observed where people are able to control the waste and how to manage it. In some Asian countries where we can find poor environmental ethics and less awareness in waste management can contribute to a country’s failure in managing solid waste (Visvanathan and Trankler, 2003). We should understand that change always begins with us, therefore education and increased awareness in environmental problems and issues should be on-going. Also, in order to increase the level of awareness and education about the waste management and in order to achieve success in our efforts, we must begin teaching our children about reserving the environment, as well as waste management, from an early age, and it is something that should be seriously considered.

1.2 Issues in the landfill

1.2.1 Landfill Gas

Gases that are generated in a landfill are methane (55%) and carbon dioxide (35%) both of which are generated due to the disposal of organic waste into the landfills. These gases are released into the atmosphere (Fauziah and Agamuthu, 2004). Landfill is the main source of emission of methane gas and that it is as much as 38% of the total anthropogenic source (Popov and Power 1999). A younger landfill emits lesser quantity of gas compared to an older one (Chan et al., 2000).

In order to control landfill gas, adequate gas collection system is required. There are several different technologies which are used to control landfill gas accumulation and migration. It can also be collected by using a network of vertical gas extraction wells with sufficient operating systems (Popov, 2005). The mains factors for gas emission from landfills are concentration and temperature gradients that grow within the
landfill. When this happens the gas will be emitted into the atmosphere and migrate laterally through the surrounding soil. Two issues are associated with landfill gas: they are environment pollution and safety, which requires control of gas migration (Miroslav Nastev et al., 2001).

1.2.2 Leachate

Landfill leachate is liquid that occasionally leaks from a landfill and enters the environment. This liquid may either exist in the landfill or it may be created after rainwater mixes with the chemical waste in a landfill. Landfill leachate can also be defined as strong industrial wastewater (Tatsi and Zouboulis, 2002). The best method of leachate treatment depends on the characteristics of leachate. There are different methods of treatment of leachate, one of which is the biological process which is suitable for young” or “freshly” produced leachates, but it is less efficient for the treatment of “older” leachate. Another method, the physical - chemical process is not suitable for treating young leachate (Ntampou et al, 2006). Leachate is generated due to precipitation, surface run-off, and infiltration or intrusion of groundwater percolating through a landfill. It can cause great environmental problems if it gets into underground water, especially because it has organic matter (both biodegradable and non-biodegradable carbon) ammonia-nitrogen, heavy metals, chlorinated organic and inorganic salts. However, some of these pollutants can be degraded by microorganisms (Wang et al., 2002).

Landfill leachate has an impact on the environment because it has very dangerous pollutants such as ammonium nitrogen (NH$_4^+$-N), biodegradable and refractory organic matter and heavy metals. In fact, the ammonium concentration in leachate found to be up to
several thousand mg/L (Li et al., 1999; Wichitsathian et al., 2004). In addition, Landfill leachate cause serious pollution to groundwater and surface waters. It is important to note that the chemical characteristic of leachate varies significantly and is usually different from country to country and from residential to residential area as a function of a number of factors such as waste composition, the degradation degree of waste, moisture content, hydrological and climatic conditions (Wang et al., 2003).

1.3 Problem Statement

Several of the environmental problems in the world today are caused by municipal solid waste due to its improper management (Huang et al., 1992). One of these problems is the leachate which has a negative impact on the environment. The leachate produced is highly variable in quality (Table 1.1). In Malaysia the average amount of leachate generated is 150 L/tonne of waste. The leachate consists of organic matter, nitrogen (ammonical), suspended solids, salt and colouring matter (Agamuthu, 2001).

Also, the leachate shows great variation in the flow rate and chemical composition due to several factors, such as the site, the design, and mechanism of operating a landfill. Leachate causes contamination of the soil, ground, and surface water if it is not properly collected, treated and disposed. Leachate can also cause a lot of environmental problems because it has a high density of organic material (Galvez et al., 2005).
Table 1.1: Components of landfill leachate

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Value (mg/L)*</th>
<th>Range†</th>
<th>Typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bod₅ (5-day biochemical oxygen demand)</td>
<td></td>
<td>2,000-30,000</td>
<td>10,000</td>
</tr>
<tr>
<td>TOC (total organic carbon)</td>
<td></td>
<td>1,500-20,000</td>
<td>6,000</td>
</tr>
<tr>
<td>COD (chemical oxygen demand)</td>
<td></td>
<td>3,000-45,000</td>
<td>18,000</td>
</tr>
<tr>
<td>Total suspended solids</td>
<td></td>
<td>200-1,000</td>
<td>500</td>
</tr>
<tr>
<td>Organic nitrogen</td>
<td></td>
<td>10-600</td>
<td>200</td>
</tr>
<tr>
<td>Ammonia nitrogen</td>
<td></td>
<td>10-800</td>
<td>200</td>
</tr>
<tr>
<td>Nitrate</td>
<td></td>
<td>5-40</td>
<td>25</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td></td>
<td>1-70</td>
<td>30</td>
</tr>
<tr>
<td>Orthophosphorus</td>
<td></td>
<td>1-50</td>
<td>20</td>
</tr>
<tr>
<td>Alkalinity as CaCO₃</td>
<td></td>
<td>1,000-10,000</td>
<td>3,000</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>5.3-8.5</td>
<td>6</td>
</tr>
<tr>
<td>Total hardness as CaCO₃</td>
<td></td>
<td>300-10,000</td>
<td>3,500</td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
<td>200-3,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
<td>50-1,500</td>
<td>250</td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
<td>200-2,000</td>
<td>300</td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
<td>200-2,000</td>
<td>500</td>
</tr>
<tr>
<td>Chloride</td>
<td></td>
<td>100-3,000</td>
<td>500</td>
</tr>
<tr>
<td>Sulphate</td>
<td></td>
<td>100-1,500</td>
<td>300</td>
</tr>
<tr>
<td>Total iron</td>
<td></td>
<td>50-600</td>
<td>60</td>
</tr>
</tbody>
</table>

(Source: Agamuthu, 2001)

†Representative range of value. Higher maximum values have been reported in the literature for some of the constituent.

The process of leachate treatment is the same as the wastewater treatment plant process which is commonly practiced due to the nature and high levels of pollutants present in it (i.e. high COD, low biodegradability, heavy metals, pathogens, etc.). Leachate treatment facility is required before discharging leachate into the environment and this depends on several factors such as the characteristics of leachate, costs, and
regulations. Specific treatment techniques can be used to treat this hazardous wastewater in order to protect the ecosystem such as, coagulation/flocculation, biological process, chemical oxidation, Activated Carbon Adsorption, membrane filtration, leachate recirculation through the landfill, grassland spray irrigation, and constructed wetlands, etc. (Chedly et al., 2007).

In Malaysia, landfill leachate is characterized by BOD of 120 to 1990 mg/L, and COD, of 1250 to 6660 mg/L (Fauziah and Agamuthu, 2003). Heavy metals in leachate, normally include cadmium, lead, zinc, iron, chromium, manganese, and copper which indicates clearly that pretreatment is required prior to biological treatment (Aziz et al., 2004). This study was conducted to investigate the effectiveness of P-Floc775 and Ferric Chloride (FeCl₃) as a coagulant to treat the leachate which was brought from Bukit Tagar Sanitary landfill. Heavy metals investigated include cadmium (Cd), lead (Pb), zinc (Zn), and copper (Cu) at various coagulant concentration, pH, and mixing speeds.

1.4 Research Site

The Bukit Tagar Sanitary Landfill (BTSL) was developed based on a construction and operation agreement with the Government of Malaysia, supervised by the Ministry of Housing and Local Government. It was developed on a 700- acre footprint, with an additional 1,000 acres of buffer zone comprising undeveloped land surrounding the landfill footprint. It is set in the middle of an oil palm plantation in a sparsely populated area in Hulu Selangor district.

Bukit Tagar Sanitary landfill has a total capacity of 120 million tonnes of solid waste. This should make the landfill last well beyond 40 years. Currently the waste
handled is predominantly MSW but will soon be extended to other forms of waste excluding scheduled and toxic waste. Currently, about 1600 tonnes of MSW from Taman Beringin landfill transfer station in Kuala Lumpur is disposed at Bukit Tagar Landfill. This daily tonnage will be increased to 3000 tonnes when the Government finalizes arrangement to send MSW from other parts of the Klang Valley to this landfill. The Bukit Tagar Sanitary Landfill is located around 50 kilometers from Kuala Lumpur and is accessible from the North South Expressway through the purpose-built Bukit Tagar interchange (Plate 1.1) (Kub-Berjaya Enviro Sdn. Bhd., 2005).

Plate 1.1: location of landfill
1.5 Project Objectives

Leachate treatment is very important for reducing the pollution level in the surface and ground water. This consequently will improve the water quality and reduce health hazards.

This project investigates the use of Physico-Chemical treatment of Bukit Tagar Sanitary Landfill Leachate using Ferric Chloride and P-Floc775. The focus of this project is to remove the heavy metal content (zinc, lead, copper and cadmium).

The main objectives of this project are:

- To determine the characteristics of untreated leachate
- To study the effectiveness of treating leachate using:
  - Ferric chloride (FeCl₃).
  - P-Floc775.

As coagulants and flocculants at:

  i. Different concentrations.
  ii. Different pH, and.
  iii. Different mixing speeds.

- To compare the efficiencies between Ferric Chloride and P-Floc775, to reduce heavy metals.
2.1 Municipal Solid Waste

The end of each product being a discard, the production process of any product is considered as a primitive source of solid waste. This is considered as being an important portion of the solid waste stream (Li et al., 2008). The main reason for solid waste generation is always human activity. Waste is material perceived to have little or no value by society or consumers. Nearly, all human activities produce waste (Kumar et al., 2004).

Solid waste contain all types of waste generated by the different types of sources such as domestic wastes (DSW), construction and demolition (C&D), industrial and agricultural wastes. Household solid waste (HHSW) is the remains of food like grease, fats, bones, skin meat vegetables, fruits, grain etc which are from animals and plants. It also contains paper, textiles, glass and empty refreshment cans. HHSW also include restaurant and hotel wastes. In addition it includes waste from street sweeping, septic tank pump, construction and demolition work and sludge from wastewater treatment plant (AL-Meshan and Farahat, 2002). On the other hand commercial solid wastes include paper, cartons, wood, tires, used oils, used furniture and electronic appliances such as refrigerators and heaters etc. The sources of commercial wastes are stores, commercial malls, markets and organization of the governmental and private companies (Burnley, 2007).

Municipal solid waste can also consist of toxic substances (paints, pesticides, used batteries, medicines), compostable organic matter (fruit and vegetable peels, food waste) and soiled waste (blood stained cotton, sanitary napkins, and disposable
syringes). Some of the municipal solid waste can be recycled, for example (plastic, glass, paper, metals, etc.) (Jha et al., 2003).

### 2.1.1 Generation

Solid waste generation increase due to the population growth in both industrialized and developing countries (Alam et al., 2008). Solid waste problems are managed in most developed countries through proper waste management which includes a lot of different techniques. Good environmental awareness among the people in developed nations, with stringent regulations and enforcement, and committed participation has enabled the improvement of waste management and reduce the waste generation. Malaysians generated around 26,000 tonnes MSW every day (Figure 2.1) (Agamuthu, 2008).

![Figure 2.1 Waste generation in Malaysia (Agamuthu, 2008).](image-url)
Failure of waste management could be traced to lack of public participation, lack of environmental consciousness among people, and also indifferent attitude. Malaysia like other countries faces the same problems (Fauziah et al., 2003; Choy et al., 2002).

However, rising incomes and general improvements in developmental status are often accompanied by an increase in consumption - a term generally associated with high expenditure on goods and services which is a sign of waste generation. Also, the waste generation increase is related to the food industry due to high demand for either fresh or processed foods. Coupled with rising populations, this consumption pattern results in considerable food wastes and by-products. As a result of improvement in development and industrial status, the per capita waste generation increased, for example percentage of paper in the waste composition, but organic waste such as putresibles decreased (Grover, 2002).

In the year 1997, Malaysian municipal solid waste generation amounted to about 5.6 million tonnes or 15000 tonnes/day. This amount can be divided into domestic waste which was around 80% (about 12100 tonnes/day) and the rest was commercial waste which was about 3100 tonnes/day. The production of domestic and commercial waste was estimated at about 8.0 million tonnes/year in the year 2000 (Agamuthu, 2001). In Kuala Lumpur alone, the people generated a huge quantity of municipal solid waste which is roughly 3070 tonnes/day (Agamuthu, 2001). Currently, around 26,000 tonnes of municipal solid waste is produced in Malaysia every day (Agamuthu, 2008).

The percentage of paper product is higher in high socio-economic area compared to the low income group. The differences are mainly due the degree of industrialization and urbanization. In contrast, the percentage of food waste is higher in
the low socio-economic area than the more affluent group (Table 2.1) (Agamuthu, 2001).

Table 2.1 MSW generated by the high, medium and low socio-economic areas in Petaling Jaya

<table>
<thead>
<tr>
<th>Composition (%)</th>
<th>Socio-economic status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Paper products</td>
<td>19.79</td>
</tr>
<tr>
<td>Plastic and rubber</td>
<td>21.05</td>
</tr>
<tr>
<td>Glass and ceramics</td>
<td>14.99</td>
</tr>
<tr>
<td>Food waste</td>
<td>24.13</td>
</tr>
<tr>
<td>Metals</td>
<td>8.80</td>
</tr>
<tr>
<td>Textiles</td>
<td>1.57</td>
</tr>
<tr>
<td>Garden waste</td>
<td>5.50</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
</tr>
</tbody>
</table>

(Source : Agamuthu, 2001)

Waste generation inside Malaysia was found to depend on the resource of municipal solid waste (MSW). The rate of generation varied depending on the premises (houses, shops, etc.) (Figure 2.2) with housing areas producing the largest quantity of waste while hospital produced the smallest quantity (Agamuthu, 2001).

Figure 2.2 Waste generation Sources in Malaysia
Generally, developed and industrialized countries generate high proportions of recyclables and packaging materials (paper, plastics, and metals) in their MSW. Developing countries, on the other hand, generate high proportion of organic wastes (food residue) in their MSW (Figure 2.3).

Figure 2.3: Per capita generation rate of municipal solid waste for developing countries (Grover, 2002)

Municipal solid waste management in India will face some problems due to the unavailability of appropriate services to treat and dispose the larger quantity of MSW generated every day in urban towns (Rathi, 2006; Sharholy et al., 2005; Ray et al., 2005;
Jha et al., 2003; and Kansal, 2002) and also per capita generation rate of MSW will increase over time (CPCB, 2000). Fig. 2.4 shows that the per capita generation rate is high in some cities like Madras and Ahmedabad. This may be the result of the rapid economic growth, the high living standards, and the high level of urbanization in these states and cities. However, the per capita generation rate is lower in other states such as Nagpur, Pune and Indore.

![Per capita waste generation rate for municipal solid waste in Indian cities (CBCP, 2000).](image)

Figure 2.4 Per capita waste generation rate for municipal solid waste in Indian cities (CBCP, 2000).

The quantity of solid waste generation in Singapore is around 4.5-4.8 million tonnes per year. This represents a gross per capita waste generation rate of between 3.37 and 3.52 kg/day. The per capita SW generation rate in Tehran in 2005 was 0.88 kg/day.
In comparison, the per capita SW generation rate was 1.21 kg/day in China (Suocheng et al., 2001) and 0.95 kg/ day in Turkey (Metin et al., 2003). The total quantity of household solid waste generation (tonne) in Tehran for different seasons of 2005 is shown in Table 2.2 (OWRC, 2006).

Table 2.2 Household solid waste (SW) generation (tonne per year) in Tehran in different seasons of 2005

<table>
<thead>
<tr>
<th>Season</th>
<th>Household</th>
<th>Stale bread</th>
<th>Plastic</th>
<th>Paper and cardboard</th>
<th>Metal</th>
<th>Glass</th>
<th>Pet</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>448,811.4</td>
<td>8522.0</td>
<td>1970.9</td>
<td>4043.1</td>
<td>1758.4</td>
<td>291.7</td>
<td>230.7</td>
<td>3275.5</td>
</tr>
<tr>
<td>Summer</td>
<td>396,612.6</td>
<td>9696.9</td>
<td>2351.8</td>
<td>4445.0</td>
<td>1936.7</td>
<td>360.2</td>
<td>158.8</td>
<td>3057.0</td>
</tr>
<tr>
<td>Autumn</td>
<td>382,441.0</td>
<td>8982.2</td>
<td>2107.8</td>
<td>5106.3</td>
<td>1770.2</td>
<td>326.6</td>
<td>159.6</td>
<td>2389.0</td>
</tr>
<tr>
<td>Winter</td>
<td>379,612.5</td>
<td>8408.5</td>
<td>2368.2</td>
<td>5049.4</td>
<td>2049.7</td>
<td>385.1</td>
<td>220.5</td>
<td>2163.7</td>
</tr>
<tr>
<td>Average</td>
<td>401,869.4</td>
<td>8902.4</td>
<td>2199.7</td>
<td>2661.0</td>
<td>1878.7</td>
<td>340.9</td>
<td>189.9</td>
<td>2721.3</td>
</tr>
<tr>
<td>Total</td>
<td>1,607,477.6</td>
<td>35,609.7</td>
<td>8798.6</td>
<td>18,643.8</td>
<td>7515.0</td>
<td>1363.5</td>
<td>759.6</td>
<td>10,885.2</td>
</tr>
</tbody>
</table>

Source: OWRC (2006b).

a Polyethylene Terephthalate bottles and dishes.
b Refers to any unknown or hardly classified material in solid waste.

