Ludwig's Applied Process Design for Chemical and Petrochemical Plants

Volume 1

Fourth Edition

A. Kayode Coker

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In Gratitude to Our Creator with Awe, Humility,

Dedication and Love

In Memory of Ernest E. Ludwig

(A Great Chemical Engineer)

and

In Loving Memory of my dear Mother

Modupe Ajibike Coker

To my wife, Victoria

Love and thanks

Preface to the Fourth Edition

This complete revision of *Applied Process Design for Chemical and Petrochemical Plants*, Volume 1, builds upon the late Ernest E. Ludwig's classic text to further enhance its use as a chemical engineering process design manual of methods and proven fundamentals with supplemental mechanical and related data, nomographs, and charts (some in the expanded appendices). Significantly expanded and thoroughly updated, fourth edition contains new topics that will assist the engineer in examining and analyzing problems and finding design methods and mechanical specifications to secure the proper mechanical hardware to accomplish a process objective.

This latest edition includes improved techniques and fundamental design methodologies to guide the engineer in designing process equipment and applying chemical processes to the properly detailed hardware (equipment), because without properly sized and internally detailed hardware, the process will not achieve its unique objective. The various derived and proven equations have been employed in actual plant equipment design, and some of the most reasonable available to inexperienced and experienced engineers (excluding proprietary data and design methods).

This book further provides both fundamental theories where applicable and directs application of these theories to applied equations essential in the design effort. A conscious effort has been made to offer guidelines of sound engineering judgment, decisions, and selections with available codes (e.g. ASME, API, ANSI, TEMA, ASTM, NFPA, BS) and specifications, as some of these are illustrated as problems in the text. This approach at presentation of design information serves well for troubleshooting plant operation problems and equipment/system performance analysis.

This fourth edition presents many developed and executable computer programs and Excel spreadsheet programs, which are readily available to assist the engineer in his or her design problems. Additionally, there are nearly 50 process data sheets in either Excel spreadsheet format or hard copies that can be readily accessed. This book can be used as a classroom text for senior and graduate level chemical plant design courses at the university level. For the first time, the appendices provide with examples of various numerical methods that prove useful for undergraduate and graduate students.

The text material assumes that the reader is at least an undergraduate engineer with a sound knowledge of the fundamentals of the profession. The book will provide the reader with design techniques to actually design as well as mechanical detail for construction. The aim of the process engineer is to ensure that results of his or her process calculations for equipment are specified in terms of something that can be economically constructed or selected from the special designs of manufacturers. This edition follows the format of previous editions in emphasizing the mechanical codes and some requirements that can be important in the specifications as well as the actual specific design details. An added feature is professional ethics incorporating codes of conduct from the Institution of Chemical Engineers and the American Institute of Chemical Engineers.

Economic evaluations are essential in determining the viability of any project, so the chemical or process engineer must be able to ascertain the economic impact of a new or existing chemical process and judge whether the project will provide a return on investment for his company. The techniques of economic analysis are used to assess the profitability of projects involving both capital expenditures and yearly operating costs.

Because the engineer should have the ready access to essential physical property data of compounds for design calculations of process equipment, this revised volume includes more than 20 physical property data for liquids and gases in Excel spreadsheet format and hardcopy with example problems. Such data are usually found in specialized texts or simulation design packages, or obtained by conducting experiments to measure the properties of individual substances or of mixtures, which may exhibit nonideal behavior, but this is often time-consuming and expensive. Thermodynamic data of this type are required in most calculations such as sizing vessels, process pipe lines, separation of multicomponents, gas absorption and chemical reactor design, and so are now included in this volume.

