INTEGRATION OF REFINERY FLARE GAS SYSTEM WITH FUEL GAS NETWORK FOR POWER GENERATION

Jayasinghe Arachchige Amila Indika

(128362R)

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Engineering

Department of Mechanical Engineering

University of Moratuwa
Sri Lanka

February 2017
DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or institute of higher learning to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: .......................... Date: ..........................
J. A. A. Indika
Registration Number: 128362R

The above candidate has carried out research for the Master's Thesis under my supervision

Signature: .......................... Date: ..........................
Dr. R. A. C. P. Ranasinghe
Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa
**ABSTRACT**

The high price of crude oil, strict environmental regulations and increasing demand for energy have made refineries adopt a more holistic approach to integrating energy, economics and environment in their design and operation. In this situation gas flaring can be considered as a major course for wasting energy in oil and gas refineries. It can be modified and use it for power generation and in-house heat generation. In this study a novel methodology is introduced to utilize the flare gas generated in a refinery through utilizing the pressure energy generated within the process. The proposed methodology uses pressure stages to regulate the pressures in predefined values and use either natural gas or LPG to makeup the gas requirement other than the gases from the process and flare system. Especial attention was given to regulate the existing FGN operation and to recover steady flow out for power generation. According to the cases analyzed with different input parameters, there was no observed variations in the vessel pressures and desired gas output flows. The gas flow from the plant values was set to vary up to 1574 g/s and the flare gas flow is varied up to 422 g/s. The profitability of using the flare gas recovered has been analyzed in 6 cases. Accordingly the total profit gain depends on the excess gases generated within the refinery, total gasses used in the process furnaces, total electricity demand and the makeup gas price. Considering LPG as a makeup gas and with the low LPG prices, there is maximum profit gain of 7,141,943 LKR in the situation where the power is generated using flare gas in the peak hours only.

**Key words**: Flare gas system, Fuel gas system, power generation, LPG, Natural gas
ACKNOWLEDGEMENT

I am very much grateful to Dr. H. K. G. Punchihewa, Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa, Dr. R. A. C. P. Ranasinghe Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa and Eng. K. G. H. Kodagoda, Manager (Operations), Ceylon Petroleum Corporation, Oil Refinery for giving me their utmost support and guidance on this research.

I wish to thank Dr. Udaya Chinthaka Jayatilake, Senior Lecturer, Department of Mathematics, University of Moratuwa, for helping me formulating the equations and modeling them. Further I wish to thank Eng. N. D. Premadasa, Engineer, Sri Lanka Sustainable Energy Authority, Eng E.N.P De Silva, Engineer, Ceylon Electricity board, Mr. S.D.L. Sandanayake, Lab Attendant, Department of Mechanical Engineering, University of Moratuwa, for their support and being the resource people for the research. This research was carried out under the supervision of Dr. R. A. C. P. Ranasinghe, Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa. I am grateful to them for their valuable guidance, kind hearted cooperation and encouragement extended to me throughout the study. Finally, I would appreciate everybody, who helped me in numerous ways at different stages of the research, which was of utmost importance in bringing out this effort a success.
TABLE OF CONTENTS

DECLARATION .................................................................................................................. i
ABSTRACT ......................................................................................................................... ii
ACKNOWLEDGEMENT ...................................................................................................... iii
TABLE OF CONTENTS ........................................................................................................ iv
LIST OF FIGURES .............................................................................................................. ix
LIST OF TABLES ................................................................................................................ xi
LIST OF ABBREVIATIONS .............................................................................................. xii
CHAPTER 1 : INTRODUCTION ......................................................................................... 1
   1.1. Background ............................................................................................................. 1
   1.2. Present status ........................................................................................................ 2
   1.3. Problem statement ............................................................................................... 2
   1.4. Aim and Objectives ............................................................................................. 5
CHAPTER 2 : LITERATURE REVIEW ............................................................................... 6
   2.1. Introduction ........................................................................................................... 6
   2.2. Advantages of flare gas recovery ......................................................................... 10
      2.1. Environmental impacts of gas flaring .............................................................. 10
      2.2. Economic impacts .......................................................................................... 11
      2.3. Health and safety ............................................................................................ 11
      2.4. Commercially available flare gas recovery options ....................................... 12
      2.5. GTL technology .............................................................................................. 12
      2.1. Compression method ...................................................................................... 14
      2.2. Electricity production from purge gases via gas turbines .............................. 14
      2.3. Gas turbines to generate power using excess fuel gases ............................... 15
         2.3.1. Combined cycle systems ....................................................................... 16
         2.3.2. Turbine Power Output ............................................................................ 16
         2.3.1. Simple cycle turbines system efficiency .............................................. 16
         2.3.2. Combined cycle turbines ....................................................................... 17
         2.3.3. Fuels used for gas turbine applications ............................................... 17
         2.3.4. Applications ......................................................................................... 17
      2.4. Waste heat recovery ......................................................................................... 18
2.5. Waste heat recovery boilers .................................................. 18
2.6. Heat recovery steam generator .............................................. 19
2.7. Types of HRSG .............................................................. 20
   2.7.1. Fired and Unfired .................................................. 20
   2.7.2. Single and multiple pressure operation .......................... 20
   2.7.3. Horizontal and vertical ........................................... 20