2.1.2 Composition

Around 72% of waste generated in Malaysia is compostable and it consists of organic waste, paper, textile/ leather, and wood. The typical example of waste in fast developing countries is plastic. In the year 2001, total plastic waste is around 16% which is considered a high proportion of the waste composition in Malaysia, while in USA it was estimated at 10% in the year 2000 (Table 2.3).
Table 2.3 Composition of MSW in Malaysia and USA (% dry weight)

<table>
<thead>
<tr>
<th>Waste Composition (%)</th>
<th>Range</th>
<th>Typical</th>
<th>Malaysia</th>
<th>US 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic/food waste</td>
<td>5</td>
<td>17</td>
<td>32.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Yard waste</td>
<td>0</td>
<td>10</td>
<td>-</td>
<td>15.0</td>
</tr>
<tr>
<td>Paper</td>
<td>10</td>
<td>33</td>
<td>29.5</td>
<td>38.0</td>
</tr>
<tr>
<td>Plastic</td>
<td>2</td>
<td>5</td>
<td>16.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Textile/leather</td>
<td>0</td>
<td>2</td>
<td>3.4</td>
<td>7.0</td>
</tr>
<tr>
<td>Rubber</td>
<td>0</td>
<td>0.5</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td>Wood</td>
<td>1</td>
<td>2</td>
<td>7.0</td>
<td>-</td>
</tr>
<tr>
<td>Glass</td>
<td>4</td>
<td>5</td>
<td>4.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Ceramic</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>Ferrous metal</td>
<td>1</td>
<td>1</td>
<td>3.7</td>
<td>8.0</td>
</tr>
<tr>
<td>Non-ferrous metal</td>
<td>0</td>
<td>1</td>
<td>0.6</td>
<td>-</td>
</tr>
<tr>
<td>Others</td>
<td>0</td>
<td>8</td>
<td>0.9</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Source: (Agamuthu, 2008).

In modern cities such as Petaling Jaya, Shah Alam, and Bangi, where the inhabitants are in the high and middle income group, Malaysians generated MSW which is considered a typical composition in developing countries (Table 2.4). The main component of MSW is garbage which ranged from 37 to 48%. The second most abundant component is paper and cardboard, both of which was at 18 to 30% while the percentage of plastic waste was between 9 to 16%. The capital city, Kuala Lumpur, generated only 9% plastic compared to 14 to 16% generated by the three cities around the capital city. This could be due to high income with the people in three urban centers (Agamuthu, 2001).
Table 2.4: Solid waste composition (% dry weight) of selected urban localities in Malaysia

<table>
<thead>
<tr>
<th>Waste composition</th>
<th>P. Jaya</th>
<th>K. Lumpur</th>
<th>Shah Alam</th>
<th>Bangi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garbage</td>
<td>36.5</td>
<td>45.7</td>
<td>47.8</td>
<td>40.0</td>
</tr>
<tr>
<td>Plastic</td>
<td>16.4</td>
<td>9.0</td>
<td>14.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Bottle/ glass</td>
<td>3.1</td>
<td>3.9</td>
<td>4.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Paper/ cardboard</td>
<td>27.0</td>
<td>29.9</td>
<td>20.6</td>
<td>18.0</td>
</tr>
<tr>
<td>Metal</td>
<td>3.9</td>
<td>5.1</td>
<td>6.9</td>
<td>4.0</td>
</tr>
<tr>
<td>Fabric</td>
<td>3.0</td>
<td>2.1</td>
<td>2.4</td>
<td>6.0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>10</td>
<td>4.3</td>
<td>4.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Source: (Agamuthu, 2001).

The highest composition of MSW in Malaysia in the year 2004 was organic waste which was estimated at 46%, the second highest composition was paper at 14% while plastic was at 10%. Wood and other materials have a percentage at 7 and 6% respectively while rubber, textile, metals and glass were at 3% each (Figure 2.5) (Agamuthu, 2008).

![Figure 2.5 Composition of MSW in Malaysia (2004) (Source: Agamuthu, 2008)](image_url)
The amounts and composition of solid waste generated vary from country to country and between residential and non residential areas. The studies carried out in many countries indicate that per capita output of household wastes is different from one country to another (Table 2.5).

Table 2.5 Composition of Municipal Solid Waste in selected countries (%dry weight)

<table>
<thead>
<tr>
<th>Waste composition</th>
<th>Hong Kong</th>
<th>Korea</th>
<th>Indonesia</th>
<th>Italy</th>
<th>Hungary</th>
<th>Ireland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>25.8</td>
<td>24</td>
<td>20.6</td>
<td>28</td>
<td>15</td>
<td>31</td>
</tr>
<tr>
<td>Organic</td>
<td>38.1</td>
<td>28</td>
<td>55.4</td>
<td>29</td>
<td>29</td>
<td>25</td>
</tr>
<tr>
<td>Plastic</td>
<td>18.6</td>
<td>8</td>
<td>13.3</td>
<td>5</td>
<td>17.5</td>
<td>11</td>
</tr>
<tr>
<td>Glass</td>
<td>3.7</td>
<td>5</td>
<td>1.9</td>
<td>13</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Metals</td>
<td>2.5</td>
<td>7</td>
<td>1.1</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Textile</td>
<td>2.9</td>
<td>N.A.</td>
<td>0.6</td>
<td>N.A.</td>
<td>N.A</td>
<td>N.A</td>
</tr>
<tr>
<td>Other inorganic metal</td>
<td>8.4</td>
<td>28</td>
<td>4.7</td>
<td>22</td>
<td>35</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>


In India, industrialization and population explosion have forced people to migrate from villages to cities. As a result, the composition of municipal solid waste changed over time, especially since India strives to achieve industrialized nation status by the year 2020 (Sharma and Shah, 2005; CPCB, 2004).
The composition of household SW in Tehran is shown in Table 2.6. Household SW composition in Tehran depends on factors like dietary habits, cultural traditions, lifestyle, climate and income (Jin et al., 2006). As shown in Table 2.6 the main element in Tehran’s household MSW is stale bread (42.6%). Wheat bread is one of the primary sources of food in Iran, particularly in medium and low income households (OWRC, 2006b).

Table 2.6 Composition of household solid waste in Tehran (% dry weight) in different seasons of 2005.

<table>
<thead>
<tr>
<th>Season</th>
<th>Household Stale Bread</th>
<th>Plastic</th>
<th>Paper and cardboard</th>
<th>Metal</th>
<th>Glass</th>
<th>Pet(^a)</th>
<th>Others(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>42.2</td>
<td>9.8</td>
<td>20.1</td>
<td>8.8</td>
<td>1.5</td>
<td>1.1</td>
<td>16.3</td>
</tr>
<tr>
<td>Summer</td>
<td>44.1</td>
<td>10.7</td>
<td>20.2</td>
<td>8.8</td>
<td>1.6</td>
<td>0.7</td>
<td>13.9</td>
</tr>
<tr>
<td>Autumn</td>
<td>43.1</td>
<td>10.1</td>
<td>24.5</td>
<td>8.5</td>
<td>1.6</td>
<td>0.8</td>
<td>11.5</td>
</tr>
<tr>
<td>Winter</td>
<td>40.7</td>
<td>11.5</td>
<td>24.5</td>
<td>9.9</td>
<td>1.9</td>
<td>1.1</td>
<td>10.5</td>
</tr>
<tr>
<td>Total</td>
<td>42.6</td>
<td>10.5</td>
<td>22.3</td>
<td>9.0</td>
<td>1.6</td>
<td>0.9</td>
<td>13.0</td>
</tr>
</tbody>
</table>

\(^a\) Polyethylene Terephthalate bottles and dishes.
\(^b\) Refers to any unknown or hardly classified material in solid waste.

The composition of solid waste in Singapore has been found to be reasonably steady (Table 2.7). Food waste accounts for 39% of the whole waste stream and paper is roughly 21%. While, combustible waste represents around 85% of the total solid waste generated, (Renbi et al., 2002).
Table 2.7: Solid waste composition in Singapore.

<table>
<thead>
<tr>
<th>Composition % on dry weight</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1997&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Food waste</td>
<td>38.80</td>
</tr>
<tr>
<td>Paper/cardboard</td>
<td>20.60</td>
</tr>
<tr>
<td>Plastic</td>
<td>5.79</td>
</tr>
<tr>
<td>Construction debris</td>
<td>4.51</td>
</tr>
<tr>
<td>Wood/timber</td>
<td>8.91</td>
</tr>
<tr>
<td>Horticulture waste</td>
<td>2.70</td>
</tr>
<tr>
<td>Earth spoils</td>
<td>2.70</td>
</tr>
<tr>
<td>Ferrous metals</td>
<td>2.70</td>
</tr>
<tr>
<td>Non-ferous metals</td>
<td>0.50</td>
</tr>
<tr>
<td>Used slag</td>
<td>4.29</td>
</tr>
<tr>
<td>Sludge</td>
<td>1.80</td>
</tr>
<tr>
<td>Glass</td>
<td>1.10</td>
</tr>
<tr>
<td>Textile/leather</td>
<td>0.90</td>
</tr>
<tr>
<td>Scrap tyres</td>
<td>0.20</td>
</tr>
<tr>
<td>Other</td>
<td>4.51</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: <sup>a</sup>Ministry of environment in Singapore (2000a); <sup>b</sup>United Nation Statistics Division, 2007.

2.1.3 Collection

Municipalities in Malaysia manage the solid waste management service. After 1995 the authorities have passed the responsibility of waste collection and disposal to the private sectors. The local authority has given the work of municipal solid waste
collection and disposal in the central and eastern region of Malaysia, covering the states of Selangor, Phars, Terengan, Kelantan and Federal Territory of Kuala Lumpur to Alam flora (Alam Flora, 2004b).

Currently, four companies are doing solid waste collection and disposal in Malaysia (Table 2.8). They are responsible for several wastes such as domestic waste, commercial waste, non-toxic industrial waste, and construction waste. All of them have the same responsibilities which include collection, transport, treatment and storage of solid waste. In addition, they are responsible for cleaning roads and trying to achieve the minimum level of recycling.

Table 2.8: Consortium responsible for the management of solid waste in Malaysia.

<table>
<thead>
<tr>
<th>Region</th>
<th>Consortium</th>
<th>States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central and Eastern</td>
<td>Hicom Berhad (Alam flora Sdn. Bhd.)</td>
<td>Kuala Lumpur, Selangor, Phang, Kelantan, Terengganu</td>
</tr>
<tr>
<td>Southern</td>
<td>Concees Gali Sdn. Bhd. (Southern Waste Management)</td>
<td>Johor, negari Sembilan, Malacca</td>
</tr>
<tr>
<td>Northern</td>
<td>eIdaman company</td>
<td>Perak, Kedah, Penang and Perlis</td>
</tr>
</tbody>
</table>


Currently in Malaysia three methods are being used. They are open dump, landfilling and incineration. Malaysia had 161 landfills in 2000. (Table 2.9) shows the number and distribution of landfills in the Malaysia (Noor Zalina, 2000).
Table 2.9: Types of landfill in each state in Malaysia in 2000.

<table>
<thead>
<tr>
<th>No.</th>
<th>State</th>
<th>Landfills</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Johor</td>
<td>13</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>Melaka</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Neg. Sembilan</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Selangor</td>
<td>0</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>Perak</td>
<td>9</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>6</td>
<td>Kedah</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>9</td>
<td>18</td>
</tr>
<tr>
<td>7</td>
<td>Pulau Pinang</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Perls</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Pahang</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Terenngganu</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Kelantan</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>Sarawak</td>
<td>15</td>
<td>11</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Sabah</td>
<td>12</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>W.P. Labuan</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>W.P. Kuala</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Total</td>
<td>77</td>
<td>49</td>
<td>19</td>
<td>10</td>
<td>6</td>
<td>161</td>
<td></td>
</tr>
</tbody>
</table>

Source: Noor Zalina, 2000

Landfill types in Malaysia
0 open dump
1 controlled tipping
2 Landfill with bund and daily soil cover.
3 Landfill with leachate recirculation.
4 Landfill with leachate treatment facilities.

2.2 An Integrated system of solid waste management

2.2.1 Open dump and Landfill

Open dumping is the main disposal method of municipal solid waste in developing countries (Bulent et al., 2004). The dumping of disposable waste is not a solution toward waste problems even if it is dumped in suitable areas, especially away from residential areas. In addition, the open dump sites in most developing Asian
countries are located near residences. The toxic chemicals from these sites have negative effects on human life, wildlife, and environmental quality (Tanabe, 2002). Developing Asian countries face a problem in the dumping sites in the form of uncontrolled burning of solid waste by waste pickers (Minh et al., 2003).

Malaysia has around 161 landfill and most of them are open dumps. They do not practice a proper system in these landfills as what is practiced in sanitary landfills, which have several facilities to help to protect the ecosystem and human health. Some examples of the facilities are leachate collection pipes, layer of protection liner, and treatment facilities.

2.2.2 Sanitary landfill

In Malaysia around 95 – 98% of the municipal solid waste goes to landfills. However, untreated waste in landfills can be a source for many issues such as insects, diseases, and different kinds of pollution (www.infoplease.com, 11/1/2008; Agamuthu, 2004). Hence, there is an urgent need for actions to protect the ecosystem by improving waste collection services, developing treatment facilities, constructing sanitary landfill for solid waste disposal as an alternative method for landfills, and increasing allocation for collection equipment and facilities (Mohamed, 2004).

Sanitary landfill or controlled tipping is defined as a “method of disposing refuse on land without creating a nuisance or hazard to public health or safety by utilizing the principles of engineering to confine the refuse to the smallest practical area and to reduce it to the smallest practical volume and cover it with a layer of earth at the conclusion of each day’s operation or at such more frequent intervals as may be necessary”. The main aim of a sanitary landfill is to use it for a longer time for disposal of solid waste with less negative effect to the ecosystem. Also, if the sanitary landfill is
designed for energy extraction, the landfill gas can be used as a source of energy. Moreover, in some countries, reclamation of land is done especially where land is limited (Agamuthu, 2001).

Although, the sanitary landfills have a lot of benefits but they also have some disadvantages. Landfills require usable land which should be located near several cities. Unfortunately land is in short supply and some times expensive. Secondly, sanitary landfills can pollute ground water with toxic waste like pesticides and paints. Another disadvantage is that they produce methane gas which causes air pollution. They also tend to destroy many habitats, especially wetland. Finally, it may cause loss of resources which may become extinct (Chiras, 2001).

The landfill should be located far away from water resources such as streams, lakes and aquifers in order to reduce the problems of water pollution. There must be several monitoring wells around the landfill to monitor the movement of pollutants. There should also be a special drainage system which can help to reduce the flow over from the landfill surface. Thus, the amount of water that penetrates it will be reduced. Typically, impermeable clay cap located at the top of landfill can prevent the infiltration of water through the landfill.

Air pollution problems which are caused by the emission of methane gas from the sanitary landfills into the atmosphere can be reduced by using special pipes which draws out methane gas.
2.2.3 Incineration

Incineration is another technology currently used in many industrial countries. It is considered to be one of the most suitable methods and is environmentally secure for the disposal of many of the solid and hazardous waste. It has a good design and excellent operating systems which are able to destroy all kinds of wastes especially hazardous waste (Vijaya, 2002).

Incineration of MSW has many advantages including a significant reduction in volume (about 70–90%), recovery of energy and complete disinfection (Abanades et al., 2001) However, when compared with other methods, it has some disadvantages, for example it is expensive, generates fly and bottom ashes, emits toxic gases and particulate matters into the atmosphere, and requires much energy (Nabajyoti et al., 2007). Sometimes the ash can be used as a replacement for quarried aggregate in construction (Scottish Environmental Protection Agency, 2006). The composition of the solid residues produced during incineration depends mainly on the waste characteristics (Margarida et al., 2007).

2.2.4 Composting

Currently, one of the problems in developing countries is the management of organic waste. Most of the countries are trying to reduce the amount of organic waste which is deposited in landfills by applying different technologies. Composting is a more appropriate technique for recycling organic waste and changing it into ecologically stable product beneficial for the soil (Ouatmane et al., 2000; Jouraiphy et al., 2005).
Hence, composting is a better method compared to other methods because it is an environment-friendly technology that allows treating and recycling organic wastes. It can be used at home for treating household wastes, be applied for other activities such as residuals from industrial activities, municipal or industrial wastewater sludge (Gea et al., 2004) and animal by-products (Manios, 2004). The quality of compost depends on several factors such as the amount of bedding used, and the composting method (e.g. turning frequency), (Parkinson et al., 2004; Larney et al., 2004).

2.3 Land filling of Waste

2.3.1 Leachate Generation

The most popular and easiest method employed for the disposal of solid waste in Malaysia is the landfill method because more than 98% of all MSW that is collected is disposed into landfills (Agamuthu et al., 2004). The composition of municipal solid waste will be changed physically-chemically and biologically after landfilling directly, due to weathering conditions. When rain falls it will combine with waste and generate a high contaminant liquid called leachate. The waste in the landfill undergoes changes from a short acidic phase (aerobic) to much longer acidogenic and methanogenic phases (anaerobic decomposition) (Tonni et al, 2005).

A general pattern of leachate generation is presented in Figure 2.6 (Farquar, 1989). The leachte generation process consists of several procedures which are illustrated below:-

1. Precipitation falls on the landfill and some of it becomes runoff.
2. Some of the precipitation infiltrates the surface (uncovered refuse, intermediate cover, or final cover).
3. Some of the infiltration evaporates from the surface and (or) transpires through the vegetative cover if it exists.

4. The remainder of the infiltration, remaining after evaporation, and the storage water moves downward was forming percolate arid which eventually becomes leachate as it reaches the base of the landfill.

5. Percolation may be increased by infiltration of groundwater.

Figure 2.6 Pattern of leachate generation
2.3.2 Leachate formation

Landfill leachate formation depends on several phases (Figure 2.7), which are related by changes in the solid waste composition. These phases are hydrolysis and acidification (phase I), Initial methane generation (phase II), Stable methane (phase III), Slow-down (phase IV), and Final storage (phase V).

In Phase I, the decomposition of solid waste by bacteria begin through aerobic process which requires oxygen. In the Phase II, the anaerobic process starts, while the amount of oxygen decreases. The presences of organic acids reduce the pH in the leachate. Also through this stage the methanogenic bacteria starts to grow slowly. Furthermore, the consumption of simple organic compounds helps to produce methane and carbon dioxide within the landfill.