The techniques of applied chemical plant process design continue to improve as the science of chemical engineering develops new and better interpretations of the fundamentals of chemistry, physics, metallurgical, mechanical, and polymer/plastic science. Accordingly, this fourth edition presents additional reliable design methods based on sound experimental data, proven techniques developed by companies and individuals and groups considered competent in their subjects and who are supported by pertinent data. In breaking with tradition of previous editions, the fourth edition has incorporated the use of S.I. units in some of its design calculations. The text also provides useful conversion table in electronic format to aid the engineer when required. Every chapter has been expanded and updated with new materials. The appendix contains many process flow diagrams and piping and instrumentation diagrams (P & IDs) of some chemical processes that should assist the designer for comparison.

For further information, and for supplementary materials, please visit http://books.elsevier.com/companions/9780750677660. In addition, all figures and diagrams from this text will also be available online, as well as additional material.

A. Kayode Coker, C.Eng

Preface to the Third Edition

This volume of *Applied Process Design* is intended to be a chemical engineering process design manual of methods and proven fundamentals with supplemental mechanical and related data and charts (some in the expanded Appendix). It will assist the engineer in examining and analyzing a problem and finding a design method and mechanical specifications to secure the proper mechanical hardware to accomplish a particular process objective. An expanded chapter on safety requirements for chemical plants and equipment design and application stresses the applicable Codes, design methods, and the sources of important new data.

This manual is not intended to be a handbook filled with equations and various data with no explanation of application. Rather, it is a guide for the engineer in applying chemical processes to the properly detailed hardware (equipment), because without properly sized and internally detailed hardware, the process very likely will not accomplish its unique objective. This book does not develop or derive theoretical equations; instead, it provides direct application of sound theory to applied equations useful in the immediate design effort. Most of the recommended equations have been used in actual plant equipment design and are considered to be some of the most reasonable available (excluding proprietary data and design methods) that can be handled by both the inexperienced as well as the experienced engineer. A conscious effort has been made to offer guidelines of judgment, decisions, and selections, and some of this will also be found in the illustrative problems. My experience has shown that this approach at presentation of design information serves well for troubleshooting plant operation problems and equipment/systems performance analysis. This book also can serve as a classroom text for senior and graduate level chemical plant design courses at the university level.

The text material assumes that the reader is an under-graduate engineer with one or two years of engineering fundamentals or a graduate engineer with a sound knowledge of the fundamentals of the profession. This book will provide the reader with design techniques to actually design as well as mechanically detail and specify. It is the author's philosophy that the process engineer has not adequately performed his or her function unless the results of a process calculation for equipment are specified in terms of something that can be economically built or selected from the special designs of manufacturers and can by visual or mental techniques be *mechanically* interpreted to actually perform the process function for which it was designed. Considerable emphasis in this book is placed on the mechanical Codes and some of the requirements that can be so important in the specifications as well as the actual specific design details. Many of the mechanical and metallurgical specifics that are important to good design practice are not usually found in standard mechanical engineering texts.

The chapters are developed by *design function* and not in accordance with previously suggested standards for unit operations. In fact, some of the chapters use the same principles, but require different interpretations that take into account the *process* and the *function* the equipment performs in the process.

Because of the magnitude of the task of preparing the material for this new edition in proper detail, it has been necessary to omit several important topics that were covered in the previous edition. Topics such as corrosion and metallurgy, cost estimating, and economics are now left to the more specialized works of several fine authors. The topic of static electricity, however, is treated in the chapter on process safety, and the topic of mechanical drivers, which includes electric motors, is covered in a separate chapter because many specific items of process equipment require some type of electrical or mechanical driver. Even though some topics cannot be covered here, the author hopes that the designer will find design techniques adaptable to 75 percent to 85+ percent of required applications and problems.

The techniques of applied chemical plant process design continue to improve as the science of chemical engineering develops new and better interpretations of the fundamentals of chemistry, physics, metallurgical, mechanical, and polymer/plastic sciences. Accordingly, this third edition presents additional reliable design methods based on proven techniques developed by individuals and groups considered competent in their subjects and who are supported by pertinent data. Since the first and second editions, much progress has been made in standardizing (which implies a certain amount of improvement) the hardware components that are used in designing process equipment. Much of the important and basic standardization has been incorporated in this latest edition. Every chapter has been expanded and updated with new material.