CHAPTER 3 : METHODOLOGY .......................................................... 21
3.1. Introduction ................................................................. 21
3.2. Typical fuel gas and flare gas networks ............................... 21
3.3. Model objective ............................................................ 23
   3.3.1. Data on model formulation ..................................... 23
   3.3.2. Assumptions .......................................................... 23
3.4. Model development ........................................................ 24
   3.4.1. Flow numbering ...................................................... 24
   3.4.2. Vessel numbers ...................................................... 25
   3.4.3. Pressure notations .................................................. 25
   3.4.4. Mass flow notations ................................................. 26
   3.4.5. Mass changes in vessels ......................................... 26
   3.4.6. Control valves ........................................................ 26
   3.4.7. Gas flow in a pipe line ............................................. 27
   3.4.8. Van der Waals equation .......................................... 28
3.5. Developing the model ....................................................... 29
   3.5.1. Considering the F vessel .......................................... 29
   3.5.2. Considering the gas vessel i .................................... 29
   3.5.3. Considering the FG vessel ........................................ 30
   3.5.4. Considering the Buff vessel ...................................... 30
   3.5.5. Flow i1 ............................................................... 30
   3.5.6. Flow 2 ................................................................. 31
   3.5.7. Flow 3 ................................................................. 31
   3.5.8. Flow i2 ............................................................... 31
   3.5.9. Flow LPG_F .......................................................... 32
   3.5.10. Flow LPG_FG ....................................................... 32
4.5.3. The two main flows to be maintained ..................................59
4.6. Flow 1 and flow i3 as coinciding sin waves..........................60
  4.6.1. Process parameter variation.............................................61
  4.6.2. Excess flows from vessels..............................................62
  4.6.3. The two main flows to be maintained ...............................63
4.7. Flow 1 in a sin wave and flow i3 in a cosine wave coinciding ...63
  4.7.1. Process parameter variation.............................................64
  4.7.2. Excess flows from vessels..............................................66
  4.7.3. The two main flows to be maintained ...............................67
4.8. Flow 1 in a cosine wave and flow i3 as a sin wave coinciding ...68
  4.8.1. Process parameter variation.............................................69
  4.8.2. Excess flows from vessels..............................................70
  4.8.3. The two main flows to be maintained ...............................70
4.9. Discussion...........................................................................71

CHAPTER 5 : CASE STUDY ..................................................................73
  5.1. Background.........................................................................73
  5.2. Flare gas recovery...............................................................74
  5.3. Data collection.....................................................................75
  5.4. Current situation .................................................................75
    5.4.1. Gas from fuel gas network to flare.................................76
    5.4.2. Gases goes directly to flare system.................................76
    5.4.3. Total gas to flare ............................................................77
    5.4.4. Current LPG make up flow.............................................78
    5.4.5. Total Fuel gas to Units ...................................................78
  5.5. Case 1 ..................................................................................79
    5.5.1. Flow description..............................................................79
    5.5.2. Total Gases generated in 18 bar.....................................81
    5.5.3. Gases having pressure below 18 bar ...............................82
  5.6. Case 2 ..................................................................................83
    5.6.1. Flow description..............................................................83
    5.6.2. Total Gases in 12 bar.......................................................86
    5.6.3. Gases in pressures below 18 bar and 12 bar .................86
LIST OF FIGURES

