LIST OF REFERENCES


Breure, A.M., Phase separation in anaerobic digestion, National Institution of Public Health and Environmental Protection.


Kansal, A., Rajeshwari, K.V., Balakrishnan, M., Kusum lata, Kishore, V.V.N., Anaerobic digestion technologies for energy recovery from industrial wastewater-astudy in Indian Context, *TERI Information Monitor on Environmental Science*, 3 (2), 67-75


# TABLE OF CONTENTS

Abstract

Table of Contents...........................................................................................................i
List of Tables................................................................................................................iii
List of Figures...............................................................................................................iv
List of Abbreviations........................................................................................................v

1 Introduction............................................................................................................. 1
  1.1 Background ........................................................................................................ 1
  1.1.1 High strength industrial wastewater........................................................... 1
  1.1.2 Treatment of wastewater ............................................................................ 2
  1.2 Objectives .......................................................................................................... 3
  1.3 Scope of the study .............................................................................................. 4
  1.4 Significance of the study .................................................................................... 4

2 Literature Review................................................................................................... 6
  2.1 Anaerobic treatment techniques ......................................................................... 6
  2.2 Process microbiology and biochemistry ............................................................ 7
    2.2.1 Hydrolysis and fermentation ...................................................................... 8
    2.2.2 Acetogenesis ............................................................................................. 8
    2.2.3 Methanogenesis.......................................................................................... 8
  2.3 Environmental conditions .................................................................................. 9
    2.3.1 Substances contained in wastewater ........................................................ 10
    2.3.2 Temperature ............................................................................................. 10
    2.3.3 pH and alkalinity ...................................................................................... 11
    2.3.4 Nutrients ................................................................................................... 11
    2.3.5 Toxic substances ...................................................................................... 11
  2.4 Characteristics of anaerobic bacteria ............................................................... 12
  2.5 Anaerobic wastewater treatment technologies................................................. 14
    2.6 Upflow anaerobic sludge blanket reactor (UASB) .......................................... 16
      2.6.1 Specifics of UASB process ...................................................................... 16
    2.7 Reactor start-up and operation ......................................................................... 19
      2.7.1 Characteristics of seed sludge .................................................................. 19
      2.7.2 The volume of seed sludge ...................................................................... 20
      2.7.3 Upflow velocity ....................................................................................... 20
      2.7.4 Characteristics of influent wastewater ..................................................... 21

3 Materials and Methodology ................................................................................. 22
  3.1 Experimental set-up ........................................................................................... 22
    3.1.1 Storage tank ............................................................................................. 23
    3.1.2 Peristaltic pump ....................................................................................... 23
    3.1.3 Reactor column ........................................................................................ 23
    3.1.4 Influent distribution system ...................................................................... 23
    3.1.5 GSL (Gas Solid Liquid) separator ........................................................... 24
    3.1.6 Gas collection unit ................................................................................... 25
  3.2 Reactor start-up and operation ......................................................................... 25
    3.2.1 Reactor start up stage ............................................................................... 26
  3.3 Chemical analysis ............................................................................................. 31
4 Observations, Results and Discussion ................................................................. 33
  4.1 Overview .......................................................................................................... 33
  4.2 Characteristics of the seed sludge and wastewater .......................................... 33
  4.3 Reactor Start-up and Operation ................................................................... 34
    4.3.1 First trial ................................................................................................... 34
    4.3.2 Second trial .............................................................................................. 39
  4.4 Effect of HRT and upflow velocity on the removal efficiency ....................... 43
  4.5 Gas production ............................................................................................... 44
  4.6 Reactor profile ............................................................................................... 48
  4.7 Sludge granulation ........................................................................................ 51
  4.8 Limitations ...................................................................................................... 52
5 Conclusions and Recommendations .................................................................... 54
  5.1 Conclusions .................................................................................................... 54
  5.2 Recommendations ......................................................................................... 55