All of the chapters have been carefully reviewed and older (not necessarily obsolete) material removed and replaced by newer design techniques. It is important to appreciate that not all of the material has been replaced because much of the so-called "older" material is still the best there is today, and still yields good designs. Additional charts and tables have been included to aid in the design methods or explaining the design techniques.

The author is indebted to the many industrial firms that have so generously made available certain valuable design data and information. Thus, credit is acknowledged at the appropriate locations in the text, except for the few cases where a specific request was made to omit this credit.

The author was encouraged to undertake this work by Dr. James Villbrandt and the late Dr. W. A. Cunningham and Dr. John J. McKetta. The latter two as well as the late Dr. K. A. Kobe offered many suggestions to help establish the usefulness of the material to the broadest group of engineers and as a teaching text.

In addition, the author is deeply appreciative of the courtesy of The Dow Chemical Co. for the use of certain noncredited materials and their release for publication. In this regard, particular thanks is given to the late N. D. Griswold and Mr. J. E. Ross. The valuable contribution of associates in checking material and making suggestions is gratefully acknowledged to H. F. Hasenbeck, L. T. McBeth, E. R. Ketchum, J. D. Hajek, W. J. Evers, and D. A. Gibson. The courtesy of the Rexall Chemical Co. to encourage completion of the work is also gratefully appreciated.

Ernest E. Ludwig, P.E.

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1

PROCESS PLANNING, SCHEDULING, AND FLOWSHEET DESIGN

Process engineering design is the application of chemical, mechanical, petroleum, gas and other engineering talents to the process-related development, planning, designs, and decisions required for economical and effective completion of a process project [1]. Although process design engineers are organizationally located in research, technical service, economic evaluation, as well as other specific departments, the usual arrangement is to have them available to the engineering groups concerned with developing the engineering details as well as to evaluate bids for the various equipment items. Process design is usually a much more specific group responsibility in engineering contractor organizations than in a chemical or petrochemical production company, and the degree of distinction varies with the size of the organization.

The average process engineer has the following responsibilities:

1. *prepares studies of process cycles and systems for various product production or improvements or changes in existing production units; prepares material and heat balances;*
2. *prepares economic studies associated with process performance;*
3. *designs and/or specifies equipment items required to define the process flowsheet or flow system; specifies corrosion-resistant materials of construction;*
4. *evaluates competitive bids for equipment;*
5. *evaluates operating data for existing or test equipment;*
6. *guides flowsheet draftsmen in detailed flowsheet preparation.*

The process engineer also develops tests and interprets data and information from the research pilot plant. He/she aids in scaling up the research type flow cycle to one of commercial feasibility.

The process engineer must understand the interrelationship between the various research, engineering, purchasing, expediting, construction, and operational functions of a project. He/she must appreciate that each function may and often does affect or influence the process design decisions. For example, it is futile to waste time designing or calculating in detail when the basic components of the design cannot be economically fabricated, or if capable of being fabricated, cannot possibly be delivered by the construction schedule for the project. Some specific phases of a project that require process understanding include plant layout, materials of construction for corrosion as well as strength, start-up operations, troubleshooting, maintenance, performance testing, and so forth.

1.1 ORGANIZATIONAL STRUCTURE

The process design function may be placed in any one of several workable locations in an organization. These locations will be influenced by the primary function of the overall company, that is, chemical production, engineering, engineering sales, design, and manufacture of packaged or specific equipment manufacture, and so on. For best efficiency, regardless of the business nature of the company, the process design being a specialty type operation, works best when specifically identified and given the necessary freedom of contact within and without the company to maintain a high level of practical, yet thorough direction.