Figure 1-1: Flare stacks .................................................................1
Figure 1-2: Flare gas generated ..................................................3
Figure 1-3: Total Fuel Gas from the process ..................................4
Figure 1-4: Total Fuel Gas to process heaters ..............................4
Figure 2-1: Global gas flaring and oil production 1996-2015 ..........7
Figure 2-2: The top 30 gas flaring countries ...............................7
Figure 2-3: Top 30 countries by flaring intensity .........................8
Figure 2-4: Flaring intensity .........................................................8
Figure 2-5: A simple flare gas recovery system ............................10
Figure 2-6: GTL Process ..............................................................13
Figure 2-7: GTL Simple process flow diagram ............................13
Figure 2-8: Gas turbine 1 ............................................................15
Figure 2-9: Electricity cogeneration ............................................16
Figure 2-10: Heat recovery steam generator ...............................19
Figure 3-1: Typical fuel gas network .........................................22
Figure 3-2: Typical flare gas network .........................................22
Figure 3-3: Model schematic ......................................................24
Figure 4-1: Vessel input parameter variation – Analysis 1 ............44
Figure 4-2: Vessel pressures and mass accumulation variation – Analysis 1 ....45
Figure 4-3: Excess flow generation - Analysis 1 .........................46
Figure 4-4: The regulated flows - Analysis 1 ...............................47
Figure 4-5: Vessel input parameter variation – Analysis 2 ............48
Figure 4-6: Vessel pressures and mass accumulation variation – Analysis 2 ....49
Figure 4-7: Excess flow generation – Analysis 2 .........................50
Figure 4-8: The regulated flows - Analysis 2 ...............................51
Figure 4-9: Vessel input parameter variation – Analysis 3 ............52
Figure 4-10: Vessel pressures and mass accumulation variation – Analysis 3 ....53
Figure 4-11: Excess flow generation – Analysis 3 .......................54
Figure 4-12: The regulated flows – Analysis 3 .............................55
Figure 4-13: Vessel input parameter variation – Analysis 4 ..........56
Figure 4-14: Vessel pressures and mass accumulation variation – Analysis 4
Figure 4-15: Excess flow generation – Analysis 4
Figure 4-16: The regulated flows – Analysis 4
Figure 4-17: Vessel input parameter variation – Analysis 5
Figure 4-18: Vessel pressures and mass accumulation variation – Analysis 5
Figure 4-19: Excess flow generation – Analysis 5
Figure 4-20: The regulated flows – Analysis 5
Figure 4-21: Vessel input parameter variation – Analysis 6
Figure 4-22: Vessel pressures and mass accumulation variation – Analysis 6
Figure 4-23: Excess flow generation – Analysis 6
Figure 4-24: The regulated flows – Analysis 6
Figure 4-25: Vessel input parameter variation – Analysis 7
Figure 4-26: Vessel pressures and mass accumulation variation – Analysis 7
Figure 4-27: Excess flow generation – Analysis 7
Figure 4-28: The regulated flows – Analysis 7
Figure 5-1: Fuel gas to flare
Figure 5-2: Gases goes directly to flare system
Figure 5-3: Total gas to flare
Figure 5-4: Current LPG make up flow
Figure 5-5: Total Fuel gas to Units
Figure 5-6: Case 1 with only 18 bar vessel
Figure 5-7: Total Gases in 18 bar
Figure 5-8: Gases having pressure below 18 bar
Figure 5-9: Case 2
Figure 5-10: Total Gases in 12 bar
Figure 5-11: Rest gases except gases having 18 bar and 12 bar
Figure 5-12: Total Gases in 7 bar
Figure 5-13: Total Gases in above 3 bar and below 7 bar
Figure 5-14: Case 3
Figure 5-15: Total LPG or makeup gas requirement
LIST OF TABLES

Table 4-1 : Pipe diameters .................................................................42
Table 6-1 : Purchased electricity cost.....................................................93
Table 6-2 : Generating power using the flare gas recovery system .............95
Table 6-3 : Generating only the peak and day loads using flare gas recovery ...96
Table 6-4 : Generating only the peak and day loads ..................................98
Table 6-5 : Generating electricity only for the peak loads .........................100
Table A-1 : Average flare gas composition .............................................107
Table A-2 : Element wise weight fraction .............................................107
### LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GGFR</td>
<td>Global Gas Flaring Reduction (GGFR)</td>
</tr>
<tr>
<td>FGN</td>
<td>Fuel gas network</td>
</tr>
<tr>
<td>CEB</td>
<td>Ceylon electricity board</td>
</tr>
<tr>
<td>HRSG</td>
<td>Heat recovery steam generation</td>
</tr>
<tr>
<td>GTL</td>
<td>Gas to liquid technology</td>
</tr>
</tbody>
</table>