Waste decomposition can take many years. The transition from phase II to phase III may not be completed for decades. Phase III is called the acid phase due to the production of acids during the phase. This stage includes many activities such as the beginning of methane production, growth of methanogenic bacteria which is responsible for degradation of soluble organic compounds in the leachate. Furthermore, the biochemical oxygen demand (BOD₅), chemical oxygen demand (COD) and conductivity of leachate will increase due to the dissolution of the organic acids in the leachate. Many inorganic constituents, in particular heavy metals, will be solubilized during this phase due to the low pH of the landfill leachate.
Figure 2.7: Development of gas and leachate in a landfill
Source: Christensen and Kjeldsen, 1989.
The leachate that is produced in phase III has a lower value of pH as well as a lower ratio of BOD\textsubscript{5} to COD. Moreover, both ammonia and nitrogen will be present at higher levels in the leachate. A number of inorganic constituents, for example heavy metals and also many essential substances will be solubilized in this phase. The composition of phase III is distinguished by neutral pH; low concentration of volatile fatty acid, sharply decreasing redox potential, and higher refractory organic matter concentrations. The longest phase is the methanogenic phase which undergoes more stabilization than other phases.

In phase IV a group of microorganisms convert the acetic acids and hydrogen gas to methane and carbon dioxide. The microbes responsible for this reaction are called methanogenic or methanogens. The pH values, due to methanogenic reaction, will rise to more neutral range of 6.8-8. The BOD\textsubscript{5} and COD values of the landfill leachate and the concentration of heavy metals will reduce.

Phase V which is the maturation Phase starts after the biodegradable organic material. In this phase the leachate contains higher concentration of fulvic and humic acids. Leachates produced during this phase are characterized by relatively low BOD values and low ratios of BOD/COD. Also, heavy metal concentration, organic compounds and fatty acids are depleted, while the ammonia –nitrogen remains at high level and the pH in this stage will increase (Diego, 2003).

However, the amount of pollutants in the leachate varies with time. Generally, the biodegradable organics tend to reach peak concentrations in the leachate in the earlier period (months) of leaching and then decreased. On the other hand, some pollutants such as poorly biodegradable organics and heavy metals such as iron tend to persist in the leachate for several years. This is shown in Fig. 2.8 (Farquar, 1989). It is
also apparent from this data that contaminants are added to the leachate for many years even after the site is closed.

Figure 2.8: Illustration showing the amount of pollutants in the leachate (Source: Farquar, 1989).

Usually, the main reason for the presence of heavy metals in landfill leachate is the lack of awareness among the people. A lot of hazardous waste such as clinical bandages, batteries and medicine are found in the refuse sent to landfills (Hamidi et al, 2003). Also, heavy metals such as iron, manganese, zinc, chromium, lead, copper and cadmium are present in high concentrations in the landfill leachate. These minerals can cause pollution to groundwater, surface water and reservoirs (Aziz et al., 2004).
2.3.3 Leachate Composition and characteristics

The composition of leachate is decided by many factors, for example waste composition, site hydrology, the availability of moisture and oxygen, design and operation of the landfill and its age. Many studies indicate that the leachate is rich with minerals and many other resources (Christensen et al., 2001; Warith et al., 2002; Rivas et al., 2004). Furthermore, leachate may contain large amounts of organic matter (biodegradable), but also refractory materials and biodegradation materials (Marttinen et al., 2002). Furthermore, the leachate can also contain hazardous organic substances, e.g. aromatic compounds, chlorinated aliphatic compounds, phenols, phthalates and pesticides (Paxéus, 2000; Schwarzbauer et al., 2002; Baun et al., 2003, 2004).

The operation of landfills posses a great challenge in the production and management of the leachate especially if it is not properly collected, treated, and disposed. It is considered an environmental problem because it is one of the main sources of contamination of soil, ground water, and surface water. The environmental problem is created since leachate contain large quantities of materials like organic matter, ammoniacal nitrogen, heavy metals, and chlorinated organic and inorganic compounds (Al-Yaqout et al., 2003).

A knowledge of leachate composition and its seasonal variation helps to choose the best method of treatment (Tasti et al., 2002, and Tatsi et al., 2003). The old landfills which have a large quantity of organic matters use a combination of techniques because it is more efficient to do so. However, biological treatment is insufficient for old landfills (Silva et al., 2003).
Table 2.10 shows the difference in leachate quality which is dependent upon landfill age. The results of recent studies shows that even leachate from young landfills contain low organic concentration (Aziz et al., 2007). The reason for it may be the fact that the leachate recirculation method is practiced in many landfills according to Chan et al., (2002). The concentration of chemical materials in the leachate will change over time. Hence it is difficult to be specific as to the concentration of a particular chemical in leachate at a given time. The composition and characteristics of leachate used to determine the kind of leachate treatment methods needed and appropriate.

Table 2.10 Characteristics of different types of landfill leachate

<table>
<thead>
<tr>
<th>Type of leachate</th>
<th>Young</th>
<th>Intermediate</th>
<th>Stabilized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of landfill (years)</td>
<td>&lt;1</td>
<td>1-5</td>
<td>&gt;5</td>
</tr>
<tr>
<td>pH</td>
<td>&lt;6.5</td>
<td>6.5-7.5</td>
<td>&gt;7.5</td>
</tr>
<tr>
<td>BOD/COD</td>
<td>0.5-1.0</td>
<td>0.1-0.5</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>COD (g/L)</td>
<td>&lt;15</td>
<td>3 – 15</td>
<td>&lt;3</td>
</tr>
<tr>
<td>NH3-N (mg/L)</td>
<td>&lt;400</td>
<td>NA</td>
<td>&gt;400</td>
</tr>
<tr>
<td>TOC/COD</td>
<td>&lt;0.3</td>
<td>0.3 – 0.5</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Heavy metals (mg/L)</td>
<td>&gt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

Source: Alvarez et al., 2004.

Also, Table 2.11 illustrates the characteristics of landfill leachate in Malaysia. Kundang Landfill displays low BOD, high COD, and neutral pH as the leachate was generated through the methanogenic phase, while Sungai Sedu landfill displays low BOD and the pH was found to be slightly acidic, at pH 6.72. Total suspended solids in
the Kundang landfill was low because the leachate originated from methanogenic phase that most complex particle had undergone microbial degradation to form simple ionic and other particles. The Sungai Sedu landfill also has low TSS and this due to the dilution factor influenced by the surface runoff (Fauziah and Agamuthu, 2005).

Table 2.11 Characteristics of landfill leachate from Kundang and Sungai Sedu landfill

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kundang landfill</th>
<th>Sungai Sedu landfill</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD5 (mg/l)</td>
<td>27.5 ± 0.66</td>
<td>22.27 ± 0.46</td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td>6232 ± 1824.3</td>
<td>169.3 ± 76.95</td>
</tr>
<tr>
<td>pH</td>
<td>7.43 ± 0.04</td>
<td>6.72 ± 0.02</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>0.06 ± 0.01</td>
<td>0.09 ± 0.001</td>
</tr>
<tr>
<td>Hardness (CaCO3) (ppm)</td>
<td>429.3 ± 240.0</td>
<td>135 573.3 ± 3144.9</td>
</tr>
<tr>
<td>Cd (ppm)</td>
<td>0.002 ± 0.001</td>
<td></td>
</tr>
<tr>
<td>Cr (ppm)</td>
<td>0.193 ± 0.02</td>
<td>0.006 ± 0.005</td>
</tr>
<tr>
<td>Cu (ppm)</td>
<td>0.003 ± 0.002</td>
<td>0.005 ± 0.004</td>
</tr>
<tr>
<td>Pb (ppm)</td>
<td>0.027 ± 0.012</td>
<td>0.147 ± 0.172</td>
</tr>
<tr>
<td>Zn (ppm)</td>
<td>0.060 ± 0.044</td>
<td>0.153 ± 0.102</td>
</tr>
<tr>
<td>Mg (ppm)</td>
<td>4.245 ± 0.420</td>
<td>7.480 ± 3.780</td>
</tr>
</tbody>
</table>

Source: Fuziah and Agamuthu, 2005.

Table 2.12 shows the characteristics of leachate from Vancouver landfill. The mean ratio of BOD: COD in the leachate was 0.13 which is indicative of mature landfill (Henderson et al., 1997).
The comparison of physical and chemical characteristics of sanitary landfill leachate between two Malaysian landfills with leachate from other countries is shown in Table 2.13. The leachate consists of organic matters, nitrogen (ammonical), suspended solid, salt and colouring matters. Usually the concentration of pollutants parameters in leachate will be highest during the first 2-3 years (Agamuthu, 2001).

Table 2.12 Characteristics of the Vancouver landfill leachate of 27 years old.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Monitoring Frequency</th>
<th>Mean (mg/L)</th>
<th>Min. (mg/L)</th>
<th>Max. (mg/L)</th>
<th>No. of Sample</th>
<th>Detection limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity (ms)</td>
<td>Tri- weekl</td>
<td>4.7</td>
<td>2.4</td>
<td>7.5</td>
<td>77</td>
<td>-</td>
</tr>
<tr>
<td>Site pH (unit)</td>
<td>Tri- weekly</td>
<td>7.4</td>
<td>7.0</td>
<td>7.8</td>
<td>110</td>
<td>-</td>
</tr>
<tr>
<td>Lab pH (unit)</td>
<td>Weekly</td>
<td>7.5</td>
<td>6.8</td>
<td>8.5</td>
<td>62</td>
<td>-</td>
</tr>
<tr>
<td>TSS</td>
<td>Weekly</td>
<td>67</td>
<td>10</td>
<td>308</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td>Al-Kalinity as Ca\textsubscript{2}Co\textsubscript{3}</td>
<td>Weekly</td>
<td>2380</td>
<td>453</td>
<td>3810</td>
<td>60</td>
<td>0.5</td>
</tr>
<tr>
<td>No\textsubscript{3} – N</td>
<td>Weekly</td>
<td>0.34</td>
<td>ND</td>
<td>3.40</td>
<td>63</td>
<td>0.002</td>
</tr>
<tr>
<td>No\textsubscript{2} – N</td>
<td>Weekly</td>
<td>0.026</td>
<td>ND</td>
<td>1.100</td>
<td>62</td>
<td>0.002</td>
</tr>
<tr>
<td>COD</td>
<td>Weekly</td>
<td>368</td>
<td>146</td>
<td>532</td>
<td>60</td>
<td>25</td>
</tr>
<tr>
<td>NH\textsubscript{3} – N</td>
<td>Weekly</td>
<td>202</td>
<td>83</td>
<td>336</td>
<td>94</td>
<td>0.02</td>
</tr>
<tr>
<td>BOD\textsubscript{5}</td>
<td>Monthly</td>
<td>50</td>
<td>27</td>
<td>89</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>TKN</td>
<td>Monthly</td>
<td>230</td>
<td>136</td>
<td>392</td>
<td>11</td>
<td>0.5</td>
</tr>
<tr>
<td>TKN: NH\textsubscript{3}-N ratio</td>
<td>-</td>
<td>1.1:1</td>
<td>1:1</td>
<td>1.4:1</td>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td>BOD:COD ratio</td>
<td>-</td>
<td>0.13:1</td>
<td>0.08:1</td>
<td>0.19:1</td>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td>Cr</td>
<td>Monthly</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>13</td>
<td>0.03</td>
</tr>
<tr>
<td>Fe</td>
<td>Monthly</td>
<td>15.1</td>
<td>11.8</td>
<td>20.2</td>
<td>13</td>
<td>0.03</td>
</tr>
<tr>
<td>Pb</td>
<td>Monthly</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>13</td>
<td>0.08</td>
</tr>
<tr>
<td>Mn</td>
<td>Monthly</td>
<td>1.2</td>
<td>0.8</td>
<td>1.5</td>
<td>13</td>
<td>0.003</td>
</tr>
<tr>
<td>Ni</td>
<td>Monthly</td>
<td>0.019</td>
<td>ND</td>
<td>0.041</td>
<td>13</td>
<td>0.025</td>
</tr>
<tr>
<td>Zn</td>
<td>Monthly</td>
<td>0.0.129</td>
<td>0.035</td>
<td>0.310</td>
<td>13</td>
<td>0.015</td>
</tr>
<tr>
<td>Al-Kalinity as Ca\textsubscript{2}Co\textsubscript{3}</td>
<td>Weekly</td>
<td>2380</td>
<td>453</td>
<td>3810</td>
<td>60</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Source: Henderson et al., 1997
Table 2.13 Physical and chemical characteristics of Sanitary Landfill leachate from two Malaysian landfills compared with leachate from other countries.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>North Jinjang</th>
<th>Kelana Jaya</th>
<th>Canada</th>
<th>Spain</th>
<th>Norway</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>184.32</td>
<td>619.84</td>
<td>860</td>
<td>113.65</td>
<td>110-9425</td>
<td>3800-38800</td>
</tr>
<tr>
<td>pH</td>
<td>8.18</td>
<td>8.15</td>
<td>6.8</td>
<td>8.4</td>
<td>5.9-7.0</td>
<td>5.4-6.4</td>
</tr>
<tr>
<td>Conductivity (MS)</td>
<td>27.5</td>
<td>5.04</td>
<td>-</td>
<td>18.52</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N-total</td>
<td>19.36</td>
<td>20.25</td>
<td>-</td>
<td>-</td>
<td>16.6-254</td>
<td>56-630</td>
</tr>
<tr>
<td>P-total</td>
<td>25.33</td>
<td>8.25</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
<td>5.9-11.3</td>
</tr>
<tr>
<td>Mg</td>
<td>327.49</td>
<td>32.99</td>
<td>350</td>
<td>-</td>
<td>13-19</td>
<td>-</td>
</tr>
<tr>
<td>Ca</td>
<td>919.98</td>
<td>94.98</td>
<td>180</td>
<td>318.5</td>
<td>99-400</td>
<td>-</td>
</tr>
<tr>
<td>K</td>
<td>5099.96</td>
<td>534.96</td>
<td>16</td>
<td>730</td>
<td>21.3-219</td>
<td>-</td>
</tr>
<tr>
<td>Na</td>
<td>2319.88</td>
<td>389.88</td>
<td>140</td>
<td>938</td>
<td>34.8-462</td>
<td>-</td>
</tr>
<tr>
<td>Cl</td>
<td>2979.8</td>
<td>439.42</td>
<td>190</td>
<td>-</td>
<td>68-680</td>
<td>-</td>
</tr>
<tr>
<td>F</td>
<td>2.75</td>
<td>3.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fe</td>
<td>115</td>
<td>5.4</td>
<td>5</td>
<td>148.5</td>
<td>11.5-234</td>
<td>-</td>
</tr>
<tr>
<td>Mn</td>
<td>8.88</td>
<td>0.63</td>
<td>-</td>
<td>148.5</td>
<td>11.5-234</td>
<td>-</td>
</tr>
<tr>
<td>Zn</td>
<td>11.65</td>
<td>0.65</td>
<td>2.5</td>
<td>2.16</td>
<td>0.055-2.65</td>
<td>5.3-155</td>
</tr>
<tr>
<td>Pb</td>
<td>5.2</td>
<td>2.5</td>
<td>1</td>
<td>0.52</td>
<td>0.001-0.015</td>
<td>0.1-1.4</td>
</tr>
<tr>
<td>Cu</td>
<td>0.79</td>
<td>0.79</td>
<td>1.7</td>
<td>0.34</td>
<td>0.008-0.085</td>
<td>0.18-1.3</td>
</tr>
<tr>
<td>Cd</td>
<td>0.59</td>
<td>0.19</td>
<td>-</td>
<td>0.23</td>
<td>0.0001-0.002</td>
<td>0.01-0.03</td>
</tr>
</tbody>
</table>

Source: Agamuthu, 2001

There are specific technologies which are used to reduce the concentration of contaminants in the leachate. Treatment methods like physio-chemical treatment, biological treatment, advanced oxidation process (AOP) as well as natural systems such
as constructed wetlands (Klomjek et al., 2005) and leachate recirculation (Warith et al., 2001) have been developed in recent years. These treatments not only minimize the generation of toxic contaminants from leachate, but also comply with the increasingly stringent discharge standards in different countries (Table 2.14).

Table 2.14 Maximum discharge standard for landfill leachate from selected countries.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>USA (1)</th>
<th>Germany (2)</th>
<th>France (3)</th>
<th>Hong Kong (4)</th>
<th>South Korea (5)</th>
<th>Malaysia standard (A) (6)</th>
<th>Malaysia standard (B) (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>NA</td>
<td>200</td>
<td>120</td>
<td>200</td>
<td>50</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>BOD5</td>
<td>NA</td>
<td>20</td>
<td>30</td>
<td>800</td>
<td>NA</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>NH3-N</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>5</td>
<td>50</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>NA</td>
<td>70</td>
<td>30</td>
<td>100</td>
<td>150</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>NA</td>
<td>30</td>
<td>NA</td>
<td>25</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Cd (II)</td>
<td>0.01</td>
<td>0.1</td>
<td>NA</td>
<td>0.1</td>
<td>NA</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Cr (III)</td>
<td>NA</td>
<td>0.5</td>
<td>NA</td>
<td>0.1</td>
<td>NA</td>
<td>-</td>
<td>0.05</td>
</tr>
<tr>
<td>Cr (VI)</td>
<td>0.05</td>
<td>0.1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>-</td>
<td>0.05</td>
</tr>
<tr>
<td>Ni (II)</td>
<td>0.013</td>
<td>1</td>
<td>NA</td>
<td>0.6</td>
<td>NA</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Pb (II)</td>
<td>0.03</td>
<td>0.5</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Cu (II)</td>
<td>0.07</td>
<td>0.5</td>
<td>NA</td>
<td>1.0</td>
<td>NA</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Zn (II)</td>
<td>0.3</td>
<td>2</td>
<td>NA</td>
<td>0.6</td>
<td>NA</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Ag (I)</td>
<td>0.05</td>
<td>NA</td>
<td>NA</td>
<td>0.6</td>
<td>NA</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: (1) Environmental Protection Agency (EPA), 2005; 2- Melin et al., 2002; 3- Terbouet et al., 2001; 4-environmental Protection Department (EPD), 2005; 5- ahn et al., 2002; 6,7 Fuziah and Agamuthu, 2005.)
2.3.4 Leachate Control

Cleaning of polluted ground water is very expensive. Hence, using the best ways for leachate treatment in order to keep the ground water safe and clean is very essential. Currently, landfill management is governed by strict rule, design, and construction instructions in order to prevent the migration of leachate into the ground water. The design of the lining system offers less permeability in the movement of leachate into ground water. The lining materials are mostly made of low-permeability soils (typical clays) or synthetic materials (e.g. plastic). Sometimes the landfill design has more than one liner.

