Cooper Machinery Services
16250 Port Northwest
Houston, Texas 77041

Course Name: **Combustion Theory and Emissions Reduction Class**

Course Length: Classroom lecture with problem solving exercises – 4.5 days

Prerequisites: Basic to mid-level knowledge of reciprocating internal combustion engines.

Target Audience: Rotating equipment engineers, managers, and technical personnel responsible for the safe, reliable, efficient, and emission compliant operation of reciprocating internal combustion engines.

Goal: Provide advanced knowledge of combustion in reciprocating internal combustion engines and how it is affected by operations and external factors.

CLASSROOM ACTIVITIES/TOPICS	SCHEDULE
SECTION ONE – Day 1 (8:00 am – 4:30 pm)	
COOPER COMPANY INTRODUCTION • Introduction to Cooper Machinery Services • Review the product and service offerings	**8:00 am – 9:00 am**
Chapter 1: COURSE INTRODUCTION • Introduction to the eight (8) changes that affect the operation and performance of reciprocating internal combustion engines: • Speed – Chapter 4 • Torque – Chapter 5 • Air/fuel ratio– Chapter 6 • Detonation- Chapter 7 • Ignition timing– Chapter 8 • Misfire– Chapter 9 • Dead Cylinder– Chapter 9 • Pre-Ignition – Chapter 10 • Review the engine models of the class participants.	**9:00 am – 10:00 am**
Session Break – 15 Minutes	**10:00 am – 10:15 am**
Chapter 2: FUNDAMENTALS OF RECIPROCATING INTERNAL COMBUSTION ENGINES (RICE) • Describe the cycle of events for a reciprocating internal combustion engine: Power, Exhaust, Intake, and Compression. • Describe and understand the difference between 2-stroke cycle or 4-stroke cycle operation and performance.	**10:15 am – 11:00 am**
Chapter 3: ENGINE AND COMPRESSOR ANALYSIS • Understand the use and capabilities of portable engine and compressor analyzers to diagnose the equipment performance:	**11:00 am – 12:00 pm**

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• Verify normal operating conditions • Compare actual current information to empirically proven data • Prevent minor mechanical problems from becoming serious even catastrophic failures	
Lunch Break – 1 Hour	**12:00 pm – 1:00 pm**
Chapter 3: ENGINE AND COMPRESSOR ANALYSIS – Continued	**1:00 pm – 2:30 pm**
Session Break – 15 Minutes	**2:30 pm – 2:45 pm**
Chapter 3: ENGINE AND COMPRESSOR ANALYSIS – Continued	**2:45 pm – 4:00 pm**
COOPER SOLUTIONS: EQUIPMENT ANALYSIS • Equipment Analytics: Periodical in-person or remote data collection, performance analysis, and diagnostic reporting. • Remote Condition Monitoring: Continuous data collection and analysis with diagnostic and maintenance recommendations	**4:00 pm – 4:30 pm**
SECTION ONE – Day 2 (8:00 am – 4:30 pm)	
Chapter 4: HORSEPOWER • Define horsepower as work performed over a unit of time (PLAN/33,000) • Torque = Mean Effective Pressure (MEP) • Explain the following: • The first law of thermodynamics - conservation of energy • The ways to change horsepower on a compressor • The effects of clearance on the compressor cycle • Torque and the three things that the magnitude of torque depends on • Bowdoin's law	**8:00 am – 10:00 am**
Session Break– 15 Minutes	**10:00 am – 10:15 am**
Chapter 5: ENGINE BALANCE • Describe components that make up an engine health report • Explain the important factors affecting engine balance including pressures, timing, and temperatures of each cylinder. • Understand critical problems associated with an engine balancing • Explain the impact of standing waves in the fuel manifold • Understand the advantages to balancing engines	**10:15 am – 11:30 am**
COOPER SOLUTIONS: MAINTENANCE AND TROUBLESHOOTING • OEM certified, quality parts and kits • OEM certified maintenance personnel and field service representatives • World class engineering and troubleshooting expertise	**11:30 am – 12:00 pm**
Lunch Break – 1 Hour	**12:00 pm – 1:00 pm**

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Chapter 6: AIR/FUEL RATIO - THE PARABOLIC BURNING CURVE
• Describe the fire triangle of combustion
• Understand the common air/fuel ratio control methodologies
• Understand the differences in combustion between:
  • Rich-burn engines
  • Lean-burn engines
  • Clean or ultra lean-burn engines
• Understand the impact of air/fuel ratio based on fuel gas BTU, flame front velocity, peak firing pressure, and peak firing angle.
	1:00 pm – 2:30 pm

