"Main Research Activities of NTUA-Internal Combustion Engines Laboratory"

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1. Research Activities of NTUA/ICEL

- Internal Combustion Engine Simulation focusing on engine performance and emissions.
- Detailed phenomenological models (single & multi-zone) of combustion in reciprocating diesel engines including simulation of:
  - ✓ Split (pilot & post) Injection cases.
  - ✓ Alternative Combustion cases.
- Rich Diesel Combustion for Regeneration of NOx Traps.
- Emission Reduction Techniques (EGR & Other Internal Measures).
- Diesel engine condition monitoring and fault diagnosis.
- Advanced Technologies for the Reduction of Diesel Engine Exhaust Gas Emissions (NOx & Soot) i.e.SCR, EGR, Scrubbers etc
- Experimental Investigations for the Use of Alternative Fuels on Diesel Engines.
- Development and application of specified software to conduct real-time engine measurements (cylinder pressure measurements).
- Software for processing of measured engine data for the estimation of engine operating parameters (cylinder power output & heat release rate etc.).
- Dual Fuel Combustion

2.1 INDICATIVE NTUA PARTICIPATION IN EU RESEARCH PROJECTS

- “Influence of fuel Formulation on Particulate formation in Diesel engine Combustion”. JOULE-II (JOU2-CT93-0379) in cooperation with, ELF, DAIMLER-BENZ (MERCEDES), BP, FEV Motor-Technik.
- “High Fuel Efficiency Diesel engine with significantly increased peak pressure”. BRYTE EURAM-III (Bryte Euram III, /HEDE BRPR-CT97-0451) in cooperation with DIAMLER-BENZ (MERCEDES), AVL, Goetze κλπ.
- “Determination of an Aromatic Content Threshold in Diesel Fuels concerning the Soot/Particulate and gaseous Pollutant Emissions”. JOULE-III (JOF3-CT97-0030) in cooperation with FEV Motor-Technic, Noeste Oil, κλπ.
- “New Diesel Engines and New Diesel Fuels-Influence of Future Fuel Formulations on Emissions and Performance of New DI Diesel Technology”. Growth (G5RD-CT1999-00021) in cooperation with FEV, IFP, Fortum.

2.2 Continued

- "Development of a Simulation Model for the Air-Fuel Mixing and Combustion Mechanism of DI Diesel Engines for CATERPILLAR Inc. USA.". Funded by CATERPILLAR Inc. USA.
- "PLN-based Improved Combustion for Low Emission". GROWTH Project with Daimler Chrysler (Mercedes), AVL και Robert Bosch S.A. etc.
- "Advanced Heavy Duty Diesel Engine Aftertreatment Technology", AHEDAT. GROWTH Project with Daimler Chrysler (Mercedes), AVL, Johnson Mathhey etc.
- "Development of a Portable Diagnostic System for Diesel Engines". Funded by Public Power Corp. (PPC)
- "Green Heavy Duty Engine", IP Project, FP6.
- "Development, Construction & Application of a diesel engine diagnostic system for the Hellenic Railway Organisation (OSE)".

Indicative Results from NTUA Research Activities

- Results from NTUA Multi-Zone Combustion Model.
- Results for HD-DI diesel engine exhaust heat recovery-Turbocompounding & Rankine Bottoming Cycle.
- Results from the Diagnostic Technique for Marine and Stationary Diesel Engine Applications.

3. Indicative Results using NTUA multi-zone simulation model

Focusing on multi-zone modeling of combustion

- NTUA/ICEL has developed a multi-zone simulation model for diesel combustion and emission formation.
- The on-going research interest is to develop A simulation model to predict engine performance and emissions in the following cases:

  i) Split (pilot & post) Injection cases.

  ii) Alternative Combustion Techniques.
- For this purpose, the simulation model has been validated on a Heavy Duty Diesel Engine equipped with a common rail injection system capable for pilot and post injection.
- Model validation has been conducted by AVL using experimental data under project GREEN.

3.1 Brief Description of NTUA simulation model (2)

Multizone approach introduces models for:

- Fuel spray (breakup length, angle, penetration)
- Air Swirl + Wall impingement
- Air Entrainment into spray zones
- Droplet breakup + evaporation
- Ignition Delay
- Heat & Mass transfer between the zones
- Combustion model (Arrhenius type reaction rate for local vapor)
- NO formation
- Soot formation & oxidation

- **Heavy Duty Diesel Engine with CR Injection**
- **Application Conducted by AVL**

