# CONTENTS

<table>
<thead>
<tr>
<th>ACKNOWLEDGEMENTS</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>i</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>iv</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>LIST OF FIGURES</th>
<th>x</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>LIST OF TABLES</th>
<th>xv</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>LIST OF PLATES</th>
<th>xvi</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>NOMENCLATURE</th>
<th>xvii</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>xx</th>
</tr>
</thead>
</table>

## CHAPTER 1 INTRODUCTION

1.1 Need of heat transfer enhancement 2

1.2 Heat transfer augmentation techniques 4

1.2.1 Active techniques 5

1.2.2. Passive techniques 6

1.2.3 Compound techniques 9

1.3 Performance evaluation criteria 9

1.3.1 Fixed geometry criteria 10

1.3.2 Fixed number criteria 10

1.3.3 Variable geometry criteria 10

1.4 Applications of heat transfer enhancement 11

1.4.1 Reduction of salt depositions in tubes with turbulizers 12
1.4.2 Increasing the COP of vapor compression cycles 12
1.4.3 In geothermal plants to reduce overall plant cost 13
1.4.4 Industrial applications 14
1.4.5 Major areas of applications 14
1.5 Layout of thesis 15

**CHAPTER: 2 LITERATURE REVIEW** 18

2.1 Active techniques of heat transfer augmentation 19
2.2 Passive techniques of heat transfer augmentation 21
   2.2.1 Treated surfaces 21
   2.2.2 Rough surfaces 21
   2.2.3 Extended surfaces 23
   2.2.4 Displaced enhancement devices 24
   2.2.5 Swirl flow devices 26
      2.2.5.1 Inserts 27
      2.2.5.2 Optimization 28
2.3 Heat transfer enhancement using numerical methods 29
2.4 Turbulent flow heat transfer enhancement in horizontal tubes using inserts 32
2.5 Laminar flow heat transfer enhancement in horizontal tubes using inserts 38
2.6 Ducts and channels using inserts for heat transfer enhancement 42
2.7 Double pipe heat exchangers using inserts for heat transfer enhancement 43
2.8 Shell and tube heat exchangers using inserts for heat transfer enhancement 46
2.9 Heat transfer enhancement in other types of heat exchangers 47
2.10 Heat transfer enhancement in other geometries 48
2.11 Heat transfer enhancement using nanofluids and inserts 51
2.12 Compound heat transfer enhancement 52
2.13 Scope of the present work 54

CHAPTER: 3 OBJECTIVES AND METHODOLOGY 57
3.1 Objectives 57
3.2 Methodology 59
   3.2.1 Numerical and experimental Investigations in plain tube 59
   3.2.2 Numerical and experimental investigations in plain tube with inserts 60

CHAPTER: 4 NUMERICAL AND EXPERIMENTAL INVESTIGATIONS ON HEAT TRANSFER AND FRICTION FACTOR CHARACTERISTICS OF PLAIN TUBE 64
4.1 Methods of determining solutions to flow problems 64
4.2 Significance of numerical methods 66
4.3 Computational Fluid Dynamics 67
   4.3.1 Modeling setup and governing equations 68
   4.3.2 CFD code 69
      4.3.2.1 Pre-processor 69
      4.3.2.2 Solver 69
4.3.2.3 Post-processor 70

4.4. Software used in the present work 70

4.4.1 GAMBIT 71

4.4.2 FLUENT 71

4.5 CFD analysis for plain tube in the present work 73

4.5.1 FLUENT Setup 73

4.5.2. Defining the Models 74

4.5.3 Defining the Material Properties 74

4.5.4 Defining the Boundary Conditions 75

4.5.5 Selection of Solver in Fluent 75

4.5.6 Executing the FLUENT Code 76

4.6 Numerical Results and Discussion 76

4.7 Description of Experimental Setup 79

4.7.1 Test section 81

4.7.2 Heating system 81

4.7.3. Temperature measurement 81

4.8 Experimental Procedure 85

4.9 Heat Transfer Calculations 87

4.9.1 Estimation of experimental heat transfer coefficient 88

4.9.2 Estimation of experimental friction factor 89

4.9.3 Nusselt number correlations for plain tube 89

4.9.4 Friction factor correlations for plain tube 89
4.10 Results and Discussion

**CHAPTER 5: NUMERICAL AND EXPERIMENTAL INVESTIGATIONS ON HEAT TRANSFER ENHANCEMENT IN PLAIN TUBE FITTED WITH LONGITUDINAL STRIP INSERTS**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Description of strip inserts</td>
<td>95</td>
</tr>
<tr>
<td>5.2 Modeling and numerical analysis of horizontal tube with strip inserts</td>
<td>96</td>
</tr>
<tr>
<td>5.2.1 Three Dimensional Geometrical Modeling</td>
<td>97</td>
</tr>
<tr>
<td>5.2.2 Numerical analysis for flow inside tubes with tube inserts</td>
<td>98</td>
</tr>
<tr>
<td>5.3 Numerical Results and Discussion</td>
<td>99</td>
</tr>
<tr>
<td>5.4 Description of strip inserts and Experimental procedure</td>
<td>102</td>
</tr>
<tr>
<td>5.5 Heat transfer calculations with inserts</td>
<td>106</td>
</tr>
<tr>
<td>5.6 Results and Discussion</td>
<td>107</td>
</tr>
</tbody>
</table>

**CHAPTER 6: NUMERICAL AND EXPERIMENTAL INVESTIGATIONS ON HEAT TRANSFER ENHANCEMENT IN PLAIN TUBE FITTED WITH MESH INSERTS**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Importance and description of mesh inserts</td>
<td>115</td>
</tr>
<tr>
<td>6.2 Numerical analysis of tube with mesh inserts</td>
<td>116</td>
</tr>
<tr>
<td>6.2.1 Modeling</td>
<td>118</td>
</tr>
<tr>
<td>6.2.2 Numerical analysis</td>
<td>119</td>
</tr>
<tr>
<td>6.2.3 Heat transfer measurements</td>
<td>119</td>
</tr>
<tr>
<td>6.3 Numerical Results and Discussion</td>
<td>120</td>
</tr>
<tr>
<td>6.4 Description of mesh inserts and Experimental procedure</td>
<td>128</td>
</tr>
<tr>
<td>6.5 Heat transfer calculations</td>
<td>132</td>
</tr>
</tbody>
</table>
6.5.1 Estimation of Porosity of mesh inserts 134

6.6 Results and Discussion 134

CHAPTER 7 EXPERIMENTAL INVESTIGATIONS ON HEAT TRANSFER ENHANCEMENT IN PLAIN TUBE FITTED WITH LOUVERED STRIP INSERTS 142

7.1 Description of louvered strip inserts and Experimental procedure 143
7.2 Heat transfer calculations 151
7.3 Results and Discussion 152

CHAPTER 8 OVERALL RESULTS AND DISCUSSIONS 160

CHAPTER 9 CONCLUSIONS 167
SCOPE FOR FUTURE WORK 175

REFERENCES 176

LIST OF PUBLICATIONS 200