# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER NO.</th>
<th>TITLE</th>
<th>PAGE NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td></td>
<td>xiv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td></td>
<td>xix</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td></td>
<td>xxv</td>
</tr>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1</td>
<td>CONTINUOUS STIRRED TANK REACTOR (CSTR)</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>CONTROL OF CSTR</td>
<td>3</td>
</tr>
<tr>
<td>1.2.1</td>
<td>Linear Control</td>
<td>4</td>
</tr>
<tr>
<td>1.2.2</td>
<td>Non-Linear Control</td>
<td>4</td>
</tr>
<tr>
<td>1.2.2.1</td>
<td>Proportional Integral Derivative (PID)</td>
<td>5</td>
</tr>
<tr>
<td>1.2.2.2</td>
<td>Adaptive control</td>
<td>5</td>
</tr>
<tr>
<td>1.3</td>
<td>CURRENT STATUS OF RESEARCH IN CSTR OPTIMIZATION</td>
<td>6</td>
</tr>
<tr>
<td>1.4</td>
<td>ORGANIZATION OF THE THESIS</td>
<td>8</td>
</tr>
<tr>
<td>1.5</td>
<td>SUMMARY</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>LITERATURE REVIEW</td>
<td>9</td>
</tr>
<tr>
<td>2.1</td>
<td>INTRODUCTION</td>
<td>9</td>
</tr>
<tr>
<td>2.2.1</td>
<td>Linear Methods</td>
<td>10</td>
</tr>
<tr>
<td>2.2.2</td>
<td>Non-Linear Methods</td>
<td>14</td>
</tr>
<tr>
<td>2.2.2.1</td>
<td>PID</td>
<td>14</td>
</tr>
<tr>
<td>2.2.2.1.1</td>
<td>Ziegler-Nichols (ZN) tuning</td>
<td>14</td>
</tr>
<tr>
<td>2.2.2.1.2</td>
<td>Open loop response</td>
<td>15</td>
</tr>
<tr>
<td>2.2.2.1.3</td>
<td>Closed loop response</td>
<td>15</td>
</tr>
</tbody>
</table>
2.2.2.2 Adaptive control 15
2.2.2.3 Genetic Algorithm (GA) 16
2.2.2.4 Artificial Bee Colony (ABC) algorithm 17
2.2.2.5 Particle Swarm Optimization (PSO) 17
2.2.2.6 Neural Network (NN) 18
2.2.2.7 Fuzzy Logic Control (FLC) 20

2.3 PROBLEM STATEMENT 23
2.4 OBJECTIVES OF THE RESEARCH 23
2.5 CONTRIBUTION OF THE RESEARCH 24
2.6 SUMMARY 26

3 MATHEMATICAL MODELING OF CSTR PLANT 27
3.1 INTRODUCTION 27
3.2 MODELING OF CSTR PLANT 28
3.3 TRANSFER FUNCTION 33
3.4 ANALYSIS OF CSTR PLANT WITHOUT CONTROLLER 33
  3.4.1 Simulation Results 33
3.5 ANALYSIS OF CSTR PLANT WITH PID CONTROLLER 37
  3.5.1 PID Controller 37
    3.5.1.1 Step-by-step procedure of PID controller design 38
    3.5.1.2 Tuning of PID controller using ZN method 39
    3.5.1.3 Simulation results 40
3.6 ANALYSIS OF CSTR PLANT WITH MODEL REFERENCE ADAPTIVE PID CONTROL 44
  3.6.1 Steps to Design Adaptive PID Controller 47
  3.6.2 ZN Tuning Method for Adaptive PID Controller 48
  3.6.3 Simulation Results 49
3.7 SUMMARY 56
4 DESIGN OF OPTIMIZED PID CONTROLLER
DESIGN USING GA AND
ABC ALGORITHMS 57

4.1 INTRODUCTION 57

4.2 ANALYSIS OF PID CONTROLLER DESIGN USING GA
AND ABC ALGORITHMS 58

4.2.1 GENETIC ALGORITHM (GA) 58

4.2.2 Artificial Bee Colony (ABC) 59

4.2.3 Step-by-Step Procedure in the Design of the
Proposed Optimized PID Controller Using GA
and ABC 59

4.2.4 Objective Function 61

4.2.5 Tuning of PID Controller Using ABC 61

4.2.6 Simulation Results 66

4.2.6.1 Controller without disturbance using GA 67

4.2.6.2 Controller with disturbance using GA 72

4.2.6.3 Controller without disturbance using ABC 75

4.2.6.4 Controller with disturbance using ABC 80

4.3 OVERALL COMPARATIVE ANALYSIS OF CSTR
PLANT USING VARIOUS CONTROLLERS 82

4.4 SUMMARY 85

5 DESIGN OF OPTIMIZED ADAPTIVE
PID CONTROLLER USING GA AND
ABC ALGORITHMS 87

5.1 INTRODUCTION 87

5.2 DESIGN OF ADAPTIVE PID CONTROLLER USING GA
AND ABC ALGORITHM 88
5.2.1 Step-by-Step Procedure for Designing the Proposed Optimized Adaptive PID Controller Using GA and ABC 88

5.2.2 Tuning of PID Controller Using GA 88

5.2.3 Tuning of PID Controller Using ABC 89

5.2.4 Simulation Results 89

5.2.4.1 Controller without disturbance using GA 89
5.2.4.2 Controller with disturbance using GA 96
5.2.4.3 Controller without disturbance using ABC 99
5.2.4.4 Controller with disturbance using ABC 103

5.3 COMPARATIVE ANALYSIS OF CSTR PLANT USING VARIOUS CONTROLLERS 106

5.4 SUMMARY 109

6 DESIGN OF OPTIMIZED DATA DRIVEN FUZZY LOGIC CONTROL (FLC) USING GA AND ABC ALGORITHMS 110

6.1 INTRODUCTION 110

6.2 ALGORITHM FOR ERROR MINIMIZATION IN DATA DRIVEN FLC 113

6.3 FORMULATION OF FUZZY ALGORITHM USING GA AND ABC 115

6.4 SIMULATION RESULTS 118

6.4.1 Controller Without Disturbance Using GA 118
6.4.2 Controller With Disturbance Using GA 123
6.4.3 Controller Without Disturbance Using ABC 125
6.4.4 Controller With Disturbance Using ABC 129

6.5 COMPARATIVE ANALYSIS OF THE OVERALL PERFORMANCES OF VARIOUS CONTROLLERS FOR CSTR PLANT 131