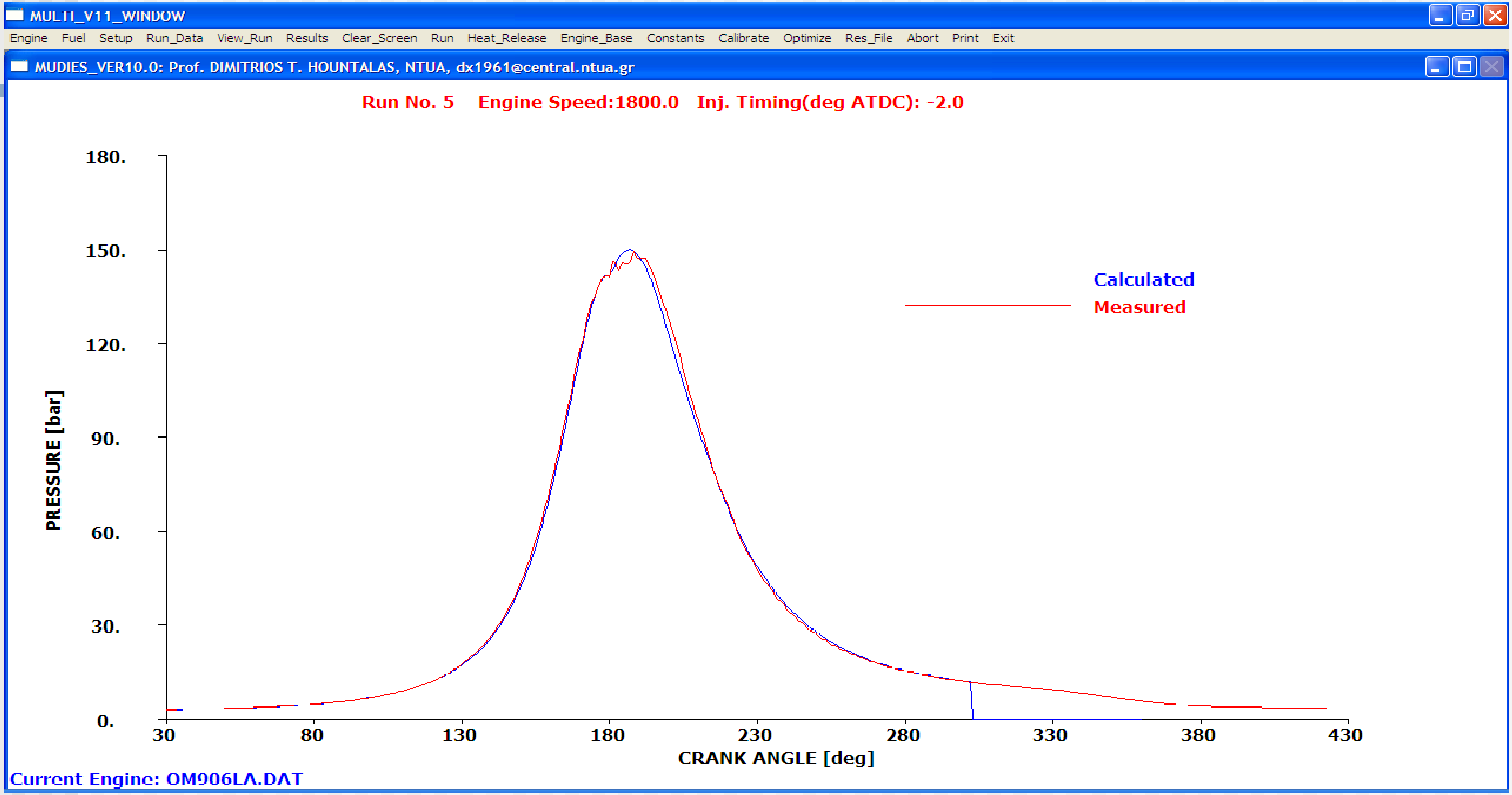
Basic Specifications		
Bore	[mm]	102
Stroke	[mm]	130
Conrod length	[mm]	215
Total displacement	[L]	6.374
Displacement per Cylinder	[L]	1.062
Number of cylinders	[-]	6
Firing order	[-]	1 - 5 - 3 - 6 - 2 - 4
Compression ratio, effective	[-]	18.5
Peak firing pressure	[bar]	180
Fuel injection equipment		Bosch CR-System (1600 bar)
Emission level		below Euro 3
Intake Valve(s)		
Inner valve seat diameter	[mm]	29.2
Number of valves	[-]	2
Valve area related to bore area	[-]	0.164
Exhaust Valve(s)		
Inner valve seat diameter	[mm]	33.45
Number of valves	[-]	1
Valve area related to bore area	[-]	0.108
Valve timing at mm clearance:		
Exhaust / intake	[mm]	1.0
EVO (deg. CRA BBDC)		44
EVC (deg. CRA ATDC)		2
IVO (deg. CRA BTDC)		-3
IVC (deg. CRA ABDC)		0
Fuel		Diesel
Lower heating value	[kJ/kg]	42980
Stoichiometric A/F ratio	[kg/kg]	14.59

Engine Operating Conditions: 12 ESC points

	Engine Speed	BMEP 100 %	BMEP 75 %	BMEP 50 %	BMEP 25 %
	[rpm]	[bar]	[bar]	[bar]	[bar]
A	1400	18.8	14.1	9.4	4.7
B	1800	18.0	13.5	9.0	4.5
C	2200	16.6	12.45	8.3	4.15