A typical working arrangement is shown in Figure 1-1 [1]. In a consulting or engineering contractor organization, process design and/or process engineering is usually a separate group responsible for developing the process with the customer, or presenting the customer with a turnkey proposed process.

In an operating or producing chemical or petrochemical company, the process engineering and design may be situated in a research, technical service, or engineering department. In most cases it is associated with an engineering department if new projects and processes are being planned for the company. If located elsewhere, the designs and planning must be closely coordinated with the engineering activity.

Most current thinking establishes a project team headed by a project engineer or manager to oversee the accomplishment of a given plant development for a process company. If the projects or jobs are small, then the scope of activity is limited and may often be consolidated in a single individual for project and process responsibility. For projects larger than $500,000, the project and process responsibility usually are best kept separate in order to expedite the specific accomplishment of the process design phase. When the process design engineer is required to interpret calculations and specification development and to follow some electrical, structural, or even expediting delivery question or problem, the design work cannot be completed at best efficiency and often the quality of process design suffers, assuming there is a fixed target date for completion of the various phases as well as the overall project.

Figure 1-2 diagrammatically suggests a team arrangement for accomplishing the planning of a process project. The arrows indicate directions of flow of communications and also the tie-in relationship of the process design function in the accomplishment of an assignment. The planning team in the box works to place the proper perspective on all phases of the engineering functions by developing a working atmosphere of understanding for accomplishing the engineering design. This is physically represented by mechanical vessels, piping, structures, electrical, instrumentation, civil, and any other specialized functions. In many projects, the Lead

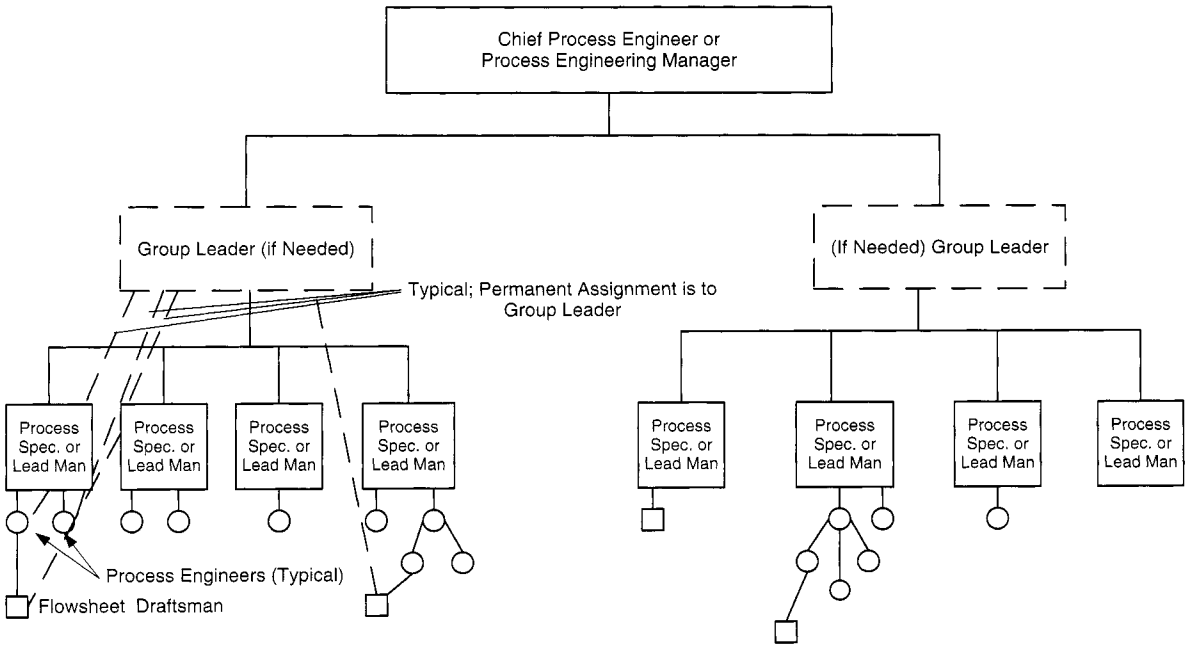

Figure 1-1 A process engineering section supervision chart. (By permission from Ludwig [1].)