Leachate collection systems (LCS) consist of several layers with different types of materials. Figure 2.9 shows the components of a collection system (listed from the solid waste layer downward) (Debra and Manoj, 2000).

![Figure 2.9 Schematic diagram showing a cross section of typical LCS](image-url)
2.3.5 Leachate Treatment

Leachate can be treated by three main methods: physical, chemical and biological treatments. Treatment can be a combination of two or three of the above methods. Air-stripping, adsorption are major physical leachate treatment methods (Amokrane et al., 1997; Bohdziewicz et al., 2001; Morawe et al., 1995; Trebouet et al., 2001), while the other methods such as coagulation, flocculation, chemical precipitation, chemical and electrochemical oxidation methods are the common chemical methods used for the landfill leachate treatment (Amokrane et al., 1997; Ahn et al., 2002; Chiang et al., 2001; Lin and Chang, 2000; Steensen, 1997; Marttinen et al., 2002). This combination method is most popularly used to achieve excellent leachate treatment efficiency (Figure 2.10) (Heyer and Stegmann, 2000).

---

Figure 2.10 Scheme of often used methods and combinations for leachate treatment

(Heyer and Stegmann, 2000)
The selection of the best treatment methods is controlled by several factors such as:-

- Leachate characteristics – organic and inorganic contents.
- Hazardous nature – concentration of organic, inorganic and toxic metals.
- Degree of treatment – leachate characteristics, legal requirements, and discharge alternatives.
- Treat-ability studies, available experimental data and applicable technology (Heyer and Stegmann, 2000).
- Cost - availability of funds

In this section, a review of the various treatments is mentioned in details. The leachate treatment processes have different effectiveness depending on the leachate from landfill of different ages. The biological treatment process has been found to be effective on leachate from young landfills (Loukidou and Zouboulis, 2000). Sometimes leachate can be treated by traditional package treatment plants on site, but this kind of treatment is expensive to build and operate (Liehr et al., 2000). An effective type of treatment is the biological process, especially for young leachate which has mainly volatile fatty acids, but it is not effective on old leachate because in many cases high COD value was found in leachate after biological treatment (Trehouet et al., 2001).

2.3.5.1 Biological treatment

The most common practice for leachate treatment worldwide is biological treatment. Biological systems can be divided in anaerobic and aerobic treatment processes. Both can be realized by using different plant concepts (Stegmann, 2005). A combination of aerobic, anaerobic and anoxic processes is the main processes used for biological treatment (Im et al. 2001). Biological treatment of landfill leachate usually

43
results in low treatment efficiencies because of high chemical oxygen demand (COD), high ammonium-N content and also presence of toxic compounds such as heavy metals (Fikret et al., 2003).

Most of organic materials in leachate from young landfill (< 2yrs) is easily biodegradable by aerobic biological oxidation. However, some adjustment needs to be made to the pH by adding nutrient to optimize the process. The most common aerobic biological treatment methods are (Renou et al., 2008):

- aerated lagoons
- activated sludge plants
- rotating biological contactors (RBC)
- trickling filter
- sequential batch plant
- co-treatment with sewage
- parts of the landfill body used as a reactor
- anaerobic filter

### 2.3.5.2 Physio-Chemical treatment

A combination of Physical–Chemical and biological methods is almost necessary for the efficient treatment of these heavily polluted leachate (Rautenbach and Mellis, 1994) Physiochemical treatments exist for not only removing refractory substances from the leachate, but also it is counted as a refining pre-step which is required before biological treatment of leachate. These methods are like those used to reduce COD, decrease suspended solids, colloidal, particles, floating material, heavy metals, suspended soil and color (Tonni et al., 2005) by either, flotation, coagulation/flocculation, adsorption, chemical oxidation and air stripping.
Physical/chemical treatments of landfill leachate are used in addition to the treatment line (pre-treatment or last purification) or to treat a specific pollutant (stripping for ammonia) (Renoua et al., 2008).

High COD and ammonium content, high COD/BOD ratio and the presence of toxic chemicals like heavy metals present difficulties in Physio-Chemical treatment of landfill leachate (Park et al., 2001). Sometimes a combination of physical, chemical and biological approaches is used for landfill leachate treatment, as it has been difficult to get efficiencies from the treatment using a single approach (Chiang et al., 2001; Ahn et al., 2002; Lin & Chang, 2000). Most of the methods used for landfill leachate treatment include sedimentation, air stripping, adsorption and membrane filtration (Bohdziewicz et al., 2001; Marttinen et al., 2002; Trebouet et al., 2001).

On the other hand, within the chemical treatment methods which are used for the leachate treatment there are some main methods like coagulation, flocculation, chemical or electrochemical oxidation (Ahn et al., 2002; Chiang et al., 2001). These methods have been developed and improved for landfill leachate treatment. Pressure driven membrane filtration methods have been used along with biological treatment of landfill leachate (Bohdziewicz et al. 2001). Before using biological treatment in order to improve COD removal, the Ozone pre-treatment should be used first. Also, chemical precipitation of ammonium as magnesium ammonium phosphate by adding of MgCl2 and Na2HPO4 has also improved COD removal by biological oxidation (Li and Zhao, 2001).

Another method which is the Up Flow Anaerobic Sludge Blanket (UASB) reactors had been used for landfill leachate treatment and it is efficient up to 92% COD removal (Kennedy & Lentz 2000). In addition, roughly 98% of the organic material has
been removed from landfill leachate by using the combination of anaerobic-aerobic and rotating biological contactor (RBC) systems which have been used by Park et al. (2001).

2.3.5.2.1 Coagulation and flocculation

Coagulation and flocculation process is usually used for treating fresh leachate and it is applied as a pretreatment before biological treatment. Furthermore, the use of combined coagulation and flocculation with other processes such as reverse osmosis (Ozturk et al., 2003), photo-oxidation process and biological treatment (Kargi et al., 2003; Hee-Chan et al., 2001; and Dae-Hee et al., 2002) have satisfactory results.

Coagulation and flocculation is used to remove heavy metals and non-biodegradable organic compounds from landfill leachate (Tatsi et al., 2003; Kargi et al., 2003). Also, the coagulation and flocculation process can be used for the removal of non-biodegradable organic matters from hazardous landfill leachate.

Coagulation the first step destabilizes the particle’s charges. Coagulants have an opposite charge to those of suspended solids. The coagulants are used in the leachate in order to defuse the negative charges on dispersed solids which are not settled like color-producing organic substances and clay. When the charge is neutralized, the small particles which are suspended stick together in order to increase the size of particles. Sometimes not all suspended particles are neutralized because the coagulant is not enough and needs more coagulant to be added (Ayoub et al., 2001). The next step after coagulation is flocculation which occurs in the moving particles that are not fixed into large flocs so that it can settle very fast. Coagulation further reduced suspended solids and neutralized pH. Figure 2.11 illustrates coagulation process.
Coagulant (FeCl₃ and P-Floc775), addition to 500ml of leachate

Agitation for 20 minutes

Settling for two hours

Figure 2.11 Coagulation process

Coagulation and flocculation studies are carried out in usual jar test equipment. For more than 50 years, the jar test has been the typical technique used in wastewater and drinking water industry to improve the addition of coagulant and flocculants (Galvez et al., 2005). The coagulation process contains several stages but the three main stages are as follows (Ebeling et al., 2003):-

1- Rapid Mixing step: coagulants are added to the flowing water and a high and fast intensity mixing is started. The main target is to get complete mixing of the coagulant with wastewater in order to increase the effectiveness of colloidal particles which are destabilized and then starts to coagulate (Nor Asikir and Agamuthu, 2007).
2- Slow mixing step: the suspension of wastewater is slowly moved in order to enhance the coagulation of particles and to facilitate the growth of large flocs.

3- Settling step: mixing is completed and the floc starts to settle.

The speed and duration of mixing are significant factors in both the first and second steps. For example if the mixing strength is too high, it could be a reason to split up the aggregated floc. The other important factor is the duration of settlement. To determine these significant factors, the literature on landfill leachate coagulation-flocculation was reviewed, and it revealed that the speed and duration of the fast and slow mixing steps and the period of settlement step used in jar test experiments were not exactly the same in all the studies. During the fast mixing step, the velocity varied between 100 and 200 rpm and the period between 2 to 5 minutes in most cases, although duration of 30 minutes also has been reported (Galvez et al., 2005). Through the slow mixing step, the speed varied between 20 to 60 rpm and the period between 5 to 55 minutes, while, in most studies the duration ranged between 15 to 30 minutes (Galvez et al., 2005). In the settling step, the duration of time differed from 15 to 60 minutes, whereas in most studies the period was 60 minutes. Finally, the flocs were shifted to a clarification basin. They settled at the bottom and were then removed, while the clarified effluent overflowed (Galvez et al., 2005).

2.3.5.2.2 Chemical precipitation

Chemical precipitation process is used extensively as pre-treatment to reduce high concentration of ammonium nitrogen (NH4 + N) in leachate. As well, the COD reduce of 79 to 95. Then, ammonium concentration reduced from 5600 to 110 mg L−1 in 15 minutes by the same method (Yangin et al., 2002). Altinbas et al., (2002), studied the behavior of magnesium ammonium phosphate (MAP) precipitation (precipitated
ammonium ions as magnesium ammonium phosphate) after anaerobic process pre-
treatment of domestic wastewater and landfill leachate mixture. They found the
maximum ammonia reduction was 66% at a pH of 9.3.

2.3.5.2.3 Adsorption using Activated Carbon

The adsorption of pollutants using Activated Carbon either in columns or in
powder form (Kargi et al., 2003, Kargi et al., 2004, Zamora et al., 2000) gives good
reduction in COD levels than the chemical processes. The main disadvantage is the
requirement for repeated renewal of columns or high utilization of powdered activated
carbon (PAC). The color, inert COD and the Nonbiodegradable organics may be
decreased to suitable levels for biological treatment landfill leachate.

Rodriguez et al., (2004), studied PAC and many other resins to decrease the
non-biodegradable organic matter from landfill leachate. He found that Activated
Carbon offered the highest adsorption capacity which was about 85% COD decrease
(Kargi et al., 2003a; Kargi et al., 2004). Heavey et al., (2003), used a pre-treated peat as
the treatment medium. Almost 100% elimination of both ammonia and BOD, and 69%
of COD were achieved. Finally, limestone has been confirmed successful in removing
metals from wastewaters. Aziz et al., (2004), indicated that 90% of Fe could be removed
from semi-aerobic landfill leachate by limestone filter.
2.3.5.2.4 Chemical oxidation

The chemical oxidation method is used for the treatment of effluents consisting of refractory compounds like landfill leachate. Currently, more interest has been focused on advanced oxidation processes (AOP). Nearly all of them with the exception of simple ozonation (O₃), use a combination of strong oxidants, e.g. H₂O₂, irradiation, e.g. ultrasound (US), ultraviolet (UV), or electron beam (EB), and some catalysts, e.g. transition metal ions or photocatalysts. However, recent studies have confirmed that AOP is efficient for treating old or well-stabilized leachate in order to improve the biodegradability of refractory organic pollutants (Wang et al., 2003). On the other hand, this method (AOP) has some disadvantages such as using a lot of energy which is necessary for devices such as UV lamps, ozonizers and ultrasounds (Lopez et al., 2004). Also, Renoua et al., (2008) confirmed that AOP, adapted to well-stabilized or old leachate, are applied to develop the biodegradability of recalcitrant organic pollutants and oxidize organic substances.

2.3.5.2.5 Air stripping

Recently, it has been found that the best method for removing a high concentration of NH₄+-N in wastewater treatment technologies is air stripping. The leachate usually contains high levels of ammonium and nitrogen, and both of them can be eliminated by using the air stripping method (Martiinen et al., 2002). This method is efficient at a high pH value because Marttinen et al. (2002) confirmed that about 89% ammonia was reduced at pH 11 within 24 h retention time. However, this method has a
disadvantage which is emission of NH$_3$ into the air which can cause air pollution if ammonia cannot be properly absorbed with either H$_2$SO$_4$ or HCl.

2.3.5.2.6 Membrane Filtration

Membrane filtration process is defined as a separation process using semi permeable membrane to remove the suspended particles from the leachate. The size of particles that pass through the membrane is used to classify the membrane filtration. The membrane filtration includes many types such as micro filtration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). However membrane filtration has some disadvantages, for example membrane fouling easily, while the life of membrane is very important for eliminating the suspended solid particles and colloidal materials from the leachate before filtration (Zhou and Smith, 2001).
CHAPTER THREE: MATERIALS AND METHODS

3.1 Research Site and leachate collection

The research was done using leachate from Bukit Tagar Sanitary Landfill in Selangor, Malaysia (Plate 3.1)

3.2 Materials:

3.2.1 Coagulants and precipitant

In this experiment, two types of coagulants have been used. These are ferric chloride (FeCl₃) and P-Floc775. Ferric chloride (FeCl₃) was (from HmbG chemical while P-Floc775 which was used in this experiment was from Accot chemical). The leachate samples in these experiments were digested using nitric acid from HmbG chemical.

3.2.2 Jar Test Instrument

The Jar test instrument model is CL6 and it consists of a mechanical stirring and speed controller. This instrument was used as a chemical floc tester and also was used in the coagulation study.

3.2.3 Inductively Coupled Plasma Emission Spectrometry

The Inductively Coupled Plasma Optical Emission Spectrometry model is ICP – OES. This instrument was used for analyzing heavy metals from the landfill leachate such as Cd, Pb, Zn, and Cu.

3.3 Leachate Sampling

Leachate samples were taken from the outlet of the leachate pipe from the landfill before it goes to the leachate collection pond and they were collected between
Augusts to December, 2007 (twice a month). The temperature of leachate samples at collection was 29 ºC. The leachate samples were collected in six containers (20 L each) every trip. For further experiments, the leachate samples were stored at 4 ºC in the cold room.

Plate 3.1: Shows the Bukit Tagar Sanitary Landfill in Selangor, Malaysia

Raw leachate was subjected to the analysis of (BOD$_5$, COD, pH, DO, TDS, Salinity, Conductivity, Turbidity, TS, TSS, Metals, Color, Total N, and NH$_3$-N, while
treated leachate was subjected to a characteristic test for turbidity, colour, total suspended solid (TSS) and heavy metals (Cadmium, lead, zinc and Copper).

3.4 Raw Leachate analysis

3.4.1 Chemical characteristics

3.4.1.1 pH

1. A 20 ml leachate sample was poured into a beaker.

2. pH meter (pH 100) was used to determine the pH of the sample in the beaker.

3. Constant reading on the pH meter was taken.

3.4.1.2 Total Suspended Solid (TSS)

1. A 25 ml leachate sample was poured into a bottle prepared.

2. 25 ml of distilled water was poured into the bottle prepared for a blank.

3. TSS was then determined with the use of a spectrophotometer (HACH DR/4000 UV –VIS).

4. The bottle with the leachate was placed in the spectrophotometer at 810 nm and the reading was taken.

3.4.1.3 Biochemical Oxygen Demand (BOD₅)

Reagents

A) Phosphate buffer solution: 8.5g potassium dihydrogen phosphate (KH₂PO₄), 21.75g dispotassium hydrogen phosphate (K₂HPO₄), 33.4g Disodium hydrogen phosphate heptahydrate (NA₂HPO₄.7H₂O) and 1.7g Ammonium chloride
4CL) were dissolved in about 500 of ml distilled water and diluted to 1L. The pH of this buffer was 7.2 without further adjustment.

B) Magnesium sulfate solution, 22.5g MgSO₄·7H₂O was dissolved in distilled water and diluted to 1L.

C) Calcium chloride solution, 27.5g anhydrous CaCl₂ was dissolved in distilled water and diluted to 1L.

D) Ferric chloride solution 0.25g FeCl₃·6H₂O was dissolved in distilled water and diluted to 1L.

E) Acid and Alkali solutions, 1N for neutralization of waste sample which were either caustic or acidic.

   I) Acid – 28ml concentrated sulfuric acid was added slowly to distilled water and diluted to 1L.

   II) Alkali – 40g sodium hydroxide was added to distilled water and diluted to 1L.

Procedure:-

1. For each BOD₅ bottle a volume of 350ml of leachate sample was prepared.

2. All Samples were diluted (150 – 200X) with distilled water then transferred into BOD bottles (2 sets for each dilution).

3. The BOD₅ bottles were filled up with the diluted leachate sample.

4. D₁= initial dissolved oxygen (D₁) was determined in the first set. Hanna instrument HI 9142 Dissolved oxygen meters was used to determine the dissolve oxygen content.

5. The BOD bottles were topped up with the remaining portion to avoid trapping air-bubbles in the bottles.

6. The second set bottles were closed with stopper was replaced tightly.
7. The bottles were incubated for 5 days and then the final dissolved oxygen content in the second set of bottles (D2) were taken after 5 days of incubation using Hanna instrument HI 9142 Dissolved oxygen meter.

BOD was calculated as formula below:-

\[ BOD_5 \text{ (mg/l)} = (D1-D2) P \]

Where

\( D1 \) = initial dissolved oxygen (mg/l)

\( D2 \) = final dissolved oxygen (mg/l)

\( P \) = Decimal volumetric fraction of sample used.

3.4.1.4 Ammonia - N, Nessler Method (0-2 500mg/l NH$_3$-N).

1. Leachate sample was filled in a 25 ml mixing graduated cylinder to the 25 ml mark.

2. Distilled water was filled in another 25 mL mixing graduated cylinder for a blank.

3. 3 drops of Mineral Stabilizer were added to each cylinder. The cylinder was inverted several times to mix.

4. 3 drops of polyvinyl alcohol dispersing agent was added to each cylinder by holding the dropping bottle vertically. It was inverted several times to mix.

5. 1.0 ml of Nessler Reagent was pipetted into each cylinder, and closed with a stopper. Mixing by inversion was done.

6. Soft key labelled "START TIMER" was pressed. Reaction period of 1 minute was begun.

7. Each solution was poured into a sample cell.
8. When the timer beeped, the blank was placed into cell holder and the light shield of the HACH DR/4000 Spectrophotometer was closed.

