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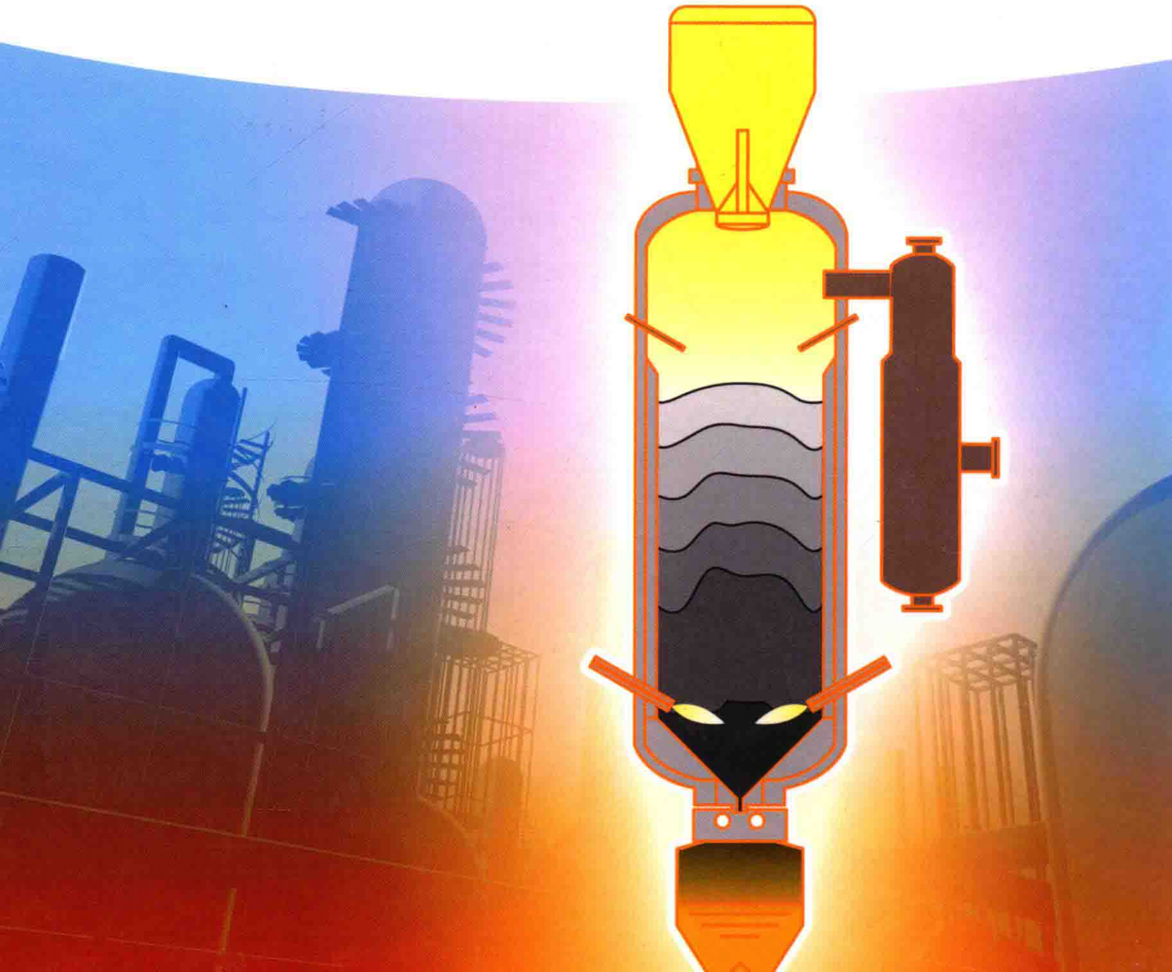

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Preface

This book provides a comprehensive overview on topics that are related to industrial coal gasification technologies, combining scientific with technological aspects. The main vision for the book is to provide the reader with an innovative, highly structured, and detailed view on coal gasification technologies. The novel ternary diagram of gasification provides the first order scheme in which all gasifiers can be compared at one glance. Special emphasis is placed on new gasification concept developments and increasing ash content of the coal.

After an introduction (Chapter 1) explaining the background and the scope, the book starts from a global perspective in Chapter 2. Coal gasification is put into a global context by identification of recent applications. Once it is clear why coal is gasified, the course of coal gasification development (generations of gasifiers) and the recent role of coal gasification (typical feedstock and products of realized plants), as well as main markets, are discussed. Subsequently, the reader will be sensitized to the main challenges hampering a broad market introduction of coal gasification and also for potential opportunities that keep coal gasification in the discussion. Chapter 2 concludes with discussion of environmental aspects, such as emissions of coal gasification plants.