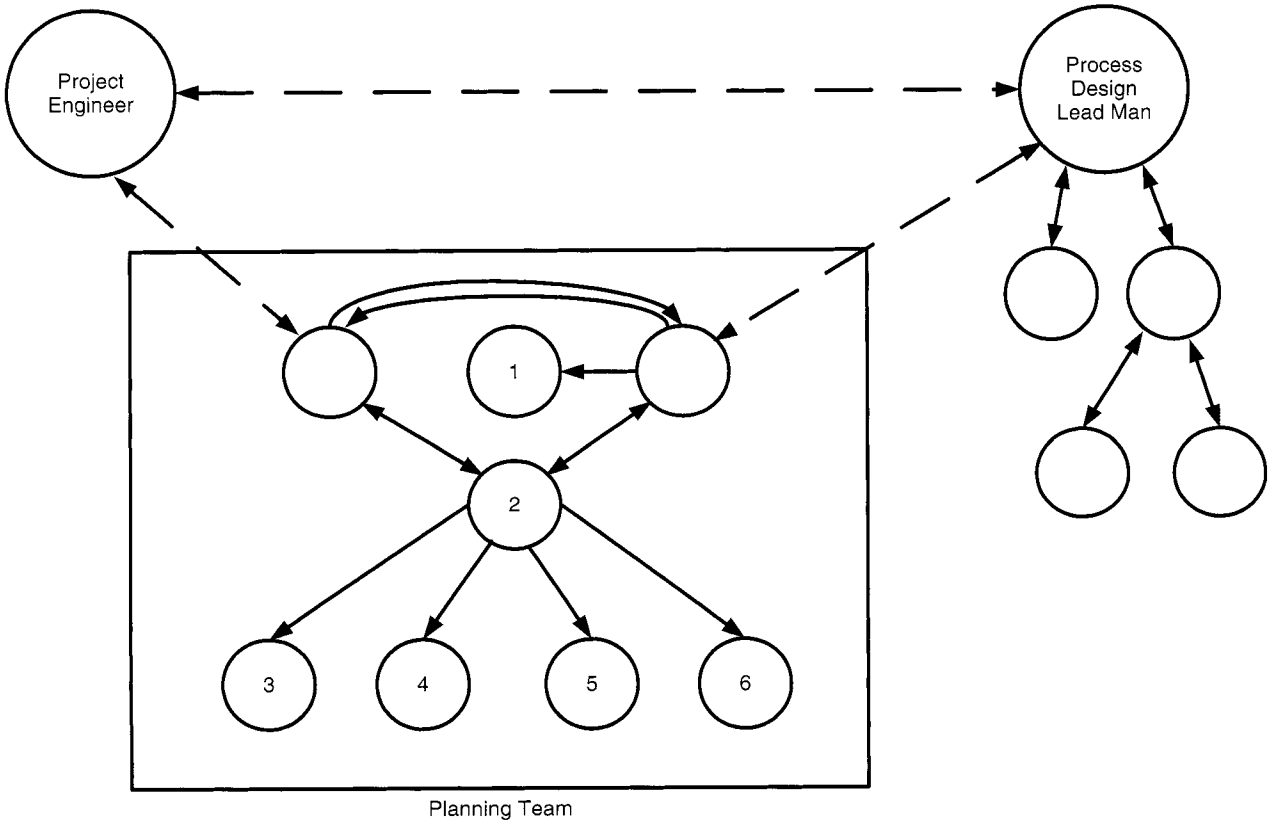

Figure 1-2 Typical organization of "engineering planning team". (By permission from Ludwig [2].)