Chapter 1: Introduction

Coal, oil and natural gas are the world’s most widely utilised energy resources, and of these coal is the most abundant fossil fuel globally. The coal-mining industry has been a major contributor in supplying the global energy demand for more than a century. Coal is considered to be a valuable solid fuel since it produces a large amount of energy and can be utilised for various applications (WCI, 2009). Presently, coal is mainly used for electricity generation, cement and steel manufacturing and as a liquid fuel in the petrochemical industry (WCI, 2009). Coal utilisation and the development of coal conversion technologies have thus far largely depended on the global energy demand, and worldwide economic fluctuations.

Coal conversion processes were developed as early as the 1600’s, when coal was used to produce coke for the metallurgical industry. Towards the end of the eighteenth century, the benefits of coal as an energy source were realised, and town gas was produced by either the devolatilisation of coal or by the water gas process (gasification). Up until this point, gasification was only important for the production of gas, which was mainly used for lighting and heating (Higman and van der Burgt, 2008). In the early 1900’s, the gasification process became increasingly important in the chemical industry, and was considered a flexible and dependable method of converting carbonaceous feedstock into synthesis gas (CO and H₂). Synthesis gas was subsequently used to produce chemicals, fertilizer, liquid fuels, hydrogen or substitute natural gas (SNG) (Gasification Technologies Council, 2008). The new-found interest in gasification as an efficient coal conversion process led to the development of numerous technologies, such as the Winkler fluid-bed process (1926), the Lurgi moving-bed pressurised gasification process (1931) and the Koppers-Totzek entrained-flow process (1940s). With the implementation of these newly developed processes, little technological development occurred during the next 40 years. With the oil crisis in 1970, followed by an unexpected shortage in natural gas, coal gasification received renewed interest as an efficient process for the production of liquid and gaseous fuels (Higman and van der Burgt, 2008).

Increased interest in the gasification process led to extensive research and development to improve available technologies. During this time Exxon Research and Engineering Company also researched possible methods to improve gasification efficiency, and discovered that the addition of potassium salts significantly enhanced the methanation of coal. This led to the development of the Exxon Catalytic Coal Gasification (CCG) process.
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(Lessard and Reitz, 1981). Exxon was the first company to develop and construct a CCG pilot plant. The pilot plant operated at 700 °C and 34 bar, with a 1 ton/day throughput of coal with added potassium catalyst, and also consisted of a catalyst recovery unit. An average coal particle size of 2380 µm and a \( \text{K}_2\text{CO}_3 \)-loading of 15 wt.% was used for pilot plant operations (Lessard and Reitz, 1981).

Since 1970, various factors have encouraged continuous research regarding the optimisation of gasification processes. These factors include environmental considerations and the current increase in the demand for synthesis gas, especially by the petrochemical industry. Environmental concerns have resulted in the development of cleaner coal technologies which are aimed at reducing the emissions of coal conversion processes (Gasification Technologies Council, 2008). On the other hand, the development of a more efficient gasification process is largely driven by the ever increasing demand for synthesis gas. With the production rate of synthesis gas increasing by an estimated 10 % per annum, the optimisation of gasification processes to produce a gas with the maximum amount of carbon monoxide and hydrogen is critical (Van Dyk et al., 2006). It has long since been realised that the use of a catalyst in gasification operations can resolve the above-mentioned issues. Firstly, the composition of the product gas can be controlled in the presence of a catalyst, consequently reducing harmful emissions. Secondly, catalyst addition increases gasification reaction rates, which results in increased process throughput (Lee and Kim, 1995).

The catalytic gasification of coal has been studied extensively in order to obtain a better understanding regarding the following associated aspects (Lee and Kim, 1995):

- Various studies have focused on determining which catalysts are most suitable for application in gasification processes, as well as identifying the most efficient catalyst addition methods (Suzuki et al., 1984; Takarada et al., 1986; Yeboah et al., 2003; Liu and Zhu, 1986; McCormick and Jha, 1995).
- Factors influencing catalytic gasification have been studied comprehensively in order to determine optimum operating conditions for catalytic gasification (Nishiyama, 1991; Sheth et al., 2003; Yeboah et al., 2003).
- Complex catalytic gasification mechanisms have been researched and proposed, which gives a clearer understanding of the role of the catalyst during gasification reactions (Wang et al., 2010; Veraa and Bell, 1987).
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Comprehensive fundamental research conducted using small coal particles or powders, have certainly resulted in a better understanding of catalytic gasification. However, the shortfall of previous research regarding catalytic gasification is a lack of knowledge regarding the use of large coal particles. Considering this deficiency, the use of large coal particles for catalytic gasification application, will be examined in this study. An effective catalyst, as well as a suitable impregnation method, will be identified and used to impregnate the coal particles. The catalytic effect on the reaction rate will be investigated by conducting steam gasification experiments, and comparing the reactivities of the raw and impregnated coal particles.

This dissertation is divided into 7 Chapters, and the outline of each chapter is briefly discussed:

- The introduction given in this chapter includes a brief discussion regarding the use of coal as a gasification feedstock, and the development of coal conversion technologies, specifically catalytic gasification.

- Chapter 2 is a detailed review of literature relevant to this investigation. The subject matter associated with this investigation include an overview of coal formation and coal composition, a summary of the gasification process and research conducted on large particle gasification, a detailed review regarding catalytic gasification and the research conducted in this specific area.

- In Chapter 3, the objectives and scope of this investigation are outlined.

- A general characterisation of the coal was conducted, which includes chemical and mineral analyses. The results obtained for the characterisation results are presented and discussed in Chapter 4.

- Chapter 5 provides a detailed description of all aspects regarding the catalyst impregnation of the large coal particles. The results presented in this chapter include impregnation measurements, catalyst loading and catalyst distribution.

- In Chapter 6, the results for the steam reactivity experiments are presented and evaluated in terms of catalytic effect, temperature influence, particle size influence, influence of impregnation, and the surface effect of catalyst addition.
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- Chapter 7 summarises the conclusions drawn from the experimental results obtained from this investigation. Based on the conclusions drawn from the study, recommendations are made in order to assist future research.