9. Zeroing was set.

10. The blank was taken out and then the sample was placed into the cell holder.

11. The reading of the sample was taken from the HACH DR/4000 Spectrophotometer and recorded.

3.4.1.5 Heavy Metals.

1. A 50 ml leachate sample was prepared in a COD flask.

2. 10 ml of concentrated HNO₃ acid was added into the same container.

3. Several glass beads were added to improve the efficiency of the digestion.

4. The heater was switched on and left for 15 minutes.

5. Next, the sample was poured into a beaker and placed on a hotplate.

6. It was heated until the solution was clear.

7. Then the sample was diluted to 100 ml and filtered.

8. Finally, the sample was analyzed for Cd, Pb, Zn, and Cu using the Inductively Coupled Plasma Optical Emission Spectrometry (ICP – OES).

3.4.1.6 Chemical Oxygen Demand (COD).

Reagents

A) Standard potassium dichromate solution, 0.250N: 12.259g K₂Cr₂O₇ was dissolved at primary standard grade and was previously dried at 103°C for 2 hours, in distilled water and diluted to 1L.

B) Sulfuric acid reagent, concentration H₂SO₄: 22g silver sulfate (Ag₂SO₄) was dissolved in 2.5L sulfuric acid per 9-1b bottle (1 to 2 doses require for dissolution).
C) Standard ferrous ammonium sulfate titrant (FAS), analytical – grade crystals, 0.1N:39g Fe (NH₄)₂(SO₄)₂.6H₂O was dissolved in distill water. 20 ml concentrated H₂SO₄ cool is added and diluted to 1L.

D) Ferroin indicator solution: 1.735g 1,10- phenanthroline dihydrate was dissolved together with 0.695g FeSO₄.7H₂O in water and diluted to 100 ml.

**Procedure:**

1. A 50 ml leachate sample at appropriate dilution was poured into COD flask.
2. One g of H₂SO₄ was added.
3. A 25ml K₂Cr₂O₇ was added to the solution.
4. A 75 ml H₂SO₄ reagent was added slowly.
5. Several glass beads were added to improve the efficiency of the digestion.
6. The heater was switched on and left for 2 hours.
7. The sample was let to cool at room temperature for 1 hour.

**Titration of reflux mixture**

1. When the sample reached room temperature, it was filled up with distilled water to 300ml.
2. Four drops of ferroin was added.
3. The sample was titrated with standardized ferrous ammonium sulfate (FAS) titrant to the first sharp colour change from blue to reddish brown.

**Standardization of ferrous ammonium sulfate (FAS)**

1. In a conical flask, 10ml of K₂Cr₂O₇ was diluted to 100ml.
2. 75ml of concentrated H₂SO₄ was slowly added and allowed to cool.
3. Four drops ferrion indicators was added and titrated by using FAS titrant.
4. The normality of the ferrous ammonium sulfate (FAS) was calculated as below:

\[
\text{Normality of ferrous ammonium sulfate (FAS) = volume of } 0.25\text{N K}_2\text{Cr}_2\text{O}_7 \text{ titrated, ml x } 0.25 / \text{volume ferrous ammonium sulfate (FAS)}.
\]

**The COD was calculated as formula below:-**

\[
\text{COD (mg/l) = (A-B) x N x 8000 / volume of sample (ml/l)}
\]

Where

\[
\begin{align*}
A &= \text{volume of ferrous sulfate (mg/l) used for blank.} \\
B &= \text{volume of ferrous sulfate (mg/l) used for sample.} \\
N &= \text{normality of ferrous ammonium sulfate (FAS).}
\end{align*}
\]

**3.4.2 Physical characteristics**

**3.4.2.1 Total Solid**

1. Clean porcelain dish was first heated to 103 °C to 105 °C for at least one hour.
2. The dish was cooled in a desiccators and then the mass of an empty porcelain dish was determined (B).
3. A 50 ml of well mixed leachate sample was measured using a graduated cylinder and transferred into the dish.
4. The sample was evaporated to dryness in an oven at 103 °C to 105 °C.
5. The dish with dried residue was cooled in the desiccators before weighing.
6. The porcelain dish was weighted again (B).
7. The Total Solid is calculated below

\[
\text{Total Solid (mg/l) = (A-B) x 100 / sample volume.}
\]

Where

\[
A = \text{weight of dried residue and dish (mg)}
\]
B= weight of empty dish.

3.4.2.2 Turbidity

1. A 25 ml of leachate sample was placed in the bottle prepared.
2. 25 ml distilled water was poured into another bottle for blank.
3. Turbidity was determined with the use of spectrophotometer.
4. Cuvette with leachate was inserted into the spectrophotometer (HACH DR/4000 UV –VIS ) and the reading was recorded.

3.4.2.3 Colour

1- A 25 ml leachate sample was poured into the spectrophotometer glass cuvette.
2- 25 ml of distilled water was used as a blank.
3- At the end, Colour American Dye Manufactures Institute (ADMI) was determined using the spectrophotometer (HACH DR/4000 UV –VIS).

3.4.2.4 Total Dissolved Solid (TDS), Salinity and Conductivity

1. A 50 ml leachate sample was poured into a beaker.
2. TDS, salinity and conductivity meter (SENS ION 7) was used to determine the TDS, salinity and conductivity of the leachate.
3. The meter reading was taken.

3.4. 3 Coagulation – flocculation studies

3.4.3.1 Coagulation and flocculation

A- Coagulation

1. A six-paddle flocculator from Stuarts scientific ( Flocculator SW1) with a capacity of 500mL each was used.
2. The leachate samples (500 mL) were coagulated with different FeCl₃ and P-Floc775 coagulant dosages, at different mixing speed, and mixing time using FeCl₃ and P-Floc775.

3. The dosage concentration of ferric chloride ranged from 0g/500mL to 12g/500ml.

4. The dosage of P-Floc775 was from 0mL/500 to 12mL/500mL.

5. These were performed to get the optimum concentration of coagulant and flocculants without any pH adjustment.

B- pH

1- After establishing the optimum concentration, pH was adjusted

2- The pH was adjusted with the optimum concentration of coagulants and it ranged from 4 to 10.

3- These were performed to get the optimum pH for removing heavy metals, turbidity, colour, and total suspended solid.

C- Mixing speed

1- After determining the optimum pH, the mixing speed was used to determine the efficiency of coagulant to remove the pollutant parameters from landfill leachate.

2- The mixing speed was used at optimum pH and optimum concentration of coagulants and it ranged between 60 rpm to 110 rpm.

3- Then the optimum mixing speed was established

4- The supernatant was taken for heavy metal analysis as discussed in section 3.2.1.5.
CHAPTER FOUR

RESULTS and DISCUSSION

4.1 Leachate Study

The main source of drinking water in Malaysia is surface water. In order to conserve this vital resource, Environment Quality (Sewage and Industrial Effluent) Regulation 1979 came into force on 1st January 1981. It includes two standards: Standard A (Appendix A) which is applied for permits located upstream of water intake point and Standard B (Appendix A) which is applied for other permits. This law is applied to the discharge of industrial effluents and leachate from municipal landfill. It is important to treat the leachate to EQA 1979 Standards. However the treatment of leachate depends on its characteristics.

The characteristics of raw leachate from the Bukit Tagar sanitary landfill (Table 4.1) show high concentration of most of the parameters. The temperature of the leachate was 29 °C. Decomposition of organic materials produced various chemicals and other substances which are clearly reflected in the organic indicators such as \( \text{BOD}_5 \) and COD of the leachate samples. The \( \text{BOD}_5 \) and COD values are 27000 mg/L and 59000 mg/L, respectively and this high readings indicate that there are organic materials in the landfill which are highly biodegradable (Miznaur et al., 1999). The ratio of \( \text{BOD}_5/\text{COD} \) of raw leachate was about 0.46 and this value shows that the organic material in the leachate is easily biodegradable and that the leachate is produced during the acid phase (Robinson, 1989). Leachate from this phase is characterized by high \( \text{BOD}_5 \) values (commonly > 10,000 mg/L), high \( \text{BOD}_5/\text{COD} \) ratios (commonly > 0.7) (Robinson, 1989), and, the values of \( \text{BOD}_5 \) and COD can be considered very high compared to the
Sewage and Industrial Effluent Regulation 1979 Standard B requirements. The allowable concentration of BOD₅ and COD in the regulation is 50 mg/L and 100 mg/L, respectively.

Table 4.1: Characteristics of raw leachate from Bukit Tagar sanitary landfill

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UNIT</th>
<th>BUKIT TAGAR LANDFILL LEACHATE</th>
<th>EQA 1974 STANDARD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Temperature °C</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>29 °C</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pH</td>
<td>6.6</td>
</tr>
<tr>
<td>BOD₅ at 20 °C</td>
<td>mg/L</td>
<td>27000</td>
<td>20</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>59000</td>
<td>50</td>
</tr>
<tr>
<td>Total Solid, TS</td>
<td>mg/L</td>
<td>1719</td>
<td>N.A.</td>
</tr>
<tr>
<td>NH₃ - N</td>
<td>mg/L</td>
<td>4300</td>
<td>50</td>
</tr>
<tr>
<td>Turbidity</td>
<td>FAU</td>
<td>3600</td>
<td>N.A.</td>
</tr>
<tr>
<td>Conductivity</td>
<td>µS/cm</td>
<td>670</td>
<td>N.A.</td>
</tr>
<tr>
<td>Salinity</td>
<td>‰</td>
<td>0.3</td>
<td>N.A.</td>
</tr>
<tr>
<td>Total Dissolved Solid, TDS</td>
<td>mg/L</td>
<td>332</td>
<td></td>
</tr>
<tr>
<td>Colour</td>
<td>ADMI value</td>
<td>15300</td>
<td></td>
</tr>
<tr>
<td>Total Suspended Solid, TSS</td>
<td>mg/L</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>mg/L</td>
<td>11.25</td>
<td>0.01</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>mg/L</td>
<td>3.6</td>
<td>0.05</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>mg/L</td>
<td>15.15</td>
<td>0.01</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>mg/L</td>
<td>17.55</td>
<td>1.0</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>mg/L</td>
<td>10.95</td>
<td>0.2</td>
</tr>
<tr>
<td>Aluminium (Al)</td>
<td>mg/L</td>
<td>15.75</td>
<td>N.A.</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>mg/L</td>
<td>397.8</td>
<td>N.A.</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>mg/L</td>
<td>764.4</td>
<td>N.A.</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>mg/L</td>
<td>84.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>mg/L</td>
<td>803.55</td>
<td>N.A.</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>mg/L</td>
<td>17.85</td>
<td>0.2</td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>mg/L</td>
<td>1.65</td>
<td>N.A.</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>mg/L</td>
<td>29.1</td>
<td>N.A.</td>
</tr>
</tbody>
</table>
The pH of the raw leachate sample was 6.6 and this indicates that the landfill is in an acid phase. Low pH is caused by the high production of volatile fatty acids and the high partial pressure of CO₂ (Robinson, 1989).

In general, the age of a landfill plays a major role in the concentration of leachate composition. A young landfill generates a leachate which has high BOD and COD, but this strength decreases rapidly after a short period of time (i.e. around one year). For example, the concentration of BOD and COD in the leachate at the age of 6 and 9 months is 10,000-20,000 mg/L and 20,000-40,000 mg/L, respectively while, the concentration of BOD and COD in the leachate at the age of one and 1½ years is 1,560-1,800 mg/L and 5370-7040 mg/L, respectively (Agamutu, 2001). Also, the pollution level of leachate decreases as the age of leachate increases (Curi et al., 1999).

Leachate contains higher concentrations of colour 15300 ADMI, total suspended solid (TSS) (13.5 mg/L), and ammonia due to the decomposition of waste mass. The higher level of NH₃-N (4300 mg/L) may be due to the decomposition of nitrogenous substances (Aziz, 2007). The high concentration of ammonia also indicates that the landfill is at an acid phase (Robinson, 1989). The leachate also shows higher concentrations of turbidity (3600 FAU) and Suspended Solids as a consequence of organic and inorganic solids present. The presence of high salt concentrations in the leachate are due to the large amount of garbage (food waste) disposed in the landfill (Agamuthu, 1999).

Leachate from the Bukit Tagar sanitary landfill (Table 4.1) contains high concentration of heavy metals such as Pb (15.15 mg/L), Al (15.75 mg/L), Zn (17.55 mg/L), Fe (84.3 mg/L), Cu (10.95 mg/L), Cd (11.25 mg/L) and As (3.6 mg/L) and all
parameters measured exceeded the regulatory standard limit of EQA 1974 (Standard A and B).

This leachate has also high concentration of Ca (397.8 mg/L), K (764.4 mg/L), Na (803.55 mg/L), Mg (29.1 mg/L), Mn (17.85 mg/L), and Se (1.65 mg/L) and all parameters measured exceeded the regulatory standard limit of EQA 1974 (Standard A and B).

Sodium is a principle alkalinity metal which tends to stay in the solution and is not subject to attenuation. The main reasons for the presence of Na in the leachate are the wide use of Na salts in industry and domestic activity (paper, soap, etc) (Robinson, 1989). K is released during refuse decomposition and the main source of K is plants and discarded food (Robinson, 1989).

The presence of heavy metals in the leachate is due to industrial waste and Household Non-Hazardous waste (Christensen et al., 2001). Heavy metals cause serious consequences to human beings and the environment, if not treated. Heavy metals can accumulate in the biological tissues of the body and cause serious diseases such as neurotoxic effects, renal failure (Pb), genetic anomalies and cancer risk (Cd, As). This indicates clearly that pretreatment of leachate is required prior to biological treatment (Parimala, 2006).

Some general observations can be made when comparing the Bukit Tagar Landfill leachate characteristics with other Malaysian landfill leachate data. For example leachate from the Bukit Tagar sanitary landfill (Table 4.1) and the Taman Beringin Landfill (Table 4.2) was found to be different. The BOD and COD in the Bukit
Tagar landfill were higher than the BOD and COD in the Taman Beringin Landfill at 560-1520mg/L, 2050-5230mg/L, respectively. This difference is due to the age of the Bukit Tagar Landfill which is younger than the Taman Beringin Landfill. However, heavy metal concentration in the Taman Beringin Landfill such as Mg, Na and K is higher than the concentration of the same heavy metals in Bukit Tagar landfill leachate while the concentration of heavy metals such as Ca, and Fe in the Bukit Tagar landfill is higher than in the Taman Beringin Landfill leachate. This can be due to the type of waste disposed in both landfills.

The same trend can be observed when comparing leachate from the Ampang landfill (Table 4.2) with the Bukit Tagar sanitary landfill. (Table 4.1) The BOD and COD found in the Ampang landfill leachate, which was 87.8 mg/L and 1071 mg/L, respectively, was lower than in BTL. This could be due to the fact that Ampang landfill has been closed. This difference may also be due to the age of the leachate as the Bukit Tagar Landfill is younger than the Ampang landfill. The total suspended solid (TSS) and total solid (TS) of Ampang landfill leachate after closure were 194.0 and 2029.0, respectively which are higher than the value of TSS and TS in the Bukit Tagar Sanitary landfill leachate (13.5, 1719 respectively). This may be due to the dilution factor influenced by the surface runoff (Fauziah and Agamuthu, 2005).

The Bukit Tagar sanitary landfill leachate has higher value for turbidity and ammonia nitrogen which was 3600 FAU, and 4300 mg/L respectively than the value of 125.5 FAU for turbidity and 690 for ammonia nitrogen in the Ampang landfill leachate. This variation may be due to the difference in the composition of waste received and the age of the landfill (Agamuthu, 2001).

66
Table 4.2: Characteristics of raw leachate from Taman Beringin Landfill and Ampang landfill compared to Environmental Quality Act (EQA) 1974 Standard A and B

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UNIT</th>
<th>Taman BERINGIN LANDFILL</th>
<th>AMPANG LANDFILL</th>
<th>EQA 1979 STANDARD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>8.07-8.50</td>
<td>7.7</td>
<td>6.0-9.0</td>
</tr>
<tr>
<td>Conductivity</td>
<td>µS/cm</td>
<td>12.6-34.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hardness as caco₃</td>
<td>mg/L</td>
<td>430-720</td>
<td>510</td>
<td>-</td>
</tr>
<tr>
<td>Alkalinity as caco₃</td>
<td>mg/L</td>
<td>4380-7580</td>
<td>2850</td>
<td>-</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>mg/L</td>
<td>63-166</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mg</td>
<td>mg/L</td>
<td>34-81</td>
<td>9.1</td>
<td>N.A.</td>
</tr>
<tr>
<td>Na</td>
<td>mg/L</td>
<td>4200-5640</td>
<td>315</td>
<td>N.A.</td>
</tr>
<tr>
<td>K</td>
<td>mg/L</td>
<td>1660-1940</td>
<td>350</td>
<td>N.A.</td>
</tr>
<tr>
<td>Fe, total</td>
<td>mg/L</td>
<td>7-9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ferrous ion</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cl</td>
<td>mg/L</td>
<td>1450-2250</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sulfate</td>
<td>mg/L</td>
<td>66-70</td>
<td>43</td>
<td>-</td>
</tr>
<tr>
<td>phosphate</td>
<td>mg/L</td>
<td>9-24</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total- N</td>
<td>mg/L</td>
<td>104-630</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Organic – N</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>mg/L</td>
<td>-</td>
<td>690</td>
<td>50</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>mg/L</td>
<td>2-23</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BOD₅ at 20 °C</td>
<td>mg/L</td>
<td>560-1520</td>
<td>87.8</td>
<td>20</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>2050-5230</td>
<td>1071</td>
<td>50</td>
</tr>
<tr>
<td>Total organic C</td>
<td>mg/L</td>
<td>1380-2070</td>
<td>2029</td>
<td>N.A.</td>
</tr>
<tr>
<td>TSS</td>
<td>mg/L</td>
<td>670-1050</td>
<td>194</td>
<td>N.A.</td>
</tr>
<tr>
<td>Turbidity</td>
<td>FAU</td>
<td>-</td>
<td>124.5</td>
<td>N.A.</td>
</tr>
<tr>
<td>Chromium</td>
<td>mg/L</td>
<td>-</td>
<td>0.115</td>
<td>0.2</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>mg/L</td>
<td>-</td>
<td>0.035</td>
<td>0.01</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>mg/L</td>
<td>-</td>
<td>0.071</td>
<td>0.2</td>
</tr>
<tr>
<td>Lead (pb)</td>
<td>mg/L</td>
<td>-</td>
<td>0.027</td>
<td>0.01</td>
</tr>
<tr>
<td>Nicle</td>
<td>mg/L</td>
<td>-</td>
<td>0.026</td>
<td>0.2</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>mg/L</td>
<td>-</td>
<td>0.095</td>
<td>1.0</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>mg/L</td>
<td>-</td>
<td>0.041</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Source: Agamuthu, 2001

Comparison between the Bukit Tagar landfill leachate (Table 4.1), and selected international landfill leachate data such as leachate from Hong-Kong and Italy (Table 4.3), demonstrates the variation in leachate composition from different landfills. This

67
value were higher than the BOD and COD in the leachate from Hong-Kong (1436mg/L, 7439mg/L, respectively) and Italy (2300mg/L, 10,540 mg/L, respectively). This variation could be due to the difference in the composition of waste received in the landfills.