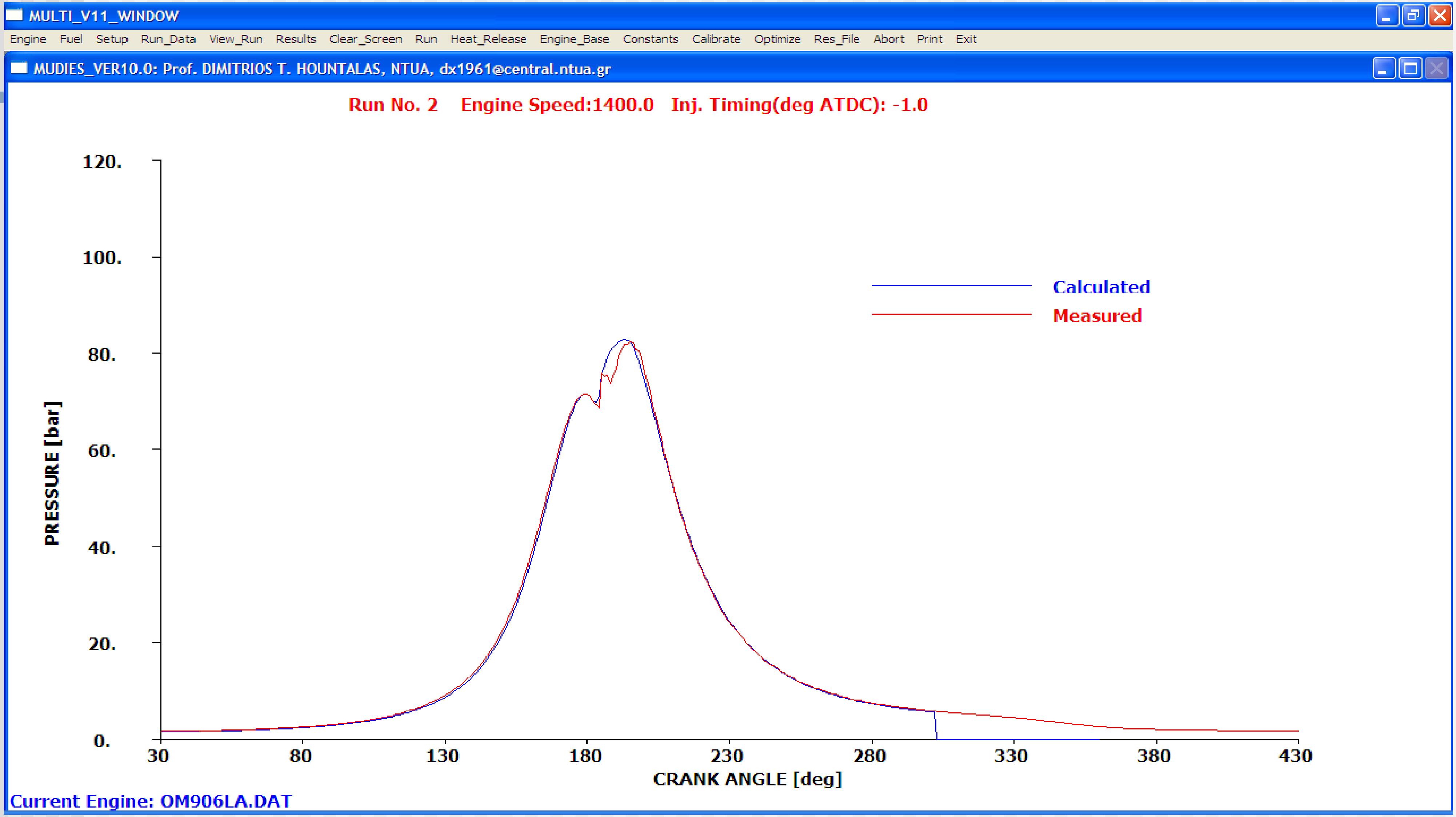
3.4 Results from NTUA multizone model application (1)

Measured vs Calculated Cylinder Pressure trace for B100 point:



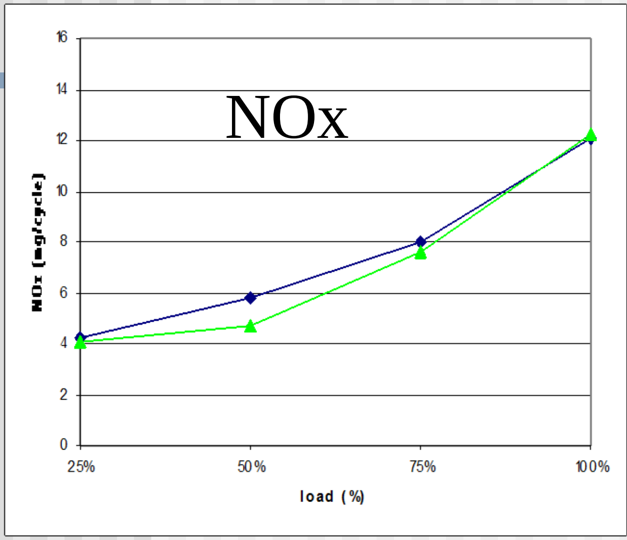
3.5 Results from NTUA multi-zone model application (2)

