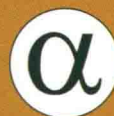


Second Edition

Engine Emissions

Fundamentals and
Advances in Control

B. P. Pundir

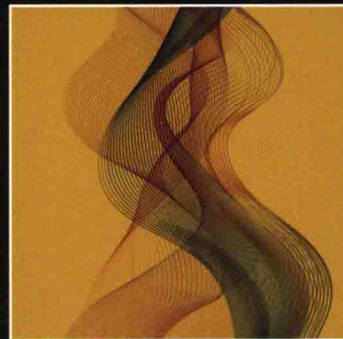


Alpha Science

Second Edition

Engine Emissions

Fundamentals and
Advances in Control



B.P. Pundir

Engine Emissions: Fundamentals and Advances in Control – Second Edition, introduces the reader to the fundamentals of pollutant formation in IC engines and advances in the engine emission control that have taken place over the years. It is an updated reference on the subject for the academics and professionals. Worldwide vehicle emission standards for the gaseous pollutants and, particulate mass and number (PN) emissions up to Euro 6 and Tier 3 regulations, test cycles including worldwide harmonized cycles e.g., WLTC, WHTC, WHSC and WMTC, and the emission measurement techniques including for PN are presented. Advanced engine concepts e.g., GDI (DISC and Sioich.) and HCCI, and the advanced aftertreatment technologies e.g., deNOx and, multi-zoned and multi-layered catalysts, GPF and DPF are discussed. The book brings to readers, the emission impact of the characteristics of petroleum and alternative fuels like alcohols, CNG, Biodiesel, DME, GTL H₂ etc, and international trends in the fuel specifications. Vehicle FE targets e.g., CAFE and others for mitigation of CO₂ emissions and global warming are dealt with. The book has 264 figures and 98 tables of data for a more complete illustration of the subject matter.



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Engine Emissions

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Second Edition

B P Pundir



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Second Edition

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Engine Emissions

Fundamentals and Advances in Control

Second Edition

This book is dedicated to my late wife
Shashi
who was a great source of support to me and our family

Preface to Second Edition

Vehicular air pollution especially in the urban areas has been a matter of serious concern all over the world for the last several decades. The vehicles powered by internal combustion (IC) engines that operate on petroleum fuels dominate the road transport sector. Many studies have shown that the emissions from the road transport contribute overwhelmingly to air pollution in the large cities. Implementation of regulations to control engine and vehicle emissions started during 1960's in the USA and in early 1970s in the European countries. Japan and several Asian and Latin American countries followed suit soon after. Since then, world over progressively more and more stringent emission standards are being enforced resulting in rapid advancements in engine and emission control technology. In the recent years, global warming caused by carbon dioxide emissions has added another dimension to the ongoing intensive research efforts for development of more fuel-efficient engines and use of low carbon and renewable biofuels.

The subject of engine emissions and their control is of considerable interest to researchers, practicing engineers and engineering students. Many academic institutes offer this subject as an independent course to post-graduate students. Since a book on this subject by the author was published in 2007, a number of important, new developments have taken place. Very stringent standards for mass emission of pollutants, the US Tier 3 and Euro 6 are under implementation. To the regulated mass emissions, limits on Particle Number (PN) emissions including those of ultrafine particles (UFPs) have been added in Euro 5(b) and Euro 6 standards. The USEPA too, is contemplating to introduce PN emission regulations shortly. For the diesel engines, particulate filters in the US and Europe are not only essential for the diesel engines to control particulate mass as well as to bring down PN emissions within the acceptable limits, but these would be applied also to gasoline direct-injection (GDI) and some port fuel injection (PFI) engines. For the measurement of engine and vehicle emissions, uniform test cycles and procedures in the form of World Harmonized Test Cycles have been developed for all categories of vehicles to enable an easier transfer of technology across the world.

Fuel quality is undergoing continuous upgradation. Ultra-low sulphur fuels having sulphur content of less than 15 ppm, have become standard fuels in the USA and Europe to enable operation of the catalytic exhaust aftertreatment devices at high efficiencies. More efficient, low cost and compact lean de-NO_x catalyst has become the new focus of catalytic converter technology development. For control of the greenhouse gas CO₂ emissions, European Union and some other countries are legislating control of the CO₂ emissions. The USEPA has notified new CAFE standards for implementation from 2016 through to 2025. It has given a renewed impetus to development of lean-burn spark ignition engines. The GDI engine is fast replacing the PFI engine in the new production gasoline vehicles. For heavy-duty truck engines various approaches of engine optimization and waste heat recovery are being studied and the goal of achieving up to 55% engine brake thermal efficiency is being pursued.

The second edition of the book has attempted to bring to the readers the above mentioned new developments and research initiatives being pursued by the engine and vehicle researchers. To provide a comprehensive exposure on the subject, the fundamentals of formation of pollutants emitted by the IC engines and, the developments in engine and emission control technology that have taken place since 1960s are covered in detail. In view of an increasing importance of reduction in CO₂ emissions for reversing global warming trends, a separate chapter on the subject is included in this edition.

Chapter 1 provides introduction to the effect of engine pollutants including UFPs on environment and health. The processes that lead to formation and emission of pollutants by the engines and the effect of various engine design and operational parameters on gaseous and particulate engine emissions are discussed in Chapter 2. Evolution of emission standards and test procedures, and measurement methods for gaseous, PM and PN emissions are discussed in Chapter 3 in detail for the benefit of the young professionals and researchers. In Chapter 4, advances in SI engine emission control technology including the developments in gasoline direct injection (GDI) engine technology are discussed. Control of NO_x emissions under lean engine operation and, control of PM and PN emissions from GDI engines are also dealt with. Chapter 5 discusses CI engine emission control including trends in the use of very high injection pressures, recent advances in diesel particulate filters, lean de-NO_x catalysts and HCCI concepts, which constitute the key emission control components on the current and future diesel engines.