The BOD/COD ratio for Bukit Tagar landfill leachate is 0.46 while the leachate from Hong-Kong is 0.19. The value decreased rapidly with the age of the landfills (Chian, et al., 1976). This is due to the release of large refractory organic molecules from the solid wastes. Accordingly, old landfill leachate is characterized by its low ratio of BOD/COD (Renoua et al., 2008). NH3-N values of the Bukit Tagar landfill leachate were 4300 mg/L. This was lower than NH3-N value of leachate from Italy which was 5210 mg/L. This difference was mainly due to the age of landfill because the old landfill leachate (Italy) has fairly higher NH3-N value (Renoua et al., 2008).

The pH of the Bukit Tagar landfill leachate was found to be slightly acidic at pH 6.6 and this may be due to the availability of readily biodegradable organics, allowing indigenous microbes to conduct biodegradation actively and produce a considerable amount of H+ ion (Tchobanoglous et al., 1993 and Forstner et al., 1988) while the pH of the landfill leachate from Hong-Kong and Italy were around 8.2, which shows that the landfill was in the methane fermentation phase (Tchobanoglous et al., 1993 and Forstner et al., 1988). Also according to Tatsi et al., (2003), fresh leachate has a lower value of pH than old leachate because the increase in pH value is due to the increase in the landfill age, and the change in pH value cause a reduction in metal solubility (Tatsi et al., 2002).
Table 4.3: Characteristics of leachate from Hong Kong – China and Italy

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UNIT</th>
<th>Hong Kong leachate</th>
<th>leachate from Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>7439</td>
<td>10,540</td>
</tr>
<tr>
<td>BOD&lt;sub&gt;5&lt;/sub&gt;</td>
<td>mg/L</td>
<td>1436</td>
<td>2300</td>
</tr>
<tr>
<td>BOD: COD (ratio)</td>
<td></td>
<td>0.19</td>
<td>0.22</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>8.22</td>
<td>8.6</td>
</tr>
<tr>
<td>Fe, total</td>
<td>mg/L</td>
<td>3.811</td>
<td>2.7</td>
</tr>
<tr>
<td>Mn</td>
<td>mg/L</td>
<td>0.182</td>
<td>0.04</td>
</tr>
<tr>
<td>Ba</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/L</td>
<td>0.12</td>
<td>-</td>
</tr>
<tr>
<td>TSS</td>
<td>mg/L</td>
<td>784</td>
<td>1666</td>
</tr>
<tr>
<td>NH&lt;sub&gt;3&lt;/sub&gt;-N</td>
<td>mg/L</td>
<td>-</td>
<td>5210</td>
</tr>
</tbody>
</table>

Source: Li, and Zhao, 2001; Lopez et al., 2004

The TSS of the Bukit Tagar landfill leachate was found to be 13.5 mg/L. This is lower than the TSS of the leachate from Hong-Kong and Italy which were found to be 784 mg/L, and 1666 mg/L, respectively. This may be due to organic and inorganic solids present in the leachate (Agamuthu, 1999).

However, the concentration of heavy metals in the Bukit Tagar landfill leachate was higher than the concentration of heavy metals in the landfill leachate from Hong-Kong and Italy. These pollutants in the leachate are usually due to industrial waste and household non-hazardous waste (Accot Technologies Sdn. Bhd, 2008). Moreover, the high concentration of heavy metals in the leachate was affected by the initial quantity of metals that was found in the domestic solid waste but heavy metals can also be leached through the degradation process inside the landfill. Young leachate has a higher value of metal solublization (Tatsi et al., 2002). This is also due to the lower pH values which
are caused by the biological production of organic fatty acids. On the other hand the
lower concentration of heavy metals in the leachate is mainly due to adsorption and
precipitation reactions by co-existing sulfide, carbonate or hydroxide anions, as a result
of the increasing age of the landfill (Lo, 1996).

4.2 Physico-Chemical treatment

In the previous section, the characteristics of the Bukit Tagar Landfill leachate
have been described. The concentration of all the heavy metals exceeded the limit set by
the Sewage and Industrial Effluents Regulation 1979 Standard A and Standard B
requirement. In this section two coagulants have been used to decrease or remove the
concentration of Cd, Pb, Zn and Cu, which are the main heavy metals. Other parameters
considered were turbidity, colour and TSS.

4.2.1 Treatment with FeCl₃

4.2.1.1 Treatment with FeCl₃ at different concentrations.

Experiments were conducted using (FeCl₃) at various concentrations. When FeCl₃
was added to the sample and stirred for a few minutes ferric hydroxide micro floc
agglomerated into longer, easily settleable flocs (Tatsi, et al., 2002). It was found that
after treatment, parameters such as turbidity, colour, TSS, Cd, Pb, Zn and Cu in the
leachate sample showed reduction with increased addition of FeCl₃. This trend
continued until optimum coagulant dosage was reached (Hamidi et al., 2007).

Figure 4.1 shows the results on the performance of FeCl₃ in removing turbidity,
colour, and TSS, at different concentrations. The optimum concentration was
2g/500mL. The reduction of turbidity was 75%, while the removal of colour and TSS
was 82% and 78%, respectively. The minimum removal of turbidity was 46% at a
dosage of 0.5g/500mL and also at 12g/500ml while the minimum reduction of leachate colour was 59% at 0.5g/500mL, and for TSS it was 33% at the same dosage.

![Graph showing removal of pollution parameters](image)

Figure 4.1 Effect of concentration of FeCl₃ on the removal of pollution parameters (turbidity, colour, and TSS) in the leachate.

Figure 4.2 shows the correlation between the effects of different concentrations of FeCl₃ on the removal of colour. The curve increased to the optimum point (2g/500mL) and then it decreased. When the curve was separated into two lines graphs (Figure 4.2a & b), regression analysis was performed to investigate the correlation of concentration of FeCl₃ on the removal of the contaminants in the leachate. It showed that they are linearly significant and $R^2$ ranged between 0.7599 to 0.9816. For example the regression coefficient for removing colour was 0.9816 toward the optimum (Figure 4.2a), and $R^2 = 0.9757$ after the optimum concentration (Figure 4.2b). The regression coefficients for the other parameters are given in Appendix E.
Figure 4.2 Effect of concentration of FeCl₃ on the leachate colour removal.

Figure 4.2a Regression analyses for removing colour from landfill leachate using FeCl₃ at various doses until the optimum.

Figure 4.2b Regression coefficient for removing colour from landfill leachate using FeCl₃ at various doses after the optimum removal.
Reduction of heavy metals (Cd, Pb, Pb, and Zn) was also observed when the sample was treated with FeCl₃ (Figure 4.3). The removal enhanced with increase in coagulant dosage until the optimum point after which the reduction rate started to reduce gradually. Two mechanisms by which high dosage coagulant can improve the coagulation rate are: by increasing the concentration of metal hydroxide precipitates and thus increasing the aggregation rate and by catching particulates into even larger aggregates by sweepfoc coagulation (Duan and Gregor, 2003). The maximum reduction of Cd, Pb, and Cu using FeCl₃ was 100% while Zn was reduced by 91% when 2g/500mL of FeCl₃ was used Cd, Pb and Cu were removed completely.

![Figure 4.3](image.png)

**Figure 4.3** Effect of concentration of Ferric chloride (FeCl₃) in the removal of heavy metals (Cd, Pb, Zn, and Cu) in the leachate.

Figure 4.4 shows Cd removal from the leachate using ferric chloride. The curve shows the removal increased to the optimum and then starts to decrease. The curve was then split into two parts as in Figure (4.4a) and Figure (4.4b). Same trends were also observed when regression analysis was performed to examine the relationship of FeCl₃ and removal of heavy metals in the leachate. There was significant correlation for removal of heavy metals (Appendix E). The regression coefficient for removing Cd was 0.893 toward the optimum (Figure 4.4a), and after the optimum R²=0.916 (Figure 4.4b).
Jayabala, (2005) established that there was significant correlation in As removal in the leachate treatment with FeCl₃ which is similar to the findings of the study.

![Figure 4.4](image1.png)

**Figure 4.4** Effect of concentration of Ferric chloride (FeCl₃) in the removal of Cd in the leachate.

![Figure 4.4a](image2.png)

**Figure 4.4a** Regression coefficients for removal of Cd from landfill leachate using FeCl₃ at various doses until the optimum removal.

![Figure 4.4b](image3.png)

**Figure 4.4b** Regression coefficients for removal of Cd from landfill leachate using FeCl₃ at various doses after the optimum removal.
Amuda and Amoo (2007) found that FeCl₃ was able to achieve 97% removal of TSS when wastewater was treated with 300mg/L. Study by Hamidi et al., (2007), found that the removal of all parameters increased with an increased dosage of FeCl₃. The removal of colour, turbidity, and suspended solids (at 200 mg/L of FeCl₃) was 66%, 57%, and 72%, respectively. Similar research was performed by Tatsi et al., (2003), who reported that the optimal removal of total suspended solids (TSS) was 80% when 1.5 g/L (without pH adjustment) of coagulant was added to stabilize leachate. However, Nor Askir and Agamuthu, 2007, stated that FeCl₃ was able to remove 85% of Pb, 88% of Cu, 90% of Al, and 92% of Zn at the optimum dosage which was 8g/L. Also, Jayabala, (2005), used FeCl₃, to reduce Cd by 83.3 % at 60 mg/L. The dosages of FeCl₃ used depend in the concentration of the pollutants in the leachate and pH.

4.2.1.2 pH effect on coagulation with FeCl₃

In order to evaluate the effect of pH on the reduction of turbidity, colour, TSS, Cd, Pb, Zn, and Cu in the leachate sample, experiments were conducted at different pH while maintaining the concentration of FeCl₃ at the optimum of 4000mg/L (Figure 4.5). The maximum removal of pollutants using FeCl₃ was at pH 7 while the minimum removal was at pH 4. At pH 7 FeCl₃ was effective in removing turbidity, colour, and TSS by 75%, 80%, and 78% respectively. These results are the same as these obtained by Nor Asikir and Agamuthu (2007), who reported that the optimum pH in reducing pollutants by PolyAluminium (PAC) was pH 7.
Figure 4.5 Effect of pH on removal of turbidity, colour, and TSS in the leachate using FeCl$_3$ at (2 g / 500 mL).

Figure 4.6 shows the effect of pH on the removal of turbidity using FeCl$_3$ at 2g/500 mL. Regression coefficient ($R^2$) for varying pH conditions was strongly linear and it ranged from 0.786 to 0.9973 (Appendix F). For example the regression coefficient for removing of turbidity before optimum pH was 0.9741 (Figure 4.6a), whereas after optimum it was 0.8526 (Figure 4.6b).
Figure 4.6 Effect of pH on removal of turbidity using FeCl₃ at 2 g / 500 mL.

Figure 4.6a Regression coefficient for pH range 4-7 for removing turbidity using FeCl₃ toward optimum pH.

Figure 4.6b Regression coefficients for pH range 7-10 for removing turbidity using FeCl₃ after optimum pH.
Reduction of heavy metals was also observed when leachate was treated with FeCl₃ at different pH. The highest reduction of heavy metal (Cd, Pb, Zn, and Cu) was at pH 7 (Figure 4.7). The reduction of Cd, Pb, Zn, and Cu with FeCl₃ at pH 7 was 100% except for Zn, it was 91%. The reduction of Cd, Pb and Cu was below the Environmental Quality (Sewage and Industrial Effluent) regulation Standard B, while Zn was still above EQA Standard B. According to Letterman et al., (1999) the optimal pH value for FeCl₃ treatment is normally at 7-9.

The finding of this study is similar to that reported by Nor Askir and Agamuthu (2007), who established that the optimum pH in reducing pollutants by FeCl₃ was 7. Ferric chloride was able to remove 97% of Pb, 90% of Cu, 82% of Al, and 80% of Fe. According to Jayabala (2005) the treatment of leachate to remove heavy metals (As and Cd) with FeCl₃ at optimum concentration (40mg/L) achieved 99.8% reduction of As and 94% of Cd at pH 6. However, Tatsi et al., (2003), found that color removal was 100% with the addition of FeCl₃ to stabilized leachate, especially when the pH was adjusted at 10. Slightly lower efficiencies (up to 93%) were measured for fresh leachate samples, while Letterman et al., (1999), stated that the optimal pH depends on the leachate characteristics.
Figure 4.7 Effect of pH on removal of heavy metals (Cd, Pb, Zn, and Cu) in the leachate using FeCl₃.

Figure 4.8 gives a good view on the effect of pH on removal of Pb in the leachate using FeCl₃. The curve increased towards the optimum and then it decreased. The correlation of pH on the removal of pollution parameters in the leachate using FeCl₃ showed there was significant correlation for all parameters (Appendix F) for example $R^2$ for Pb (Figure 4.8a) was 0.9431 before optimum pH while after optimum $R^2$ was 0.8243 (Figure 4.8b).
Figure 4.8 Effect of pH on removal of Pb in the leachate using FeCl$_3$.

![Graph](https://example.com/graph1.png)

**Figure 4.8a** Regression coefficients for pH range 4-7 for removing Pb using Ferric chloride toward optimum pH.

\[ y = 11.4x + 18.8 \]

\[ R^2 = 0.9431 \]

![Graph](https://example.com/graph2.png)

**Figure 4.8b** Regression coefficient for pH range 7-10 for removing Pb using FeCl$_3$ after optimum pH.

\[ y = -6.3x + 141.8 \]

\[ R^2 = 0.8243 \]
4.2.1.3 Effect of Various Mixing speed using Ferric chloride

Mixing speed is an important parameter in heavy metal reduction because it increased the contact between coagulating particles and helps to enhance the development of large flocs. A high mixing speed could break up the aggregated floc compared to a slow mixing speed (Galvez et al., 2005).

Figure 4.9 illustrates the effect of various mixing speeds which ranged from 60 rpm to 110 rpm using FeCl$_3$ at optimum concentration of 2g/500mL and optimum pH of 7. The optimum mixing speed required was 100 rpm, when removal of turbidity was 71%, while the optimum removal of colour and TSS was at 78% for both.

![Figure 4.9 Effect of mixing speed on the removal of turbidity, colour, and TSS in the leachate using FeCl$_3$.](image)

Similarly, Cd, Pb, Zn, and Cu concentration in the leachate sample showed reduction with change in the mixing speed using FeCl$_3$ at 2g/500mL and maintaining pH at 7 (Figure 4.10). The optimum removal of heavy metals in the leachate ranged from
89% -100%. The experiment also showed that complete removal of Cd was achieved using mixing speed of 80rpm, 90 rpm, and 100 rpm. Ferric chloride was able to reduce the concentration of Cd, Pb, and Cu within Standard B but the concentration of Zn was still above the Standard B Limit.

Nor Askir and Agamuthu (2007) established that the FeCl₃ was able to reduce about 78% of Pb, 80% of Cu, 74% of Zn, 70% of Fe and 80% of Al at mixing speed of 40-50 rpm. These results are quite similar to the findings observed in this study using FeCl₃ for the removal of heavy metals and colour.

Figures (4.11) and Figures (4.12) show the effect of mixing speed on the removal of Zn and Pb, respectively in the leachate, using ferric chloride. The regression coefficient obtained ranged from 0.7035 to 1 and it was strongly linear (Appendix G). The regression coefficient for Zn before optimum mixing speed was 0.7035 (Figure 4.11a) and after optimum mixing speed was 1 (Figure 4.11b), while for Pb was 0.9756 before optimum (Figure 4.12a) and after optimum mixing speed R² was 1.00 (Figure 4.12b).
Figure 4.11 Effect of mixing speed on the removal of Zn in the leachate using Ferric chloride.

\[ y = 0.11x + 78.8 \]
\[ R^2 = 0.7035 \]

Figure 4.11a Regression coefficient toward the optimum mixing speed (at 2g/500ml, pH 7) for removing Zn using FeCl₃.

\[ y = -0.2x + 109 \]
\[ R^2 = 1 \]

Figure 4.11b Regression coefficient after the optimum mixing speed (at 2g/500ml, pH 7) for removing Zn using FeCl₃.
Figure 4.12 Effect of mixing speed on the removal of Pb in the leachate using Ferric chloride.

\[ y = 0.59x + 26 \]
\[ R^2 = 0.9756 \]

Figure 4.12a Regression coefficient toward the optimum mixing speed (at 2g/500ml, pH 7) for removing Pb using FeCl₃.

\[ y = -1.1x + 195 \]
\[ R^2 = 1 \]

Figure 4.12b Regression coefficients after the optimum mixing speed (at 2g/500ml, pH 7) for removing Pb using FeCl₃.
4.2.2 Treatment with P-Floc775

4.2.2.1 Treatment with P-Floc775 at different concentration

P-Floc775 is a liquid cationic polyelectrolyte of medium molecular weight. It works effectively in liquid and solid coagulation process, as well as in filtration, floatation, water clarification and sludge dewatering (Accot, 2008). Maximum reduction of turbidity, colour, and TSS was observed when the leachate was treated with 2ml/500ml P-Floc775. Removal of turbidity and colour was 71% and 66%, respectively while the removal of TSS was 67% (Figure 4.13). Minimum reduction was 42% of turbidity, 45% for colour, and 22% for TSS at 0.5mL/500mL concentration.