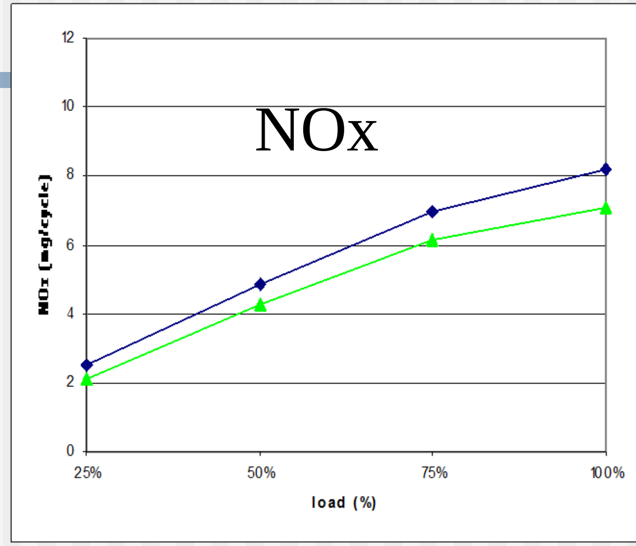
Measured vs Calculated Cylinder Pressure trace for C50 point:

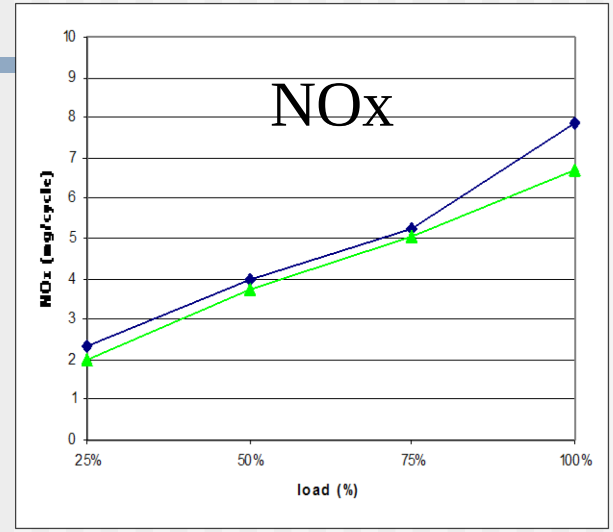


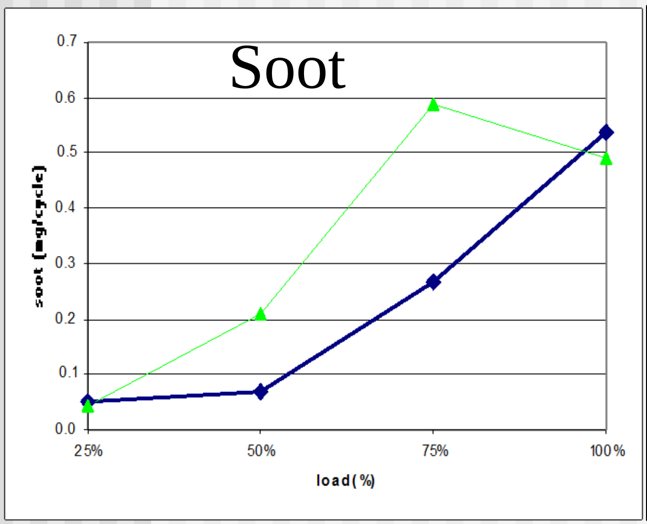
NOx & soot results for the 12 ESC points:

