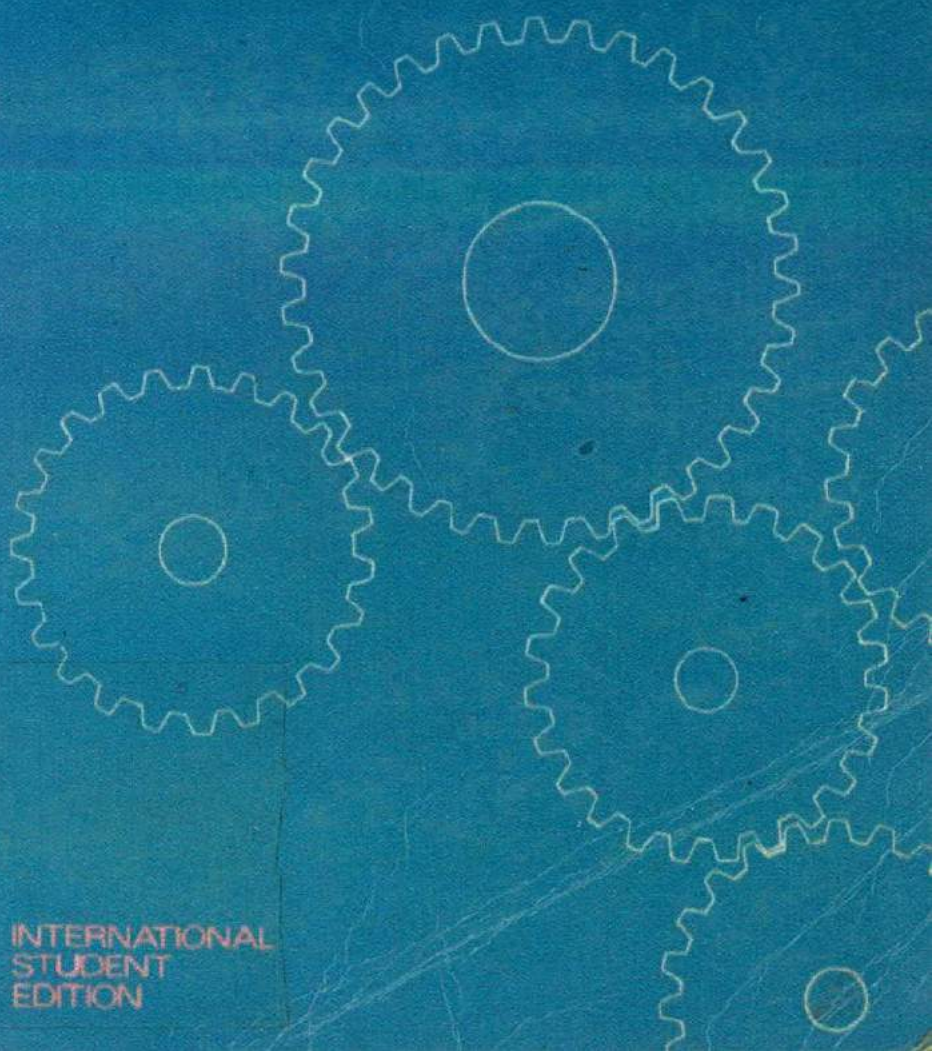


# Powerplant Technology

M.M.El-Wakil



INTERNATIONAL  
STUDENT  
EDITION

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# POWERPLANT TECHNOLOGY

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He, who through vast immensity can pierce,  
See worlds on worlds compose one universe,  
Observe how system into system runs,  
What other planets circle other suns,  
What varied Being peoples every star,  
May tell why Heaven has made us as we are.  
.....  
Who sees with equal eye, as God of all,  
A hero perish, or a sparrow fall,  
Atoms or systems into ain hurled,  
And now a bubble burst, and now a world.

ALEXANDER POPE  
(1688-1744)  
*An Essay on Man*

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## PREFACE

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This book is the outgrowth of lecture notes used in a course on powerplant technology and engineering and given to a class of senior graduate students over several years. The author is indebted to many colleagues in the academic and industrial community who have made many helpful suggestions and supplied much needed material; and to his own students, whose give and take has helped in the evolution of the lecture notes into the present manuscript.

A course on powerplants was a popular and integral part of engineering curriculums, especially mechanical engineering, in the 1940s and 1950s. The material covered then was largely nonanalytical, preferring to concentrate on system and component description and operation. The course fell out of favor with the trend toward more fundamentalism in engineering education that started in the 1960s, and because the supply of cheap fossil fuels seemed so assured that development in the field slowed down considerably.

