INTEGRATED GASIFICATION CYCLES FOR POWER GENERATION USING COMBINED MAGHARA COAL-RICE STRAW FEEDSTOCK

By

Amir Hegazy Mohamed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Chemical Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Integrated Gasification Cycles for Power Generation using Combined Maghara Coal-Rice Straw Feedstock

Key Words:
Gasification; IGCC; Entrained Flow Gasifier; Power Generation; Pre-combustion Carbon Capturing

Summary:

This study focuses on the production of syngas by co-gasification of Maghara coal and biomass (wood and rice straw) using commercial entrained flow gasifier technology. A parametric study on the gasifier was conducted using Aspen Plus. The aim of this work is to study the effect of changing the inputs to the gasifier on the produced gas in order to select the optimum operating conditions of the gasifier. Two scenarios where suggested for the power generation, namely, carbon capturing and non-carbon capturing scenarios. The results enabled the estimation of the optimum blend of Maghara coal, rice straw or wood, and gasification water satisfying the imposed constraints. Additionally, power generated was calculated for the suggested scenarios to determine which scenario is both technically and economically feasible.

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Amir Hegazy

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Nomenclature

AGR	Acid Gas Removal
ASU	Air Separation Unit
BGL	British Gas Lurgi
BTU	British Thermal Unit
CC	Carbon Capturing
CCS	Carbon Capturing and Storage
CCT	Clean Coal Technology
CSC	Convective Syngas Cooling
DEA	Diethanolamine
DGA	Diglycolamine
DIPA	Diisopropanolamine
EOS	Equation of State
FBR	Fluidized Bed Reactor
FC	Fixed Carbon
GE	General Electric
GT	Gas Turbine
HHV	Higher Heating Value
HRSG	Heat Recovery Steam Generator
HTS	High Temperature Shift
HTW	High Temperature Winkler
IGCC	Integrated Gasification Combined Cycle
LHV	Lower Heating Value
LTS	Low Temperature Shift
MC	Maghara Coal
MDEA	Methyldiethanolamine
MEA	Monoethanolamine
MW	Mega Watt
NC	Non-Conventional
NGCC	Natural Gas Combined Cycle
RSC	Radiant Syngas Cooling
SG	Syngas
ST	Steam Turbine
VM	Volatile Matters
WGS	Water Gas Shift
WHSG	Waste Heat Steam Generation

Abstract

This study focuses on the production of syngas by co-gasification of Maghara coal and biomass using commercial entrained flow gasifier technology. The biomass in the study includes rice straw and wood. A parametric study on the gasifier was conducted using Aspen Plus. The aim of this work is to study the effect of changing the inputs to the gasifier on the produced gas in order to select the optimum operating conditions of the gasifier. Three different scenarios concerning the water concentration in the feed blend were suggested and analyzed for the gasifier. The studied input parameters influencing the performance of the gasifier include the percentage of coal to biomass in the blend, the fraction of added water to the blend, and the mass percent of oxygen with respect to the mass of the blend fed to the gasifier.

The study on the co-gasification of coal and wood is based on the optimum conditions selected. This enables the comparison of the results from both rice straw and wood. The compared parameters are: temperature of the produced gas, the produced gas composition, and the heating value of the gas.

Two alternative power production schemes have been investigated. The first scheme features power generation without carbon capturing, while the second scheme involves an intermediate carbon capture subsystem including gas shift reaction and acid gas removal.

The results enabled the estimation of the optimum blend of Maghara coal, rice straw or wood, and gasification water satisfying the constraints on maximum allowable gasification temperature and maximization of rice straw usage while maintaining suitable heating value of the produced gas.