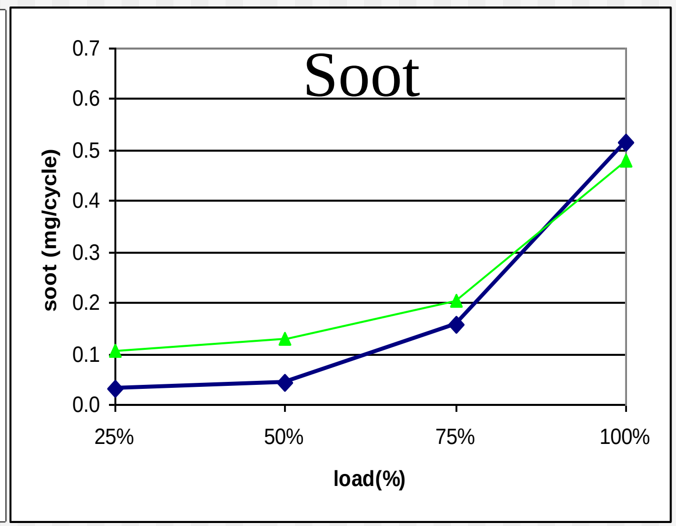
1400rpm **1800rpm** **2200rpm**

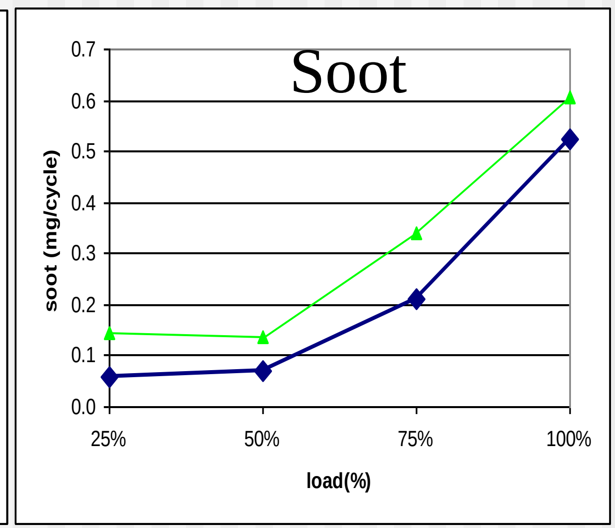












3.8 Results from NTUA multizone model application (5)

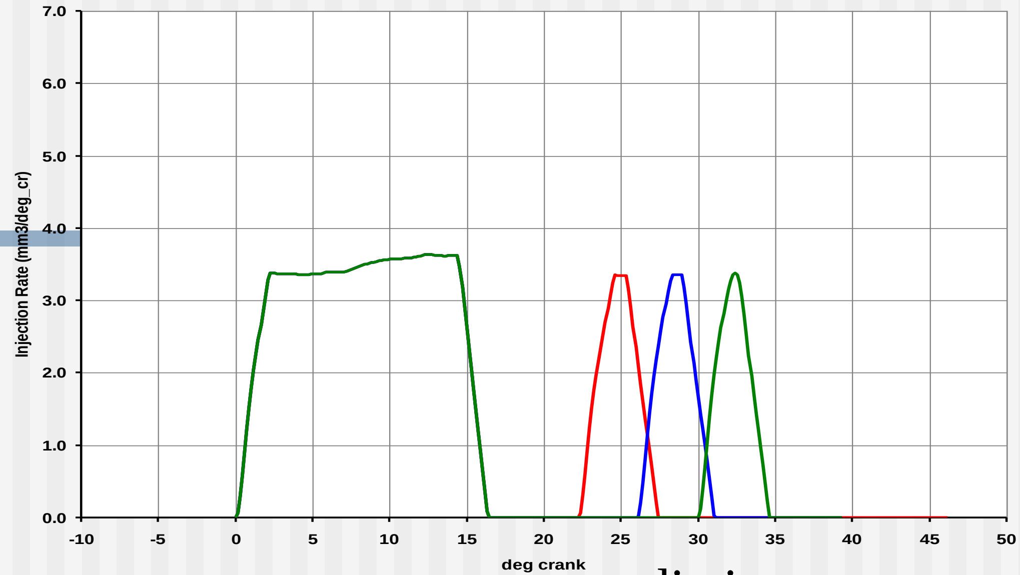
Application of NTUA model on a post injection case:

Post Injection calculations have been conducted for the following cases:

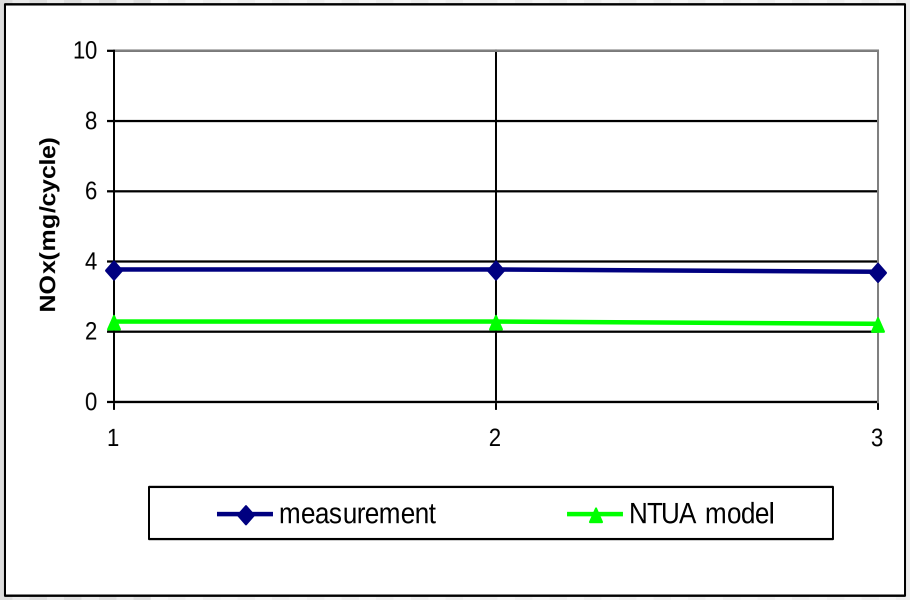
- ✓ **Effect of Dwell Angle.**
- ✓ **Effect of Post Injection Amount.**
- ✓ **Operating Case: B50**

