NOx Emissions Control from Stationary Sources

Student Manual

APTI Course 418

Reorganized & Rewritten 2009 by

Brian W. Doyle, PhD, PE
Doyle Engineering Inc

and

Chuck Solt
Lindh and Associates

Developed by
NESCAUM
September 2009

Editor's Note

The September 2009 edition of APTI 418 is reorganized and written or edited by Brian W. Doyle, PhD, PE and Chuck Solt. It combines material from the original APTI 418 (acknowledged below and the NOx Emissions and Control course developed by the Rutgers Air Compliance Center. Dr. Doyle and Chuck Solt are the original authors of the Rutgers material, which was partially funded by the USEPA. Notes at the beginning of each Chapter credit the authors and origins of the material. The video referred to in the original APTI 418 course (below) is not readily available and references to it have been deleted from the text.

Acknowledgments for the Original 2000 Version

This text combines original content provided by Dr. John R. Richards, Ph.D., P.E., with the content of EPA Workshop T002-99, *Control of Nitrogen Oxides Emissions*, which was broadcast in January 1999 to the APTI Distance Learning Network. The author of this student manual, Dr. Richards, and the editor, Robert M. Schell, are hereby acknowledged for their cooperative integration of the original broadcast materials with extended and updated technical content. The T002-99 Workshop presenters who currently appear in the broadcast video are also acknowledged for the original content they contributed. These materials provided a firm foundation and a companion video for this course. The presenters and the chapters of this manual that contain their contributions are given here.

Chapter 1	Introduction to Nitrogen Oxides Control	Mike Urban
Chapter 2	NO_X Formation in Combustion Processes	Bob Hall
Chapter 3	NO_X Emission Trends and Sources	Douglas Soloman
Chapter 4	NO_X Regulatory Programs	Dave Stonefield, Ravi Srivastava
Chapter 5	Combustion Sources	John R. Richards
Chapter 6	Combustion Modifications	Andy Miller
Chapter 7	Low NO_X Burners	Andy Miller
Chapter 8	NO_X Reburning	Bob Hall
Chapter 9	Reciprocating Internal Combustion Engines	Jack Wasser
Chapter 10	Gas Turbines	Sims Roy
Chapter 11	Selective Catalytic Reduction	Anne Johnson
Chapter 12	Selective Non-Catalytic Reduction	John R. Richards
Chapter 13	Continuous Emission Monitoring	James A. Jahnke

Disclaimer

This document is not an official policy and standards document and does not constitute U.S. Environmental Protection Agency policy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Classroom Agenda

Course 418
Control of NO_X Emissions

DAY 1

Introduction and Organization of the Course

Pre-test

Chapter

1 Introduction to NOx Control

Regulation of NO_X
Definition of NO_X
Origins of NO_X
NO_X formation mechanisms in combustion processes
Anthropogenic sources
NO_X emission trends
Ozone season emissions
Emissions projections

2 NO_X Regulatory Programs

Introduction
NO_2 NAAQS
Ozone NAAQS
PM_{10} and $PM_{2.5}$ NAAQS
Visibility impairment
Historic review of ozone control strategies
Acid rain
Other programs

3 Combustion Systems & NOx

Diffusion and premixed flames
Flame temperatures
Boiler burners
Reciprocating engines
Combustion turbines

4 NOx Control by Reducing Temperature

Flame temperature and NOx
Water Injection
Flue gas recirculation
Lean Premixed combustion
Summary

Classroom Agenda

Course 418
Control of NO_X Emissions

DAY 2

Chapter

5 Oxygen Based NOx Controls

Combustion staging concepts

Reduced Excess Air

Stratified combustion in large furnaces

Low NOx burners

Reburning

Summary

6 Reciprocating Internal Combustion Engines

Combustion control

Post-combustion control

Case study

7 Gas Turbines

Introduction

Combustion modification controls

Post combustion controls

8 Back End Controls

Selective non-catalytic reduction (SNCR)

Selective catalytic reduction (SCR)

Non-selective catalytic reduction (NSCR)

Emerging Technologies

Summary

Classroom Agenda

Course 418
Control of NO_X Emissions

DAY 3

Chapter

9 Emission Measurement, Monitoring & Reporting

CEM regulatory program

Measurement techniques

CEM systems

Quality assurance and quality control

Oxygen concentration monitors

Emissions calculations

10 Inspecting Permitted Emission Sources

Review of the Pre-test

Post-test

Adjourn

TABLE OF CONTENTS

ACRONYMS

ACRONYMS	Definitions
ACFM	Actual cubic feet per minute
AEL	Alternative emission limit
AIRS	Aerometric Information Retrieval System
BACT	Best available control technology
BBF	Burner biased firing
BDC	Bottom dead center
BEISE-2	Biogenic Emissions Inventory System-2
BOOS	Burners out of service
Btu's	British thermal units
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAM	Compliance Assurance Monitoring
CCOFA	Close coupled overfire air
CCT	Clean coal technology
CEM	Continuous emission monitoring
CFB	Circulating fluid beds
CFD	Computational fluid dynamic
CGA	Cylinder gas audit
CGSU	Centimeter gram second units
COFA	Closed overfire air
DAS	Data acquisition system
DOD	Department of Defense
DLN	Dry low NO_X
DOE	Department of Energy
DSCFM	Dry standard cubic feet per minute
EAA	Electric aerosol analyzer
EDS	Energy dispersive X-ray spectroscopy
EGR	Exhaust gas recirculation
EGU	Electric generating units
EPA	Environmental Protection Agency