The results indicate that the optimum feed conditions are: 40% coal in the feed blend, 35 % water concentration in the feed slurry, and 80% oxygen with respect to the dry feed blend to the gasifier. The power generation results indicate that in the case of non-carbon capturing, the co-gasification of coal and rice straw generates 283 MW per 100 ton of feed blend (40% coal-60% biomass),while, the co-gasification of coal and wood generates 293 MW per 100 ton of feed blend. This means that wood is more advantageous than rice straw from the power generation point of view. Moreover, the application of carbon capturing technologies results in power generation of 270 MW per 100 ton of feed blend in the case of co-gasification of coal and rice straw, and 279 MW in the case of co-gasification of coal and wood. These results suggest that the application of carbon capturing technologies is associated with a loss in power produced by 4.8%. This however means using smaller gas turbines, and more environment friendly emissions. Moreover, the huge amounts of captured carbon dioxide gas can be sold to other industries to compensate for the increased plant cost.

Chapter 1 : Introduction

To date, the production of electricity in most countries is based mainly on oil products mainly diesel, natural gas and coal. It is known that oil and gas reserves are limited to 50-60 years[1]. On the other hand, coal reserves are proven for 150 years. Biomass is a renewable energy source that could be integrated and used as fuel for power generation [1], providing for a secure and sustainable energy supply. It also provides for the possibility of decreasing greenhouse gases by carbon capturing techniques. Converting coal into liquid fuels and chemicals and its direct use for generating electricity is also a proven technology.

There are two methods for power generation from coal; direct burning, or its conversion into syngas. Direct burning of coal has been used for decades, it is based on converting the heat energy into mechanical energy. However, this method has many drawbacks, for instance, it causes air pollution where burning coal causes smog, soot, acid rain, global warming, and toxic air emissions. Moreover, it generates toxic wastes, sludge, and ash. Converting coal into syngas for electricity generation is performed in a process known as Integrated Gasification Combined Cycle (IGCC). It is a recent approach based on converting stored chemical energy within the coal into mechanical energy. It has many advantages over direct burning of coal; it is considered as a clean source of energy with less pollutant emissions, it has high conversion efficiency, and it can be used directly in the established infrastructure as a substitute for natural gas in power stations. Coal and biomass are converted into syngas by thermo-chemical gasification and successive gas cleaning. It was found that increasing the H_2/CO in syngas, causes the increase in power efficiency, this can be achieved by effective carbon dioxide removal. Operational IGCC plants are built worldwide for example the Baggenum plant in Netherlands with a capacity of 253 MW, Tampa Electric Polk power station in the United States with a capacity of 250 MW, and many other power station plants with capacities up to 500 MW[2].

Biomass such as rice straw and rice husks can also be converted into syngas by gasification. Such wastes represent a renewable source which has a lower sulfur content compared to coal, thus lower pollutant emissions. However, they have a lower energy content compared to coal. Recent studies focus on co-gasification of coal and biomass for power generation. This process enhances the H_2/CO ratio in the produced gas. Also the inorganic matters found in biomass catalyzes the coal gasification.

Although co-gasification presents many advantages, it is associated with additional technical implementation requirements. For instance, the particle size of coal and biomass should be uniform, the selection of the gasifier type should be studied carefully as it affects the composition and yield of the produced syngas. Biomass decomposition occurs at a lower temperature than that of coal so different reactors are suitable for different feedstock mixtures. Fluidized bed reactor and Entrained flow reactor have been used in Japan to gasify mixtures of bituminous coal and rice straw [37]. It has been proven that the co-gasification of rice straw and coal is applicable in IGCC plants for power generation and it is continuously developed to increase the efficiency and decrease the carbon emissions of the process [38].

The present work addresses the gasification of mixtures of locally available coal from El-Maghara coal mine and locally available biomass wastes namely rice straw and wood sawdust.

Chapter 2 focuses on the literature review associated with the IGCC process development. It describes the process units in details. It also reviews the different types of gasifiers, feedstock materials, and conditions of gasification.

Chapter 3 presents a brief outline of the scope of work and a statement of the relevant performance parameters targeted by the study.

Chapter 4 is devoted to the description of the model developed for analyzing IGCC gasification process and the software used for generating the effect of different process variables on the performance of the process.

Chapter 5 presents the results obtained for different sets of parameters and discussion of their effect in the light of physicochemical constraints and energy recovery. It also discusses the effect of including a carbon capture unit on the additional equipment requirements, calorific value of the produced syngas, and electric power generated.

Chapter 6 summarizes the conclusions and recommendations of the work.