3.9 Results from NTUA multizone model application (6)

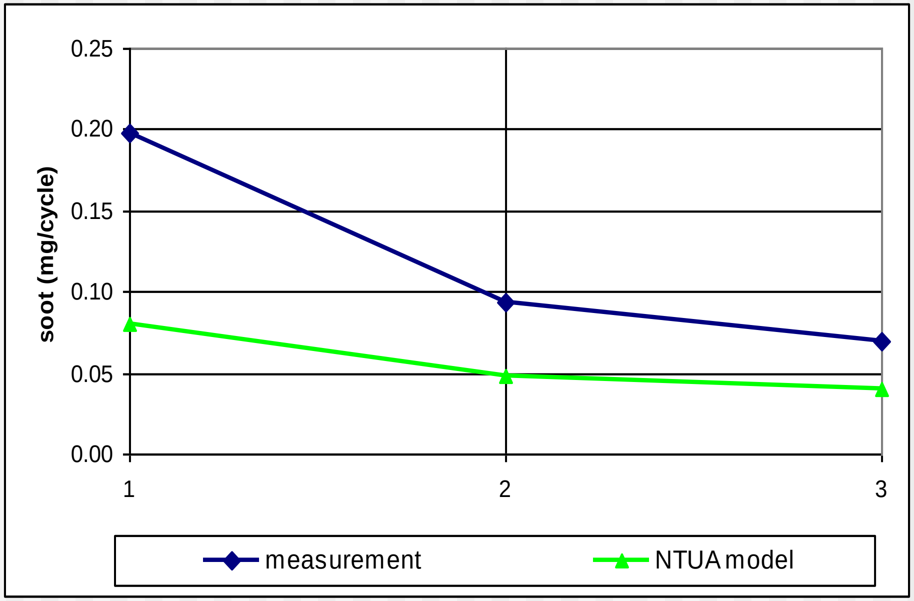
NTUA model applied for a post injection case:



NOx predictions

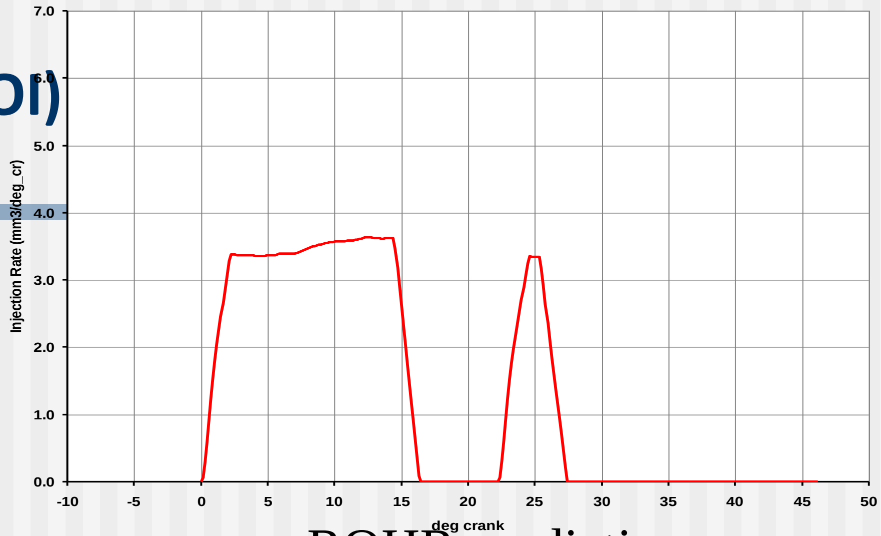


soot predictions



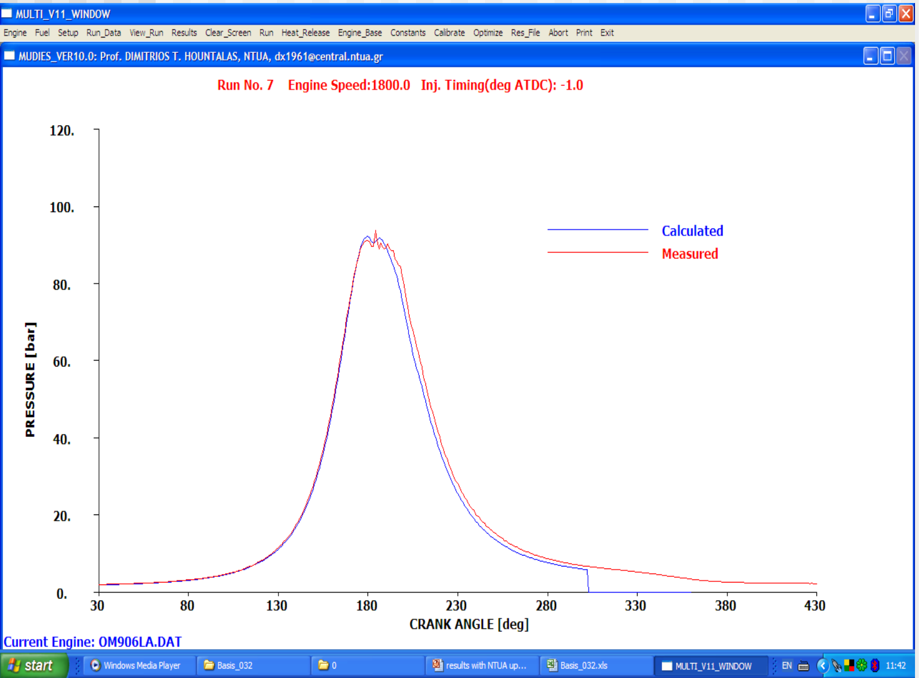
3.10 Results from NTUA multizone model application (7)