Figure 4.13 Effect of concentration of P-Floc775 on the removal of pollution parameters (turbidity, colour, and TSS) in the leachate.

Figure 4.14 shows the correlation of the effect of concentration of P-Floc775 on leachate colour removal. The regression coefficient for removing various contaminants from landfill leachate using P-Floc 775 at different concentration ranged from 0.538 to
0.9757 (Appendix H) and it was linear. For example the \( R^2 \) for removing colour (Figure 4.14a) was 0.8961 before optimum, and after optimum it was 0.9562 (Figure 4.14b).

![Graph showing the effect of concentration of P-Floc775 on the leachate colour removal.](image)

**Figure 4.14** Effect of concentration of P-Floc775 on the leachate colour removal.

![Graph showing the regression coefficient for removing colour from landfill leachate using P-Floc775 at various doses until the optimum reduction.](image)

**Figure 4.14a** Regression coefficient for removing colour from landfill leachate using P-Floc775 at various doses until the optimum reduction.

![Graph showing the regression coefficient for removing colour from landfill leachate using P-Floc775 at various doses after the optimum reduction.](image)

**Figure 4.14b** Regression coefficient for removing colour from landfill leachate using P-Floc775 at various doses after the optimum reduction.
Heavy metal (Cd, Pb, Zn, and Cu) reduction with addition of P-Floc775 is shown in Figure 4.15. The optimum concentration of P-Floc775 to remove heavy metals was 2mL/500mL and the removal of Cd and Cu was 100% while Pb, and Zn was 89%, and 87%, respectively.

![Figure 4.15 Effect of concentration P-Floc775 on the removal of heavy metals (Cd, Pb, Zn, and Cu) in the leachate.](image)

Nor Askir and Agamuthu (2007), reported that Fenton’s regent 1:6 (w/w) was effective in removing 100% of Pb, Cu, and Zn, while Jayabala, (2005) established that PAC was able to reduce 72.6% of As at 4 mg/L, 93.3 of Fe at 1mg/L, and 60% of Cd at 1mg/L. However Hamidi, et al., (2007) demonstrated that ferric (III) sulfate [Fe$_2$(SO$_4$)$_3$] was able to reduce colour, turbidity, and suspended solids (at 200 mg/L of FeCl$_3$) by 66%, 57%, and 72%, respectively because the leachate concentration in Hamidi, et al., (2007) and Jayabala, (2005) were different. For example, the BOD for Jayabala, (2005) and Hamidi, et al., (2007) was 200 mg/L, and 377 mg/L, respectively while in this work it was 27000 mg/L.

Figure 4.16 shows the correlation for removal of Zn from the leachate using P-Floc775, at different concentrations. R$^2$ analysis to examine the effect of concentration
of P-Floc775 on the removal of heavy metals in the leachate indicated that there was significant correlation (See Appendix H) for example R² for the Zn (Figure 4.16a) was 0.931 and after optimum (Figure 4.16b) R² was 0.8894.

Figure 4.16 Effect of concentration P-Floc775 on the removal of Zn in the leachate.

Figure 4.16a Regression coefficient for removing Zn from landfill leachate using P-Floc775) at various doses until the optimum removal.

Figure 4.16b Regression coefficients for removing Zn from landfill leachate using P-Floc775 at various doses after the optimum removal.
4.2.2.2 pH effect on coagulant with P-Floc775

Figure 4.17 illustrates the effect of pH on the performance of P-Floc775 at 2mL/500mL. The optimum pH for removing pollutant parameters using P-Floc775 was 7. P-Floc775 was able to remove 71% of turbidity, 70% of colour, and 67% of TSS.

![Graph showing pH effect on removal of pollutants](image)

Figure 4.17 Effect of pH on the removal of turbidity, colour, and TSS in the leachate using P-Floc775

The correlation between the effect of pH and the removal of turbidity in the leachate, using P-Floc775 is given in Figure 4.18. Regression analysis performed to investigate the pH variation using P-Floc775 on the removal of pollutants showed that the correlation was significant and linear, and ranged from 0.7504 to 0.9741 for different pollutants (Appendix I). For example the regression coefficient for removing
turbidity before the optimum pH was 0.9818 (Figure 4.18a) and after the optimum $R^2 = 0.9901$ (Figure 4.18b) and that is after separated the curve into two parts.

Figure 4.18 Effect of pH on the removal of turbidity in the leachate using P-Floc775.

Figure 4.18a Regression coefficient for various pH for removing turbidity using P-Floc775 toward optimum pH.

Figure 4.18b Regression coefficient for various pH for removing turbidity using P-Floc775 after optimum pH.
Maximum reduction of heavy metals (Cd, Pb, Zn, and Cu) was also observed (when the sample was treated with 2ml/500ml using P-Floc775) at pH7 (Figure 4.19). Heavy metal removal was 100% for Cd and Cu, 92% of Pb, and 87% of Zn. At pH8 it was effective in removing 100% of Cd and Cu. The minimum reduction of pollutant parameters occurred at pH4 and it was 95% for Cd, 74% for Pb, 59% for Zn, and 85% for Cu.

![Graph showing pH and removal percentage](image)

Figure 4.19 Effect of pH on the removal of heavy metals (Cd, Pb, Zn, and Cu) in the leachate using P-Floc775.

Figure 4.20 illustrates the effect of pH on the removal of Cu in the leachate using P-Floc775. The removal percentage increased until it reached the optimum and after that it declined. The same trend was observed when regression analysis was performed to investigate the effect of pH on the removal of heavy metals (Cd, Pb, Zn and Cu) in the leachate using P-Floc775. $R^2$ was strongly linear and it ranged from 0.7504 to 0.9692 (Appendix I). $R^2$ for Cu before the optimum pH was 0.7504 (Figure 4.20a), and after the optimum $R^2 = 0.8526$ (Figure 4.20b).
Figure 4.20 Effect of pH on the removal of Cu in the leachate using P-Floc775

Figure 4.20a Regression coefficient for various pH for removing Cu using P-Floc775 toward optimum pH.

Figure 4.20b Regression coefficient through adjusting pH for removing Cu using P-Floc775 (2ml/500ml) after optimum pH.
Maranon et al., (2008), stated that a dosage of 0.5 g Al$^{3+}$/L using Aluminium sulfate at pH 6 gave very high reduction in turbidity (92%) and colour (77%). Similar finding was reported by Jayabala, (2005), where PAC was able to reduce 50% of Cd at pH (7-8). However, Nor Askir and Agamuthu, (2007), established that PAC was able to remove 90% Pb, 92% Cu, 88% Zn and 96% of Fe, at pH 7. This is quit similar with the findings in this study.

4.2.2.3 Effect of mixing speed using P-Floc775

Optimal mixing speed was able to reduce the concentration of turbidity, colour, TSS and heavy metals using P-Floc775 (at 2ml/500ml, pH 7) at 90 rpm (Figure 4.21), where the removal of turbidity, colour, TSS was 71%, 67% and 67%, respectively. The experiment also showed that TSS had a lower removal level of 44% at 60 rpm.

![Figure 4.21 Effect of mixing speed on the removal of turbidity, colour, and TSS in the leachate using P-Floc775, at pH 7.](image-url)
Figure 4.22 explains the effect of different mixing speeds (which ranged from 60 rpm to 110 rpm) on removal of heavy metals, using P-Floc775 at optimum concentration of 2mL/500mL and optimum pH of 7. The optimum mixing speed was 90 rpm. The maximum removal of pollutant was 100% for Cd and Cu, 90% for Pb, 88% for Zn.

Figure 4.22 Effect of mixing speed on the removal of Cd, Pb, Zn, and Cu in the leachate using P-Floc775, at pH 7.

Mixing speed plays an effective role in the performance of coagulant. Nor Asikir and Agamuthu, (2007), reported that the slow mixing leads to the agglomeration of the flocs produced while rapid mixing always ensure the total mixing of the coagulant in the solution. Alum was able to reduce about 99% of Pb, 100% of Cu, 99% of Zn, 81% of Fe and 91% of Al at mixing speed of 40-50 rpm (Nor Asikir and Agamuthu, 2007) as
compared to P-Floc775 which reduced 90% of Pb, 100% of Cu, and 88% of Zn at mixing speed of 90 rpm which is established in this study. When compared with P-Floc775, alum exhibited a more effective reduction of the pollutant parameters (Table 4.4). Amitharajah et al., (1990), reported that one possible explanation for better performance of alum is that sulfate accelerates the precipitation of aluminium hydroxide.

Table 4.4 Comparison between the performance of P-Floc775 and alum

<table>
<thead>
<tr>
<th>Parameters</th>
<th>% reduction</th>
<th>P-Floc775</th>
<th>Alum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td></td>
<td>90</td>
<td>99</td>
</tr>
<tr>
<td>Zn</td>
<td></td>
<td>88</td>
<td>99</td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Figure (4.23) and Figure (4.24) show the correlation for mixing speeds (at 2ml/500ml using P-Floc775 at pH 7) in Cd and Pb removal. The removal of pollutants increased due to the increased mixing speed until the peak and then it declined. R² ranged from 0.75 to 0.9973 (Appendix J). R² for example, before the optimum mixing speed for Cd was 0.9529 (Figure 4.23a) and after the optimum it was (Figure 4.23b) 0.9868, while R² for Pb before the optimum was 0.8847 (Figure 4.24a) and after the optimum mixing speed was 0.9119 (Figure 4.24b). The graphs show that the regression was linear.
Figure 4.23 Effect of mixing speed on the removal of Cd in the leachate using P-Floc775, at pH 7.

Figure 4.23a Regression coefficients toward the optimum mixing speed, pH7 for removing Cd using P-Floc775 at (2ml/500ml).

Figure 4.23b Regression coefficients after the optimum mixing speed, pH7 for removing Cd using P-Floc775 at (2ml/500ml).
Figure 4.24 Effect of mixing speed on the removal of Pb in the leachate using P-Floc775, at pH 7.

\[ y = 0.53x + 40 \quad R^2 = 0.8847 \]

Figure 4.24a Regression coefficients toward the optimum mixing speed, pH7 for removing Pb using P-Floc775 at (2ml/500ml).

\[ y = -0.65x + 147.33 \quad R^2 = 0.9119 \]

Figure 4.24b Regression coefficients (R^2) after the optimum mixing speed, pH7 for removing Pb using P-Floc775 at (2ml/500ml).
4.3. General Discussion:

4.3.1 Characteristics of Bukit Tagar landfill

All parameters measured in the Bukit Tagar landfill leachate were above the Environmental Quality 1994 (Sewage and Industrial Effluent) Regulation Standard A and B requirements (Figure 4.25). When Bukit Tagar landfill leachate is compared with other landfill leachate, for example Taman Beringin landfill (Agamuthu, 2001) and also other landfill from Hong – Kong (Li and Zhao, 2001) and Italy (Lopez et al., 2004), it was found that most parameters in Bukit Tagar landfill leachate were at higher concentration.

![Figure 4.25 Heavy metal concentration in Bukit Tagar landfill leachate compared to EQA Standard A and Standard B.](image-url)
At optimum concentration, pH and mixing speed the two chemicals show differential reductions in the concentration of the parameters tested. FeCl₃ was able to achieve complete removal of Cd, Pb and Cu at optimum concentration, pH and mixing speed, while P-Floc775 was able to achieve complete removal of Cd and Cu only and this removal was below the EQA standard. However the removal of Zn at optimum dosage, pH and mixing speed was 92% using Ferric chloride and 88% using P-Floc775 and Zn was still above the EQA standard (Table 4.5).

Table 4.5 Comparative removal (%) of pollutant by each chemical at optimum conditions.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Parameters</th>
<th>% removal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Turbidity</td>
</tr>
<tr>
<td>P-Floc</td>
<td>Concentration</td>
<td>71</td>
</tr>
<tr>
<td>775</td>
<td>2mL/500mL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pH 7</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>Mixing speed</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>90 rpm</td>
<td></td>
</tr>
<tr>
<td>Ferric</td>
<td>Concentration</td>
<td>75</td>
</tr>
<tr>
<td>chloride</td>
<td>2g/500mL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pH 7</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Mixing speed</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>100 rpm</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.6 gives a general summary about the optimal conditions of two chemicals. Ferric chloride gave maximum removal at 2g/500ml concentration, at pH 7 and 100 rpm mixing speed, whereas P-Floc775 was optimal at 2ml/500ml, at pH 7 and 90 rpm mixing speed.
4.3.2 Leachate Treatment:–

Studies have been done over 20 years to assess the performance of the physical and chemical treatment processes for treating both raw and biological leachates. Physical and chemical treatments were found to be useful in treating leachate from older landfills because they had a lower level of biodegradable organic carbon (Qasim and Ching, 1994).

4.3.2.1 Treatment with FeCl₃:–

Results indicate that the leachate treatment with 2g/500ml (FeCl₃) at pH 7 and mixing speed 100 rpm was able to reduce the Cd (Figure 4.26), Pb (Figure 4.27) and Cu (Figure 4.28) concentration by 100%, to 0 mg/L which is below the Environmental Quality (Sewage and Industrial Effluent) Regulation standard B requirements. Treatment with 2g/500ml (FeCl₃) at pH7 and mixing speed 100 rpm was only able to reduce Zinc (Zn) by 92%, to 1.4 mg/L, which is still above Environmental Quality (Sewage and Industrial Effluent) Regulation Standard B requirement of 1.0 mg/L (Figure 4.29).
Figure 4.26: Effect of FeCl₃ on the removal of Cd in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.

Figure 4.27: Effect of FeCl₃ on the removal of Pb in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.

Figure 4.28: Effect of FeCl₃ on the removal of Cu in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.
4.3.2.2 Treatment with P-Floc775:-

P-Floc775 at 2ml/500ml, pH7 and mixing speed 90 rpm has an ability to remove 100% (0mg/L) of both Cd (Figure 4.30) and Cu (Figure 4.31) to below the Environmental Quality (Sewage and Industrial Effluent) Regulation Standard B requirements.

Figure 4.30: Effect of P-Floc775 on the removal of Cd in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.
Figure 4.31: Effect of P-Floc775 on the removal of Cu in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.

It was also found that P-Floc775 was able to reduce 90% of Pb (Figure 4.32) and 88% of Zn (Figure 4.33) in the leachate sample but these were still above the EQA Standard B.

Figure 4.32: Effect of P-Floc775 on the removal of Pb in the leachate at optimum coagulant concentration, pH and mixing speed compared to the EQA Standards A and B.
The finding of this study using P-Floc775 and FeCl₃ for the removal of heavy metal (Cd, Pb, Zn and Cu) is quite similar to the finding observed by Jayabala (2005) who established in his study that the FeCl₃ at 40 mg/L and pH 6 was able to reduce As and Cd concentration to 0.0015 mg/L which is below the EQA Standard B limits. However, in the same study using PAC at 4 mg/L was able to reduce As concentration in the leachate to 0.409 mg/L at pH 8, which was still above the EQA Standard B requirements.
CHAPTER FIVE: CONCLUSION

5.1 Conclusion

Bukit Tagar Landfill leachate contained significantly high amount of BOD (27000 mg/L), COD (59000 mg/L) and heavy metals (Cd, Pb, Zn, and Cu) which were higher than the Environmental Quality (Sewage and Industrial Effluents) Regulation 1979 Standard B requirement.

Treatment with 2mL/500mL of P-Floc775 was found to be effective in reducing Cd and Cu to below the Standard B limit. However P-Floc775 was not able to reduce Zn and Pb to below the Standard B requirement. The optimum pH for reduction of all parameters was pH 7, whereas the optimum mixing speed was 90 rpm. The reduction in turbidity, colour and TSS ranged from 60% to 90%.

Treatment with 2g/500mL of FeCl₃ was able to reduce the concentration of all (Cd, Pb, and Cu) except of Zn to below the level of Sewage and Industrial Effluent Regulation 1979 Standard B requirements. The optimum pH was pH 7 while the optimum mixing speed was 100 rpm. Turbidity, colour, TSS were reduced by 71%, 78%, and 78%, respectively.

FeCl₃ and P-Floc775 were found to be effective as coagulant and flocculent in leachate treatment, prior to biological treatment. FeCl₃ was found to be the preferred chemical compared to P-Floc775 in treating the Bukit Tagar landfill leachate because this chemical was able to give more reduction than P-Floc775.
REFERENCES


10. Agamuthu, P., (January, 2008). Lecture is presented Between Malaysia and Japan, Faculty of Science, University of Malaya.


