The Advancement of Downdraft Gasification

A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy at Massey University

Massey University
New Zealand

Richard Malcolm Sime
1998
Abstract

Integrated gasification combined cycle systems (IGCC) are currently the most efficient (up to 40 % HHV) thermal method for the conversion of woody biomass to electricity. The production cost of electricity from IGCC is high, U.S. 6.6-8.2 ¢/kW.h (Graig and Mann, 1997). The capital costs alone are U.S. 3.2-4.5 ¢/kW.h. In New Zealand the wholesale price of electricity is typically less than U.S. 2.5 ¢/kW.h.

The bottom line with current IGCC systems is that the capital cost must be greatly reduced if the technology is to be adopted for mainstream use. Methods to reduce the costs of all IGCC components should be investigated.

The use of High Temperature & Pressure (HTP) downdraft technology as an alternative to the current fluidised bed technology could reduce the capital cost of the gasifier component of IGCC by 90%.

The characteristics of the HTP downdraft are different from those of the traditional downdraft. A significant feature is that much larger throughputs are possible at gas turbine combustion pressures. The investigation of HTP downdraft technology is the focus of this thesis.
Acknowledgments

I wish to particularly acknowledge Dr Geoffrey Barnes. As a supervisor, Dr Barnes is enthusiastic and supportive.

I also thank the following:

Dinesh Chand, Electricity Corporation of New Zealand.
Roger Fairclough, East Harbour Management Systems.
Steve Goldthorpe, Woodward-Clyde.
Dr. Josephine Serrallach, Commercial Manager, Massey University.
Dr Francis Thio, Albany Campus, Massey University.
Dr. Tony Clemens, CRL
Colin Wheeler, Two Wheels Engineering
Prof. Murray Hill, former DRC member, Massey University.
Research Services Massey University.
Stevenson's Structural Engineering, Tokomaru.
The former Department of Agricultural Engineering.
Institute of Fundamental Sciences, Massey University.
# Table of Contents

ABSTRACT .............................................................................................................................. II

ACKNOWLEDGMENTS ............................................................................................................. III

1.1 GENERAL INTRODUCTION TO THE ENERGY SECTOR .................................................. 3
  1.1.1 Fossil carbon reserves ............................................................................................ 4
  1.1.2 Nuclear power ......................................................................................................... 5

1.2 BIOMASS AS A RENEWABLE CARBON RESOURCE ..................................................... 6
  1.2.1 Justification for the use of renewable biomass carbon ............................................ 6
  1.2.2 Current economic uses of bio-energy in New Zealand .......................................... 7

1.3 AIR GASIFICATION OF WOODY BIOMASS ................................................................ 8
  1.3.1 Comparison of gasification technologies ............................................................... 8
  1.3.2 IGCC configurations ............................................................................................. 10
  1.3.3 The importance of developing high pressure gasification technologies ................. 14
  1.3.4 Previous work with pressurised downdraft gasification ...................................... 14
  1.3.5 Pressurised fluidised bed gasification for power production, research activities ........................................ 15
  1.3.6 Integrated gasification advanced cycle .................................................................. 17

1.4 PRESSURISED FLUIDISED BED COMBUSTION SYSTEMS ....................................... 18

1.5 CHEMICAL PROCESSES IN A DOWNDRAFT GASIFIER ......................................... 20

1.6 MECHANISM OF OPERATION ..................................................................................... 22

1.7 CHARACTERISING A DOWNDRAFT GASIFIER ........................................................... 23

1.8 HOT GAS CLEANING OF BIOMASS SYNTHESIS GAS ...................................... 25

1.9 REDUCED TAR CONTENT AT HIGHER PRESSURES ................................................. 27

2.0 INITIAL MODEL USED FOR THE THEORETICAL DEVELOPMENT ................................ 29

  2.1 INTRODUCTION .......................................................................................................... 29
  2.2 MATHEMATICAL DESCRIPTION OF THE MODEL .................................................... 30
  2.3 CONCLUSION ............................................................................................................. 39

3.0 ATMOSPHERIC PRESSURE EXPLORATORY EXPERIMENTS ......................................... 40

  3.1 INTRODUCTION .......................................................................................................... 40
  3.2 METHOD ....................................................................................................................... 40
  3.3 RESULTS AND DISCUSSION ...................................................................................... 44
    3.3.1 Pre-steady state results ......................................................................................... 44
    3.3.2 Variation of the frictional function ...................................................................... 47
    3.3.3 Changes in the bed particle distribution ............................................................... 49
  3.4 CONCLUSION ............................................................................................................. 50

4.0 OBTAINING GOOD GASIFIER OPERATION ...................................................................... 51

  4.1 INTRODUCTION .......................................................................................................... 51
  4.2 METHOD ....................................................................................................................... 51
    4.2.1 Widening of the gasifier ....................................................................................... 51
    4.2.2 Filtering noise ...................................................................................................... 52