Session Break – 15 Minutes	**2:30 pm – 2:45 pm**
Chapter 6: AIR/FUEL RATIO - THE PARABOLIC BURNING CURVE – Continued	**2:45 pm – 4:30 pm**
SECTION ONE – Day 3 (8:00 am – 4:30 pm)	
Chapter 7: DETONATION • Define detonation, why it happens and how it affects the engine • Explain deflagration and detonation • Understand the parabolic burning curve	**8:00 am – 9:00 am**
Chapter 8: IGNITION TIMING • Explain ignition timing and how it is used in combustion control • Understand the effects of changing ignition timing on combustion	**9:00 am – 10:00 am**
Session Break – 15 Minutes	**10:00 am – 10:15 am**
Chapter 9: MISFIRES AND DEAD CYLINDERS • Define misfires and dead cylinders as they relate to combustion • Understand the causes and effects of misfires and dead cylinders on engine performance, reliability, and emission performance	**10:15 am – 11:15 am**
Chapter 10: PRE-IGNITION • Define pre-ignition • Explain the causes and detrimental effects of detonation and pre-ignition	**11:15 am – 12:00 pm**
Lunch Break – 1 Hour	**12:00 pm – 1:00 pm**

Chapter 11: CHANGING SPEED
• Explains the impact of increasing / decreasing speed on engine combustion and performance.
  • Impact on station conditions (compressor pressures and flow)
  • Impact on engine performance and combustion
	1:00 pm – 2:00 pm

Chapter 12: EMISSIONS • Explain emission formation in reciprocating engine combustion: • Nitrous oxides (NO_x) and Carbon emissions (CO, H_xC_x, CO_2, CH_2O)	**2:00 pm – 2:30 pm**

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• Explain emission formation rate versus combustion temperatures • Understand relationship of NOx and Carbon Emissions to the Parabolic Burning Curve • Understand the relationship of Oil Nitration and Oxidation to air/fuel ratio • Explain the role of Oxygen and Formaldehyde in emission • Understand application and use of catalytic converters in emissions reduction	
Session Break – 15 Minutes	**2:30 pm – 2:45 pm**
Chapter 12: EMISSIONS – Continued	**2:45 pm – 3:30 pm**
COOPER SOLUTIONS: EMISSIONS SOLUTIONS & REPLACEMENT ECONOMICS • Emissions challenges for reciprocating engines (NOx, CO2, and methane) • Economic and technical analysis of emissions upgrades versus engine replacement. • Slow Speed Emissions Upgrade: Cooper-Bessemer®, Clark Enterprise®, Ingersoll Rand, Worthington slow speed engines solutions. • Ajax integral gas compressors upgrades: Solutions to increase Ajax power, reliability and emissions. • Superior engines upgrade solutions: Emissions upgrade solutions	**3:30 pm – 4:30 pm**
SECTION TWO: COMBUSTION APPLICATION & PROBLEM SOLVING – Day 4 (8:00 am – 4:30 pm)	
Chapter 13: AUTOMATION AND CONTROLS • Describe the critical control systems that impact combustion and performance. • Explain constant torque variable speed verse constant speed variable torque • Describe supporting automation and controls related: • Alarms and Safety Shutdowns • Operating Parameters (temperature, pressure, flow, vibration) • Start-up, Stop and Loading Sequences • Speed Control • Torque Control • Compressor Load Control (Recycle Valves, Suction Control Valve, Unloading Devices and Schedule) • Ignition Timing Control • Air/Fuel Ratio Control	**8:00 am – 9:00 pm**
ENGINE COMBUSTION APPLICATION & PROBLEM SOLVING (Part I) • Review changes to the unit – engine and compressor in relation to: • Load • Speed • Air/Fuel Ratio • Ignition Timing • Misfires • Dead Cylinders	**9:00 am – 10:00 am**

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• Pre-Ignition • Detonation • Solve and predict outcome for 12 most common problems and scenarios	
Session Break – 15 Minutes	**10:00 am – 10:15 am**
• Solve and predict outcome for 12 most common problems and scenarios (continued)	
Lunch Break – 1 Hour	**12:00 pm – 1:00 pm**
• Solve and predict outcome for 12 most common problems and scenarios (continued)	**1:00 pm – 2:30 pm**
Session Break – 15 Minutes	**2:30 pm – 2:45 pm**
• Solve and predict outcome for 12 most common problems and scenarios (continued)	**2:45 pm – 4:30 pm**
SECTION TWO: COMBUSTION APPLICATION & PROBLEM SOLVING – Day 5 (8:00 am – 12:30 pm)	
ENGINE COMBUSTION APPLICATION & PROBLEM SOLVING (Part II) • Identify client problems and situations • Solve and predict outcome to client problems.	**8:00 am – 10:00 am**
Session Break – 15 Minutes	**10:00 am – 10:15 am**
• Solve and predict outcome to client problems (continued)	**10:15 am – 11:30 am**
Summary of the Week and Final Comments / Cooper Solutions	**11:30 am – 12:00 pm**