EPRI	Electric Power Research Institute
ESP	Electrostatic precipitator
FBC	Fluid bed combustors
FEGT	Furnace exit gas temperature
FETC	Federal Energy Technology Center
FGC	Flue gas conditioning
FGR	Flue gas recirculation
FHA	Federal Highway Administration
FIP	Federal Implementation Plan
fpm	Feet per minute
FRP	Fiberglass reinforced plastics
GFC	Gas filter correlation
GCVTC	Grand Canyon Visibility Transport Commission
HAP	Hazardous Air Pollutant
HPMS	Highway Performance Monitoring System
HRSG	Heat recovery steam generator
IC	Internal combustion
ID Fan	Induced draft fan
INFR	In-furnace Reduction
IR	Infrared
KW	Kilowatt
kWh	Kilowatt hour
LAER	Lowest achievable emission rate
LEA	Low excess air
LEL	Lower explosive limit
LNB	Low-NO_X burners
LOI	Lost on ignition
MACT	Maximum achievable control technology
MC	Medium cure
MMD	Mass median diameter
MND	Median number diameter
MNL(s)	Multiple nozzle lances
MVD	Median volume diameter

MW	Megawatt
MWe	Megawatts of electrical power
MWh	Megawatt-hour
NAAQS	National Ambient Air Quality Standards
NAPAP	National Acid Precipitation Assessment Program
NDIR	Nondispersive infrared
NDUV	Nondispersive ultraviolet
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NET	National Emission Trends Inventory
NIST	National Institute of Standards and Technology
NOTR	Northeast Ozone Transport Region
NO_X	Nitrogen Oxides
NSPS	New Source Performance Standards
NSR	New Source Review
OFA	Over fire air
OMS	Office of Mobile Sources
OTAG	Ozone Transport and Assessment Group
OTC	Ozone Transport Commission
PEMS	Predictive emission monitoring systems
PIC	Products of incomplete combustion
ppm	Parts per million
PSD	Prevention of significant deterioration
PSI	Pounds per square inch
PSIG	Pounds per square inch gauge
PTFE	Polytetrafluoroethylene
PURPA	Public Utilities Regulatory Policies Act
R&D	Research and development
RA	Relative accuracy
RAA	Relative accuracy audit
RACT	Reasonably available control technology
RATA	Relative accuracy test audit
RC	Rapid cure
RM	Reference method

RPM	Revolutions per minute
SARA	Superfund Amendments and Reauthorization Act
SC	Slow cure
SCA	Specific collection area
SCAQMD	South Coast Air Quality Management District
SCFM	Standard cubic feet per minute
SCR	Selective catalytic reduction
SEM	Scanning electron microscopy
SERDP	Strategic Environmental Research and Development Program
SI	Spark ignition
SIP(s)	State Implementation Plan(s)
SMD	Sauter mean diameter
SNCR	Selective non-catalytic reduction
SOFA	Separated over fire air
SR	Stoichiometric ratio
SRM	Standard Reference Materials
SS	Slow setting
STP	Standard temperature and pressure
TDC	Top dead center
T-R	Transformer rectifier
TSP	Total suspended particle
UBC	Unburned carbon
ULNB	Ultra low-NO_X burners
UV	Ultraviolet light
VMT	Vehicle miles traveled
VOCs	Volatile organic compounds
W.C.	Water column

FORWARD

This student manual is intended both as a reference and to be used in the classroom as a supplement to the slide presentation.

This manual is organized into 10 chapters that examine the environmental importance of NO_x, its regulation, how it is formed in various combustion sources and the control technologies.

- Chapter 1, *Introduction,* introduces NO_X. formation and sources
- Chapter 2, *Regulations,* presents a discussion of NO_X–related emissions regulations, which increasingly focuses on stationary source emitters.
- Chapter 3, *Combustion Systems & NOx,* is a primer on types of flames and combustion sources.
- Chapter 4, *Flame Temperature Based NOx Controls,* discusses various ways to reduce flame temperature including lean premixed combustion.
- Chapter 5 O*xygen Based NOx Controls*, discusses various air and fuel staging techniques leading to low NOx burners.
- Chapter 6, *Reciprocating Internal Combustion Engines*, discusses NOx reduction from reciprocating engines – increasingly used in distributed generation
- *Gas Turbine NOx Control* is discussed in Chapter 7.
- *Back End NOx Control* systems are discussed in Chapter 8, including emerging technologies
- Chapter 9, *Emission Measurement, Monitoring & Reporting*, presents the basic concepts of monitoring and reporting NO_X emissions.
- Chapter 10, *Inspecting NOx Sources*, is an overview of how to inspect a combustion source with particular emphasis on NOx emissions.

The manual is organized similarly to the instructor presentations included in the slide presentation of the course.