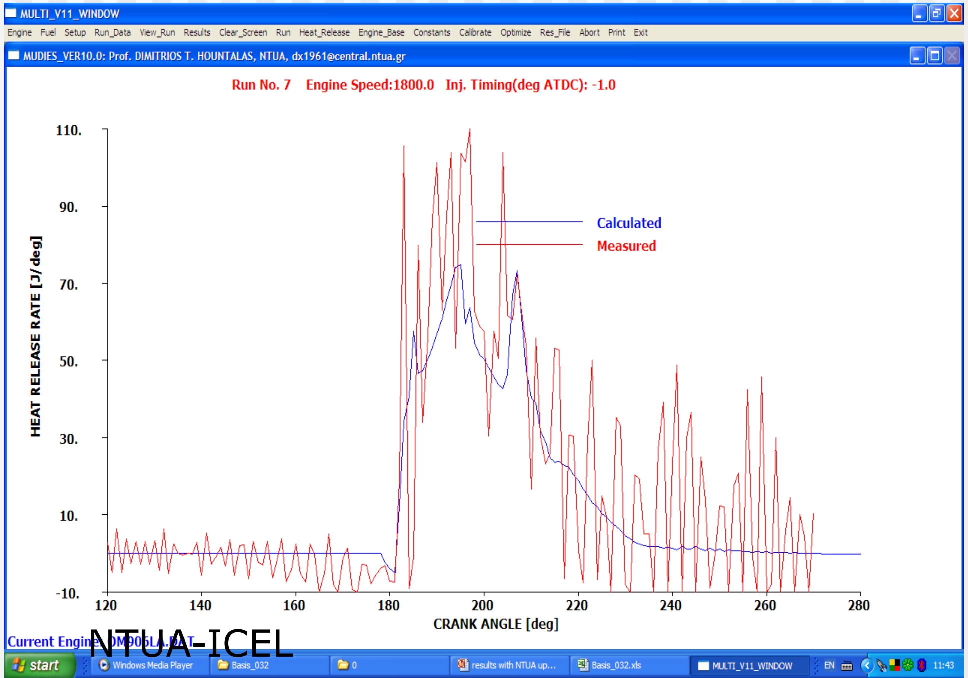
NTUA model predictions for post injection cases: 3rd case (red ROI)