### APPENDIX A

Regulatory Standards for industrial wastewater as specified in the Environmental Quality (Sewage and Industrial Effluents) Regulation, 1979; EQA, 1974

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Standard A</th>
<th>Standard B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>ºC</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>6.0-9.0</td>
<td>5.5-9.0</td>
</tr>
<tr>
<td>BOD$_5$ (5 days, 20ºC)</td>
<td>Mg/l</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>COD</td>
<td>&quot;</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>&quot;</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Mercury</td>
<td>&quot;</td>
<td>0.005</td>
<td>0.05</td>
</tr>
<tr>
<td>Cadmium</td>
<td>&quot;</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Chromium, hexavalent</td>
<td>&quot;</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Arsenic</td>
<td>&quot;</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>Cyanide</td>
<td>&quot;</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>Lead</td>
<td>&quot;</td>
<td>0.01</td>
<td>0.5</td>
</tr>
<tr>
<td>Chromium, trivalent</td>
<td>&quot;</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Copper</td>
<td>&quot;</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Manganese</td>
<td>&quot;</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Nickel</td>
<td>&quot;</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Tin</td>
<td>&quot;</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>&quot;</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Boron</td>
<td>&quot;</td>
<td>1.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Iron</td>
<td>&quot;</td>
<td>1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Phenol</td>
<td>&quot;</td>
<td>0.001</td>
<td>1.0</td>
</tr>
<tr>
<td>Free chlorine</td>
<td>&quot;</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Sulphide</td>
<td>&quot;</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Oil and grease</td>
<td>&quot;</td>
<td>Undetected</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Note: Standard A: Upstream of water supply intake.
Standard B: Downstream of water supply intake.
APPENDIX B

Results of concentration dosage for treating leachate using Ferric chloride FeCl₃ and P-Floc775

Ferric chloride

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EQA A</th>
<th>EQA B</th>
<th>Untreated Leachate (initial reading)</th>
<th>Concentration (dosage) of chemical (ml) (treated leachate samples), (final reading)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Turbidity(FAU)</td>
<td>-</td>
<td>-</td>
<td>3600</td>
<td>1950</td>
</tr>
<tr>
<td>Colour (ADMI)</td>
<td>-</td>
<td>-</td>
<td>15300</td>
<td>6300</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>-</td>
<td>-</td>
<td>13.5</td>
<td>9</td>
</tr>
<tr>
<td>Cd (mg/l)</td>
<td>0.01</td>
<td>0.02</td>
<td>11.25</td>
<td>1.35</td>
</tr>
<tr>
<td>Pb (mg/l)</td>
<td>0.01</td>
<td>0.5</td>
<td>15.15</td>
<td>6</td>
</tr>
<tr>
<td>Zn (mg/l)</td>
<td>1.0</td>
<td>1.0</td>
<td>17.55</td>
<td>9.3</td>
</tr>
<tr>
<td>Cu (mg/l)</td>
<td>0.2</td>
<td>1.0</td>
<td>10.95</td>
<td>0.9</td>
</tr>
</tbody>
</table>

P-Floc775

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EQA A</th>
<th>EQA B</th>
<th>Untreated Leachate (initial reading)</th>
<th>Concentration (dosage) of chemical (ml) (treated leachate samples), (final reading)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Turbidity(FAU)</td>
<td>-</td>
<td>-</td>
<td>3600</td>
<td>2100</td>
</tr>
<tr>
<td>Colour (ADMI)</td>
<td>-</td>
<td>-</td>
<td>15300</td>
<td>8400</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>-</td>
<td>-</td>
<td>13.5</td>
<td>10.5</td>
</tr>
<tr>
<td>Cd (mg/l)</td>
<td>0.01</td>
<td>0.02</td>
<td>11.25</td>
<td>0.45</td>
</tr>
<tr>
<td>Pb (mg/l)</td>
<td>0.01</td>
<td>0.5</td>
<td>15.15</td>
<td>5.85</td>
</tr>
<tr>
<td>Zn (mg/l)</td>
<td>1.0</td>
<td>1.0</td>
<td>17.55</td>
<td>6.9</td>
</tr>
<tr>
<td>Cu (mg/l)</td>
<td>0.2</td>
<td>1.0</td>
<td>10.95</td>
<td>4.2</td>
</tr>
</tbody>
</table>
## APPENDIX C

Results of leachate treatment with various pH value at optimum concentration using Ferric chloride FeCl₃ and P-Floc775

### Ferric chloride

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EQA A</th>
<th>EQA B</th>
<th>Untreated Leachate (initial reading)</th>
<th>Concentration (dosage) of chemical (ml) (treated leachate samples), (final reading)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>pH4</td>
</tr>
<tr>
<td>Turbidity (FAU)</td>
<td>-</td>
<td>-</td>
<td>3600</td>
<td>1650</td>
</tr>
<tr>
<td>Colour (ADMI)</td>
<td>-</td>
<td>-</td>
<td>15300</td>
<td>6000</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>-</td>
<td>-</td>
<td>13.5</td>
<td>6</td>
</tr>
<tr>
<td>Cd (mg/l)</td>
<td>0.01</td>
<td>0.02</td>
<td>11.25</td>
<td>0.45</td>
</tr>
<tr>
<td>Pb (mg/l)</td>
<td>0.01</td>
<td>0.5</td>
<td>15.15</td>
<td>5.85</td>
</tr>
<tr>
<td>Zn (mg/l)</td>
<td>1.0</td>
<td>1.0</td>
<td>17.55</td>
<td>7</td>
</tr>
<tr>
<td>Cu (mg/l)</td>
<td>0.2</td>
<td>1.0</td>
<td>10.95</td>
<td>1.8</td>
</tr>
</tbody>
</table>

### P-Floc775

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EQA A</th>
<th>EQA B</th>
<th>Untreated Leachate (initial reading)</th>
<th>Concentration (dosage) of chemical (ml) (treated leachate samples), (final reading)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>pH4</td>
</tr>
<tr>
<td>Turbidity (FAU)</td>
<td>-</td>
<td>-</td>
<td>3600</td>
<td>2400</td>
</tr>
<tr>
<td>Colour (ADMI)</td>
<td>-</td>
<td>-</td>
<td>15300</td>
<td>7200</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>-</td>
<td>-</td>
<td>13.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Cd (mg/l)</td>
<td>0.01</td>
<td>0.02</td>
<td>11.25</td>
<td>0.6</td>
</tr>
<tr>
<td>Pb (mg/l)</td>
<td>0.01</td>
<td>0.5</td>
<td>15.15</td>
<td>3.9</td>
</tr>
<tr>
<td>Zn (mg/l)</td>
<td>1.0</td>
<td>1.0</td>
<td>17.55</td>
<td>7.2</td>
</tr>
<tr>
<td>Cu (mg/l)</td>
<td>0.2</td>
<td>1.0</td>
<td>10.95</td>
<td>1.65</td>
</tr>
</tbody>
</table>
APPENDIX D

Results of leachate treatment with various mixing speed at pH 7 and optimum concentration (2g/500ml using Ferric chloride (FeCl₃) and (2ml/500ml for P-Floc775).

Ferric chloride

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EQA A</th>
<th>EQA B</th>
<th>Untreated Leachate (initial reading)</th>
<th>Concentration (dosage) of chemical (ml) (treated leachate samples), (final reading)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>60 rpm</td>
</tr>
<tr>
<td>Turbidity (FAU)</td>
<td>-</td>
<td>-</td>
<td>3600</td>
<td>1650</td>
</tr>
<tr>
<td>Colour (ADMI)</td>
<td>-</td>
<td>-</td>
<td>15300</td>
<td>4950</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>-</td>
<td>-</td>
<td>13.5</td>
<td>6</td>
</tr>
<tr>
<td>Cd (mg/l)</td>
<td>0.01</td>
<td>0.02</td>
<td>11.25</td>
<td>0.45</td>
</tr>
<tr>
<td>Pb (mg/l)</td>
<td>0.01</td>
<td>0.5</td>
<td>15.15</td>
<td>5.85</td>
</tr>
<tr>
<td>Zn (mg/l)</td>
<td>1.0</td>
<td>1.0</td>
<td>17.55</td>
<td>2.85</td>
</tr>
<tr>
<td>Cu (mg/l)</td>
<td>0.2</td>
<td>1.0</td>
<td>10.95</td>
<td>2.4</td>
</tr>
</tbody>
</table>

P-Floc775

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EQA A</th>
<th>EQA B</th>
<th>Untreated Leachate (initial reading)</th>
<th>Concentration (dosage) of chemical (ml) (treated leachate samples), (final reading)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>60 rpm</td>
</tr>
<tr>
<td>Turbidity (FAU)</td>
<td>-</td>
<td>-</td>
<td>3600</td>
<td>1800</td>
</tr>
<tr>
<td>Colour (ADMI)</td>
<td>-</td>
<td>-</td>
<td>15300</td>
<td>7200</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>-</td>
<td>-</td>
<td>13.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Cd (mg/l)</td>
<td>0.01</td>
<td>0.02</td>
<td>11.25</td>
<td>0.6</td>
</tr>
<tr>
<td>Pb (mg/l)</td>
<td>0.01</td>
<td>0.5</td>
<td>15.15</td>
<td>4.05</td>
</tr>
<tr>
<td>Zn (mg/l)</td>
<td>1.0</td>
<td>1.0</td>
<td>17.55</td>
<td>8.25</td>
</tr>
<tr>
<td>Cu (mg/l)</td>
<td>0.2</td>
<td>1.0</td>
<td>10.95</td>
<td>0.6</td>
</tr>
</tbody>
</table>
APPENDIX E

The regression coefficient for different pollutants parameters removing from landfill leachate with different concentration using Ferric chloride.

<table>
<thead>
<tr>
<th></th>
<th>R² Before Optimum</th>
<th>R² after optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Turbidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>![Graph 1]</td>
<td>![Graph 2]</td>
</tr>
</tbody>
</table>

- Graph 1:
  - Equation: \( y = 34.2x + 14.2 \)
  - \( R^2 = 0.8517 \)

- Graph 2:
  - Equation: \( y = -3.2571x + 80.467 \)
  - \( R^2 = 0.9176 \)
2. Colour

\[ y = 16x + 51 \]
\[ R^2 = 0.9816 \]

3. TSS

\[ y = -1.9286x + 85.667 \]
\[ R^2 = 0.9757 \]
CONTINUE APPENDIX E

4. Cd

\[ y = 9.6x + 82.5 \]
\[ R^2 = 0.893 \]

5. Pb

\[ y = 21.6x + 49.5 \]
\[ R^2 = 0.9769 \]
CONTINUE APPENDIX E

6. Zn

\[ y = 28.2x + 34 \]
\[ R^2 = 0.9854 \]

7. Cu

\[ y = 5.2x + 89.5 \]
\[ R^2 = 0.9941 \]

\[ y = -2.4143x + 99.067 \]
\[ R^2 = 0.9214 \]

\[ y = -0.9143x + 103.07 \]
\[ R^2 = 0.9239 \]
APPENDIX F

The regression coefficient for different pollutants parameters removing from landfill leachate at different pH using Ferric chloride.

<table>
<thead>
<tr>
<th>R² Before Optimum</th>
<th>R² after optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Turbidity</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>pH Value</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

\[
y = 7.1x + 26.7 \\
R² = 0.9741
\]

<table>
<thead>
<tr>
<th>pH Value</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

\[
y = -3.6x + 98.6 \\
R² = 0.8526
\]

- Turbidity (FAU)
- Linear (Turbidity(FAU))
CONTINUE APPENDIX F

2. Colour

\[ y = 6.4x + 34.3 \]
\[ R^2 = 0.9799 \]

3. TSS

\[ y = -3.8x + 107.3 \]
\[ R^2 = 0.8805 \]
CONTINUE APPENDIX F

4. Cd

\[ y = 1.5x + 90 \]
\[ R^2 = 0.8824 \]

5. Pb

\[ y = 11.4x + 18.8 \]
\[ R^2 = 0.9431 \]

\[ y = -3x + 191.8 \]
\[ R^2 = 0.8243 \]
6. Zn

\[ y = 10.5x + 17.5 \]
\[ R^2 = 0.9973 \]

7. Cu

\[ y = 5.4x + 60.8 \]
\[ R^2 = 0.9406 \]
APPENDIX G

The regression coefficient for different pollutants parameters removing from landfill leachate at different mixing speed using Ferric chloride.

<table>
<thead>
<tr>
<th></th>
<th>R² Before Optimum</th>
<th>R² after optimum</th>
</tr>
</thead>
</table>
| 1. Turbidity | $y = 0.47x + 25.8$  
$R^2 = 0.9473$ | $y = -0.4x + 111$  
$R^2 = 1$ |
CONTINUE APPENDIX G

2. Colour

\[ y = 0.24x + 53.6 \]
\[ R^2 = 0.9796 \]

3. TSS

\[ y = -1.1x + 188 \]
\[ R^2 = 1 \]
CONTINUE APPENDIX G

4. Cd

\[ y = 0.11x + 89.8 \]
\[ R^2 = 0.7961 \]

5. Pb

\[ y = 0.59x + 26 \]
\[ R^2 = 0.9756 \]
CONTINUE APPENDIX G

6. Zn

\[ y = 0.11x + 78.8 \]
\[ R^2 = 0.7035 \]

\[
\begin{array}{|c|c|c|c|c|c|c|c|}
\hline
\text{Mixing speed (rpm)} & 0 & 20 & 40 & 60 & 80 & 100 & 120 \\
\text{Reduction (\%)} & 91 & 90 & 89 & 88 & 87 & 86 & 85 \\
\hline
\text{Zn (mg/l)} & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit \\
\text{Linear (Zn (mg/l))} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} \\
\hline
\end{array}
\]

\[ y = -0.2x + 109 \]
\[ R^2 = 1 \]

\[
\begin{array}{|c|c|c|c|c|c|c|c|}
\hline
\text{Mixing speed (rpm)} & 98 & 100 & 102 & 104 & 106 & 108 & 110 & 112 \\
\text{Reduction (\%)} & 91 & 90 & 89 & 88 & 87 & 86 & 85 & 84 \\
\hline
\text{Zn (mg/l)} & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit \\
\text{Linear (Zn (mg/l))} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} \\
\hline
\end{array}
\]

7. Cu

\[ y = 0.58x + 41.2 \]
\[ R^2 = 0.9418 \]

\[
\begin{array}{|c|c|c|c|c|c|c|c|}
\hline
\text{Mixing speed (rpm)} & 0 & 20 & 40 & 60 & 80 & 100 & 120 \\
\text{Reduction (\%)} & 120 & 100 & 80 & 60 & 40 & 20 & 0 \\
\hline
\text{Cu (mg/l)} & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit \\
\text{Linear (Cu (mg/l))} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} \\
\hline
\end{array}
\]

\[ y = -x + 200 \]
\[ R^2 = 1 \]

\[
\begin{array}{|c|c|c|c|c|c|c|c|}
\hline
\text{Mixing speed (rpm)} & 98 & 100 & 102 & 104 & 106 & 108 & 110 & 112 \\
\text{Reduction (\%)} & 120 & 100 & 80 & 60 & 40 & 20 & 0 \\
\hline
\text{Cu (mg/l)} & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit & \diamondsuit \\
\text{Linear (Cu (mg/l))} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} & \text{\quad} \\
\hline
\end{array}
\]
APPENDIX H

The regression coefficient for different pollutants parameters removing from landfill leachate with different concentration using P-Floc775.

<table>
<thead>
<tr>
<th>R² Before Optimum</th>
<th>R² after optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Turbidity</td>
<td></td>
</tr>
</tbody>
</table>

![Graph](image1.png)

**Turbidity**

- Linear (Turbidity(FAU))
  - \( y = 32.6x + 13.4 \)
  - \( R^2 = 0.8543 \)

![Graph](image2.png)

**Turbidity**

- Linear (Turbidity(FAU))
  - \( y = -1.6714x + 73.533 \)
  - \( R^2 = 0.9641 \)
2. Colour

\[ y = 13.6x + 41 \]
\[ R^2 = 0.8961 \]

3. TSS

\[ y = 33.6x + 2 \]
\[ R^2 = 0.9864 \]
CONTINUE APPENDIX H

4. Cd

\[ y = 3x + 94.5 \]
\[ R^2 = 0.8824 \]

5. Pb

\[ y = 17.8x + 54.5 \]
\[ R^2 = 0.9503 \]
CONTINUE APPENDIX H

6. Zn

\[ y = 18x + 54 \]
\[ R^2 = 0.931 \]

7. Cu

\[ y = 41.4x + 21.8 \]
\[ R^2 = 0.7804 \]
APPENDIX I

The regression coefficient for different pollutants parameters removing from landfill leachate at different pH using P-Floc775.

<table>
<thead>
<tr>
<th></th>
<th>R² Before Optimum</th>
<th>R² after optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Turbidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>![Graph1]</td>
<td>![Graph2]</td>
</tr>
</tbody>
</table>

1. Turbidity

\[ y = 12.2x - 16.1 \]
\[ R^2 = 0.9818 \]

\[ y = -10x + 141.5 \]
\[ R^2 = 0.9901 \]
CONTINUE APPENDIX I

2. Colour

![Graph for Colour](image1)

\[
y = 5.8x + 29.6
\]

\[R^2 = 0.9953\]

![Graph for Colour](image2)

\[
y = -3.3x + 92.8
\]

\[R^2 = 0.9945\]

3. TSS

![Graph for TSS](image3)

\[
y = 8.1x + 8.2
\]

\[R^2 = 0.8945\]

![Graph for TSS](image4)

\[
y = -6.9x + 114.4
\]

\[R^2 = 0.8992\]
4. Cd

\[ y = 1.5x + 89 \]
\[ R^2 = 0.8824 \]

5. Pb

\[ y = 6.3x + 47.6 \]
\[ R^2 = 0.9692 \]
CONTINUE APPENDIX I

6. Zn

\[ y = 8.8x + 22.6 \]
\[ R^2 = 0.9308 \]

\[ y = -6.8x + 134.3 \]
\[ R^2 = 0.9437 \]

7. Cu

\[ y = 4.4x + 70.3 \]
\[ R^2 = 0.7504 \]

\[ y = -2.7x + 120.2 \]
\[ R^2 = 0.8526 \]
APPENDIX J

The regression coefficient for different pollutants parameters removing from landfill leachate at different mixing speed using P-Floc775.

<table>
<thead>
<tr>
<th></th>
<th>R² Before Optimum</th>
<th>R² after optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Turbidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>y = 0.72x + 7.5</td>
<td>R² = 0.9781</td>
<td>y = -1.05x + 166.33</td>
</tr>
</tbody>
</table>

![Graph for Turbidity](image1)

![Graph for Turbidity](image2)
CONTINUE APPENDIX J

2. Colour

\[ y = 0.45x + 26 \]
\[ R^2 = 0.9854 \]

3. TSS

\[ y = -0.55x + 118.33 \]
\[ R^2 = 0.75 \]
CONTINUE APPENDIX J

### 4. Cd

- **Equation:** $y = 0.18x + 84$
- **$R^2$:** 0.9529

![Graph for Cd](image)

### 5. Pb

- **Equation:** $y = -0.25x + 122.33$
- **$R^2$:** 0.9868

![Graph for Pb](image)
CONTINUE APPENDIX J

6. Zn

\[ y = 1.2x - 15 \]
\[ R^2 = 0.8933 \]

\[ y = -0.65x + 148.33 \]
\[ R^2 = 0.8073 \]

7. Cu

\[ y = 0.15x + 86 \]
\[ R^2 = 0.8824 \]

\[ y = -0.2x + 118.67 \]
\[ R^2 = 0.75 \]