To guide less experienced readers into the complex topic of coal conversion by means of gasification, a survey on coal characterization limited to gasification-relevant parameters is provided in Chapter 3. From a practical point of view, this chapter tells what information can be extracted from a coal sample in order to judge which gasification process is suitable. Hence, the necessary knowledge about coal standard analyses (e.g., ultimate, proximate, calorific analyses) and more sophisticated procedures, such as reactivity or maceral analyses, are presented. The most emphasis will be placed on the discussion of the minerals in the coal because they are limiting to all gasification processes. Chapter 3 concludes with a summary of physical and fluid-dynamic properties of the coal.

Chapter 4 introduces the fundamentals of technical gasification processes starting with basic reactions and chemistry. The knowledge from the previous chapter allows us to define the necessary gasification performance parameters that are needed to discuss the advantages and disadvantages of the different gasification methods. Consequently, the differences between the processes are presented in a highly structured way according to bed type (moving bed, fluidized bed, entrained bed), temperature range (ash fusibility and slag viscosity), pressure level, feeding method (dry feeding or coal-water-slurry), wall type (membrane wall, refractory lining, steam jacket), syngas cooling (water/gas/chemical quench, heat recovery), oxidant (O_2 or air), solid residue removal (ash/slag, fly ash, granulate), and catalyst addition.

Because modeling approaches and detailed technology survey results are presented in Chapter 6, it is instructive to include an overview on gasification modeling before that. Hence, Chapter 5 presents the typical starting place for modeling, which is the balancing of gasification systems. In further course, thermodynamic models, kinetic models, and computational fluid dynamics (CFD) approaches for gasification modeling are introduced. Chapter 5 provides a practical overview on these methods, discussing strengths and weaknesses, main fields of application, usable data sets, and related laboratory investigations. It will only touch basic equations and scientific background as far as necessary for understanding. Chapter 5 ends with a description of the generic modeling approach, which is used in Chapter 6, and discusses the sensitivity of selected models to the applied boundary conditions.

Chapter 6, "Coal Gasification Technology Survey," represents the core of the book. The intention is to provide the most recent and most comprehensive data collection on coal gasification processes comprising much information that has not yet been published in the English language. Chapter 6 is organized following the bed type of the gasifiers and placing special emphasis on the technologies from Shell, Uhde (i.e. high-temperature Winkler (HTW), Prenflow), GE, Siemens, CB&I (i.e., E-Gas), Lurgi (i.e., fixed-bed dry bottom (FBDB)), and Envirotherm/Zemag (i.e., British Gas/Lurgi (BGL)), as there are much public domain data available. For these processes, a historical background, a detailed process description, proposed enhancements, and current projects are presented. For selected technologies, generic model setup and results are also presented. Besides performance data from operation, which is given in the sections of detailed process description, the modeling permits the comparison of the gasifiers on unified boundary conditions pointing out the effect of high-ash versus conventional coal and standard versus enhanced systems. All other industrial coal gasification technologies, such as the new Chinese processes or other fluid-bed technologies, are introduced depending on the availability of public domain data.

In Chapter 7, the main innovation of this book is disclosed, which is the introduction of a ternary gasification diagram. This newly developed order scheme allows putting all gasifiers in one diagram according to their consumption figures based on thermodynamic calculations. This new idea is introduced to the reader step by step, ranging from the basic idea over pressure sensitivity, diagram types, domain boundaries for gasification systems, displaying gasifiers with multiple inlets to the development of derived optimum user diagrams and correlations. Subsequently, the diagram is provided for conventional (Pittsburgh No. 8) and ash-rich (South African) coal, which is discussed in detail. Chapter 7 concludes with a technology potential analysis and the assessment of the influence of the ash content, both being conclusions from the new type of diagram.

In addition, other gasification systems will be touched on and displayed in the diagram (e.g., carbon dioxide (CO_2)-gasification, biomass).

Because the thermodynamic performance parameters of gasification do not reveal the effect of the gas cooling method on the overall process, an exergetic analysis is provided in Chapter 8. As exergy is strongly dependent on the applied reference environment and the applied chemical system, Chapter 8 begins with an introduction to exergy calculations, the reference environment, and the exergy definition of the gaseous, liquid, and solid streams. The definition of efforts and benefits in the present investigation is also explained. Subsequently, the impact of gas cooling methods, and the final exergetic comparison of the gasification systems for both high-ash versus conventional coal and standard versus enhanced systems is discussed.