With the turnaround in the energy picture in the 1970s, and the need for new solutions to efficient power-generation problems, the course experienced a remarkable revival with a strong student and graduate engineer demand. That demand, which is expected to continue for the indefinite future, relied on available books, most of which lack some of the modern aspects of power generation, concentrate on problems of energy supply, demand, conservation and economics; or address a wide variety of topics that are not all relevant to the subject matter.

It has become apparent that a modern up-to-date text is sorely needed. This book was written with this goal in mind. It attempts to focus on the treatment and synthesis of electric-generating powerplant technology and engineering, with a balance between the analytical and technological aspects of powerplant design, systems, and effects. The old powerplant systems, which were almost exclusively fossil-fired, have given way to a wide spectrum of systems including improved fossil and nuclear plants and plants that rely on renewable energy sources for their input. While the author has certain opinions on the viability of some of these as serious contributors to the large demands for electric energy in the near and long term, he has attempted to give most of them more or less equal emphasis, at least for the sake of completeness. The subject



of energy, in general, generates much discussion, some of it emotional. The author has attempted to keep editorializing under control, however; but in a few instances, his opinions surfaced. Some readers may or may not agree with them.

The book is designed mainly for the use of mechanical, nuclear, and electrical engineers, but also for other engineering, energy, and applied-science majors. To accommodate a variety of backgrounds of readers, the book begins with introductory material that is necessary for the understanding and analysis of most powerplant systems. It then proceeds to cover fossil-fired powerplants of the Rankine, Brayton, and combined types. This is followed by introductory nuclear material and the current and most-promising fission-type nuclear powerplants. Fusion powerplants are not covered except in an introductory manner, since an electric-generating fusion powerplant is not now, and not expected to be, a reality in a well-defined form for decades to come. The book then proceeds to cover powerplants that rely upon renewable energy sources, such as geothermal, solar, wind, ocean temperature difference, and tide and wave energy. It terminates with presentations of various energy storage systems, most of which are still under development; and environmental aspects of electric-power generation, both fossil and nuclear.

Now a word about what this book does not cover. Probably the most important is hydroelectric energy, a major topic in its own right that is taught in separate courses and is adequately covered in many textbooks. Focusing on electric-power generation, the book does not cover areas of domestic and municipal heating and cooling, which are also covered elsewhere. It also does not cover the small but well-established electric-generating systems by internal-combustion engines which are also covered elsewhere. Power-generation systems from such sources as biomass and solid wastes, while environmentally helpful, are not expected to ever become major contributors to the electric-power-supply picture, and are covered with less emphasis than are other types.

Because of the expected variety in readers' backgrounds, a problem encountered in the author's own classes, some of the material in the book may not be necessary for some readers and may be bypassed by them, or used as a refresher. Also, because of the wide variety of topics covered, the book has been written with flexibility in mind, so that readers may change some of the order of presentation, or omit some of the material to suit their interests and purposes without loss of continuity. The book can be covered in three to five semester hours depending upon background and extent of coverage. While it is designed primarily as a college textbook with solved examples within and problems at the end of chapters, a conscious effort has been made to make it usable by graduate engineers in industry.

An engineering book that is published these days must face the dilemma of what system of units to use. Industry, particularly in the United States, still relies largely on the U. S. Customary System. In addition, many of the established heat-transfer, fluid flow, and design correlations for powerplant equipment are based on it. On the other hand, the trend in the scientific and world communities is toward use of the S. I. (Le Système International d'Unités), adopted in 1960. This book uses both systems, often together, and trusts that the reader can, or can learn to, convert easily from one to the other. It is important to keep in mind that mass is mass, force is force, and weight is a force. The dimensional conversion factor  $g_c$  used whenever mass and force appear in the same equation is used throughout. It does not vanish in the S. I.

system but simply assumes a numerical value of unity. The Appendix contains an extensive number of conversion tables, the last column of each of which is reserved for the S. I. system.

The author is indebted to colleagues, too numerous to mention, who made many suggestions and gave much encouragement, and to his students, who by their probing questions have helped put proper emphasis where it was most needed. He is also indebted to many who have contributed to the preparation and typing of the manuscript, in particular, Mary Jo Biechler, who competently and cheerfully had to beat numerous deadlines on such a difficult and long manuscript.

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*M. M. El-Wakil*