Annex 1

List of References
LIST OF TABLES

Table 1-1: Characteristics of some industrial wastewaters ....................................................... 2
Table 2-1: Temperature ranges of Psychrophilic, Mesophilic and Thermophilic anaerobic Digestion.......................................................................................................................... 10
Table 2-2: Toxic substances in anaerobic treatment ................................................................. 12
Table 2-3: Main characteristics of the different bacterial populations involved in mesophilic anaerobic digestion ............................................................................................................. 13
Table 2-4: Characteristics of different reactor types ............................................................... 15
Table 2-5: Advantages and Disadvantages of UASB process .................................................. 16
Table 2-6: Performance comparison of UASB process treating food industry waste .......... 17
Table 3-1: The chemical composition of the synthetic wastewater ....................................... 26
Table 3-2: Summary of the reactor operational conditions and COD removal efficiency .... 30
Table 3-3: Analytical methods used for measuring different parameters ............................... 31
Table 4-1: Characteristics of seed sludge ............................................................................... 33
Table 4-2: Characteristics of influent wastewater .................................................................. 34
Table 4-3: Variation of VSS and TSS along the reactor height on day 28th, 66th and 85th of trial T 2 ........................................................................................................................... 51
LIST OF FIGURES

Figure 1-1: COD transformation and energy comparison between aerobic and anaerobic treatment processes ................................................................. 3
Figure 2-1: Schematic diagram showing the conversion process in anaerobic digestion of complex substrates ................................................................. 7
Figure 2-2: Conversion reactions of Propionate to Methane ................................................ 9
Figure 3-1: Schematic flow diagram of the UASB reactor ............................................. 22
Figure 3-2: Details of influent distribution system .......................................................... 24
Figure 3-3: Details of GSL separator ............................................................................. 24
Figure 3-4: Gas collection unit ....................................................................................... 25
Figure 4-1: Influent and Effluent COD variation during the reactor operation period T1 .... 35
Figure 4-2: COD removal efficiencies obtained during the reactor operation period T1 ..... 36
Figure 4-3: Reactor sludge wash-out ............................................................................ 37
Figure 4-4: Variation of influent and effluent pH during the reactor operation period T1 .. 38
Figure 4-5: Operational conditions of the reactor during the reactor operation period T1 .. 38
Figure 4-6: Influent and Effluent COD variation during the reactor operation period T2 .... 40
Figure 4-7: COD removal efficiencies obtained during the reactor operation period T2 ..... 41
Figure 4-8: Variation of influent and effluent pH during the reactor operation period T2 .. 41
Figure 4-9: Operational conditions of the reactor during the reactor operation period T2 .. 42
Figure 4-10: Variation of gas production during the reactor operation period T1 .......... 44
Figure 4-11: Variation of gas production during the reactor operation period T2 .......... 45
Figure 4-12: Methane Yield and Methane Production during the reactor operation period T1 45
Figure 4-13: Methane Yield and Methane Production during the reactor operation period T2 46
Figure 4-14: (a) VSS (mg/l) variation along the reactor height (b) TSS (mg/l) variation along the reactor height ................................................................. 49
Figure 4-15: (a) COD variation along the reactor height (b) pH variation along the reactor height ....................................................................................... 50
Figure 4-16: Sludge blanket height on 66th day of trial T2 .............................................. 52
## LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAFEB</td>
<td>Anaerobic Attacked Film Expanded Bed Reactor</td>
</tr>
<tr>
<td>AFB</td>
<td>Anaerobic Fluidized Bed reactor</td>
</tr>
<tr>
<td>BOD</td>
<td>Biochemical Oxygen Demand</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical Oxygen Demand</td>
</tr>
<tr>
<td>CSTR</td>
<td>Completely Stirred Tank Reactor</td>
</tr>
<tr>
<td>HRT</td>
<td>Hydraulic Retention Time</td>
</tr>
<tr>
<td>OLR</td>
<td>Organic Loading Rate</td>
</tr>
<tr>
<td>SRT</td>
<td>Sludge Retention Time</td>
</tr>
<tr>
<td>STP</td>
<td>Standard Temperature and Pressure</td>
</tr>
<tr>
<td>TSS</td>
<td>Total Suspended Solids</td>
</tr>
<tr>
<td>UASB</td>
<td>Upflow Anaerobic Sludge Blanket reactor</td>
</tr>
<tr>
<td>VSS</td>
<td>Volatile Suspended Solids</td>
</tr>
</tbody>
</table>