Fuel quality has a strong inter-relationship with the modern low emission engine technology. Chapter 6 is devoted to the effect of quality of conventional petroleum fuels and alternative fuels on emissions. The more prominent alternative fuels such as; ethanol, natural gas and biodiesel are discussed in detail. The trends in fuel quality, penetration of ethanol-gasoline blends and recommendations of the Worldwide Fuel Charter proposed by the vehicle manufacturers' associations world over are presented. Finally, from the point of global warming concerns Chapter 7 discusses road transport related CO₂ emissions and the regulatory and technological steps for its mitigation.

The book is intended for the senior undergraduate and postgraduate students, the practicing engineers and the researchers. The reader is expected to have a prior knowledge of the working processes and basic design features of the reciprocating internal combustion engines.

I express my gratitude to many academicians, professional colleagues and friends who provided valuable feedback on First Edition of this book. I again express my sincere thanks to Emitec India, Emitec GmbH, and Corning Inc. to have given permission for reproduction of some of their illustrations. My family has extended their love and full support to me in this endeavor and I am indebted to them for it. Finally, I thank my publishers Narosa Publishing House Pvt. Ltd for their continued support.

B. P. Pundir

November 2017

Preface to First Edition

Air pollution caused by emissions from engines especially that power the road transport in the urban centers all over the world has been of serious concern for the last several decades. In the early 1960's, legislation was enacted in the USA and, the European countries followed soon after and passed laws to control the engine and vehicle emissions. Since then, more and more stringent emission regulations have been enforced and many countries have joined this effort. In the recent years, global warming caused by carbon dioxide emissions has added another dimension to the engine development. The engines and vehicles are being developed that are fuel efficient and are capable of running on renewable biofuels.

The subject of engine and vehicle emissions and its control has generated considerable interest among practicing engineers researchers and engineering students. It now constitutes an important topic of the course on Internal Combustion (IC) Engines taught to the engineering students. Many academic institutes offer this subject as an independent course to the post-graduate students who have already studied basic course on IC engines. Text books mostly cover the engineering science aspects in detail but do not devote much space to the emission standards, test procedures and control technology. To the practicing and research engineers detailed coverage of various interrelated topics on the subject is generally not available in a single book. Only a few reference books are available on the subject and these lack coverage of the newer technological developments that have taken place in the recent years. The practicing engineers are required to refer several sources for the necessary information. The author has worked in this area for over two decades as a researcher, teacher consultant and member of national committees to formulate national vehicle emission standards and implementation strategy keeping in view the vehicle and emissions control technology and fuel quality that can be introduced in marketplace in the available time frame. Lack of a book that provided coverage of various interrelated topics and current advancements in emission control technology motivated the author to write the present book.

This book has been written with emission of pollutants from the internal combustion engines as the central theme. Chapter 1 provides introduction to the effect of engine pollutants on environment and health. The processes that cause formation of pollutants in engines and, various engine design and operation parameters affecting the emission discussed in Chapter 2. Evolution of emission standards and test procedures, and measurement methods are discussed in Chapter 3 in more details than generally found in most books. Chapter 4 discusses advances in SI engine emission control technology. Newer developments to meet the ULEV, SULEV and PZEV emission targets are covered. Gasoline direct engine development and other modern engine developments like variable valve timing and lift technology are discussed. Chapter 5 discussed CI engine emission control technology including trends in use of ultra high injection pressures, diesel particulate filters, lean de-NO_x catalysts and HCCI concepts, which would constitute key emission control components on future diesel engines.

Fuel quality has strong inter-relationship with modern low emission engine technology. Finally, Chapter 6 is devoted to the effect of quality of conventional petroleum fuels and alternative fuels on emission. The trends in fuel quality necessitated by the vehicle emission regulations over the years are discussed.

This book is intended for the interested senior under graduate and post graduate students, practicing engineers and researchers. The book provides the breadth at senior UG and PG level that was felt necessary while teaching a course for several years on the subject. The reader is expected to be familiar with the working processes and basic design features of the reciprocating internal combustion engines.

I wish to express my thanks to many people, faculty and friends who provided valuable inputs during preparation of this text. I thank especially Prof. P. S. Mehta, IIT Madras, Prof. R. P. Sharma (formerly at IIT Madras), Prof. P. K. Panigrahi, IIT Kanpur and Prof. K. Murlidhar. Head, Mechanical Engineering, IIT Kanpur for their valuable suggestions and help. I express my deep gratitude to my daughter-in-law, Manju who besides providing immense help in preparation of figures for the book, kept on encouraging me to complete this task. Special thanks are due to Mr. Manoj Sharma for providing help in preparation of the manuscript.

I wish to acknowledge the following publishers for their kind permission to reproduce figures from their publication: SAE International, John Wiley and Sons Inc., Elsevier, and Council of the Institution of Mechanical Engineers, London. I also express my thanks to Emitec Indian, Emitec GmbH, and Corning Inc. to have given permission for reproduction of some of their illustrations.

Finally, the financial support provided by the Centre for Development of Technical Education (CDTE), Indian Institute of Technology, Kanpur in preparation of this book is gratefully acknowledged, I also thanks Profs. G. Biswas and R. K. Thareja, Chairmen, CDTE for their timely help and support.

B. P. Pundir

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