Taking together all conclusions from the previous chapters, a theoretical concept study is carried out designing a gasifier that potentially can cope with high-ash fine coal. There is no gasification technology on the market for such coal at the moment. The structure of Chapter 9 is similar to the gasifier descriptions in Chapter 6, comprising process basic principle, detailed process description, layout of the reaction chamber, gasifying agent injection, gas cooling, ash removal, and expected performance and control. In this framework, the utilization of the Reh diagram and the setup of a thermodynamic model will be discussed. Conclusions for process scale-up and suggestions for further development steps complete Chapter 9.

A brief overall conclusion summarizing the trends in gasification development is given in Chapter 10, finishing the book.

Contents

1
Introduction

A tendency toward a decrease in coal quality is reported from various parts of the world, especially in the coking coal sector. In terms of steam coals, countries such as South Africa [1], India [2], Japan [3], or even China [4] report about utilization of coal with elevated ash content. According to MacDonald *et al.* [5] and the ISO 11760 classification [6], coals are referred to as "high ash" or "moderately high ash" if they have an ash yield greater than 20 wt% (wf). In terms of gasification, several disadvantages can be expected as the ash content increases:

1) The physical heating and cooling and melting of the ash material reduce process efficiency.
2) High ash content is detrimental to carbon conversion for reasons of carbon encapsulation.
3) Addition of fluxing agents to influence the ash behavior is limited.
4) Increasing amounts of vaporized ash compounds could increase fouling in downstream heat exchangers.
5) Coal preparation expenditures increase in terms of grinding, drying, or de-ashing.

Mineral matter reactions can additionally hamper the process, that is, oxygen consumption by substances that are not fully oxidized, such as Fe_3O_4 or FeS_2, or CO_2 release from carbonates. Special solvents might be considered to de-ash the coal [7]. However, because of recovery and regeneration problems, operational and capital costs increase while availability decreases and this option is mostly abandoned. As soon as the ash contains certain constituents (quartz and pyrite in particular), wear and abrasion in milling systems lead to extensive maintenance programs [8]. Thus, crushing should be kept at the lowest possible level.

The traditional approach to gasify such kind of feedstock is, of course, employing moving-bed systems featuring dry-ash removal, for example, Lurgi fixed-bed dry bottom (FBDB) gasification. But moving-bed technologies require a suitable grain size for bed percolation and can cope only with limited amounts of fine coal. In addition, modern mining technologies produce increasing quantities

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of fine coal and the high-ash content prevents acceptable agglomeration properties, for example, for briquetting. Consequently, vast amounts of high-ash coal fines are left over from moving-bed processes or other coal washing and beneficiation processes. These cannot be gasified efficiently using today's standard technologies [9].

The task of the present book is to investigate the capability of existing technologies and the potential of new concepts for processing high-ash coal. A study is carried out using a high-ash coal from South Africa – especially fines for pulverized coal application – compared to a baseline standard coal, which is American Pittsburgh No. 8 bituminous coal. To compare the different approaches, thermodynamic modeling and exergy analysis will be applied. The evaluation of the results should lead to the identification of the most promising concept, which is intended to be investigated in a case study.

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2
Coal Gasification in a Global Context

2.1
Applications of Coal Gasification

Any carbonaceous feedstock, may it be gaseous, liquid, or solid, can undergo a partial oxidation. As soon as oxidation heat is released, high-temperature conditions evolve permitting other gases, such as steam or carbon dioxide, to react with the carbonaceous feedstock. The result is the autothermal breakdown of the feedstock to the smallest stable chemical units that can still carry some energy. These units are the gases hydrogen, carbon monoxide, and sometimes methane. The breakdown process is called *gasification* and the gaseous product is called *synthesis gas* or *syngas*. Although the term "syngas" traces to gases produced for the sole purpose of downstream syntheses, it established itself as a term for any product gas from gasification independent of application. (Further details and thermodynamic definitions are provided in Chapter 4.)

The composition of the syngas varies and is essentially linked to the quality of the feedstock and the conditions of the gasification process, such as temperature and pressure. Furthermore, each kind of gasification process is specialized in a certain feedstock spectrum. Finally, the usage of the gas produced specifies varying parameters, such as heating value, pressure level, H_2/CO ratio, and maximum concentration of sulfur compounds.

Hence, the closing of the gap between carbonaceous feedstock and a selected final product, which is intended to be sold from the plant, is a technical and economical optimization problem with usually more than one solution. In this framework, the different gasification technologies are the basis for competition on the market.

The conversion chain of gasification plants as shown in Figure 2.1 can be generalized in three steps moving from feedstock to product: gasification, gas treatment, and conversion to product.

In Figure 2.1, the sum of installed and under-construction capacity in GW syngas is distinguished for feedstock and products. On the feedstock side, it can be seen that coal with 126.9 GW represents more than 75% of the global feed for gasification plants. And coal is expected to grow by another 74 GW

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