Cylinder Pressure predictions

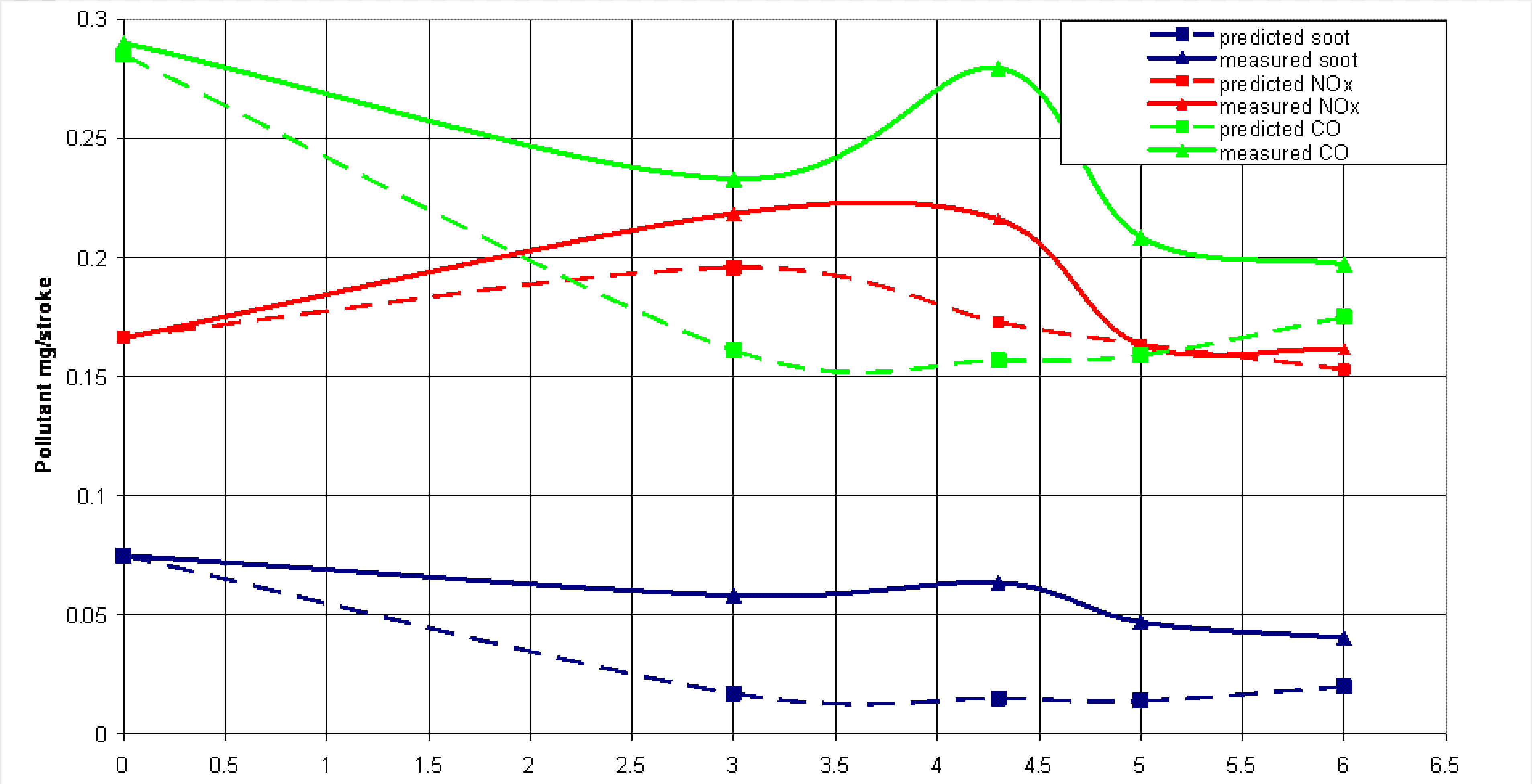
ROHR predictions





3.11 Results from NTUA multizone model application (8)

NTUA model predictions for <u>post injection</u> operation. This picture is provided from industrial partner where the simulation model was applied on a prototype diesel engine without specific calibration for various post injection strategies.



3.12 Applications of NTUA multi-zone simulation model in the Industry

NTUA multizone simulation model has been provided fin the past for internal use to :

- **Caterpillar (has purchased the combustion software).**
- **AVL List GmbH**
- **Robert Bosch S.A.**
- **Daimler Chrysler**

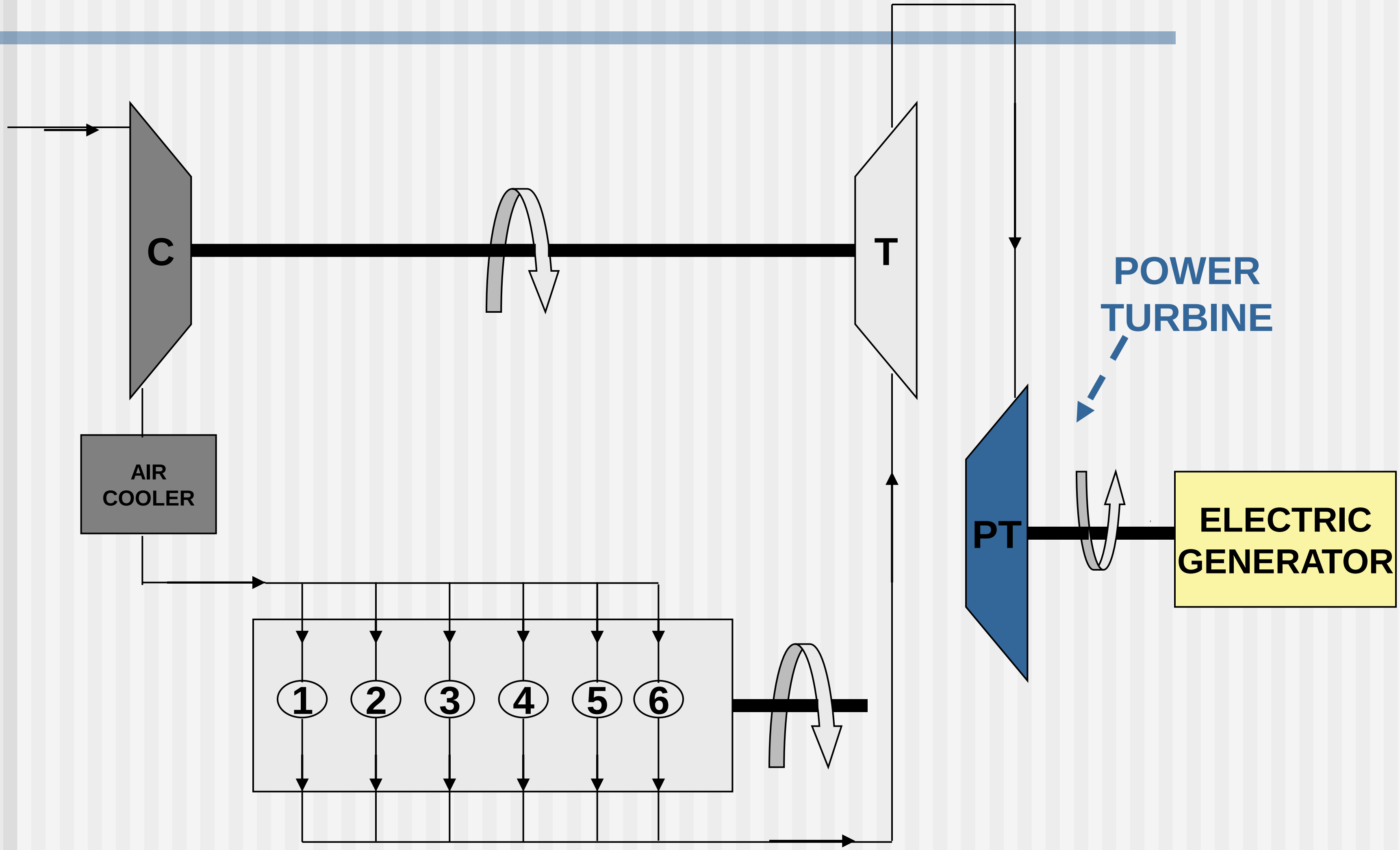
4. Indicative Results Achieved Through Our Participation in Research Project GREEN-Exhaust Heat Recovery

Focusing on Exhaust Gas Aftertreatment Technologies

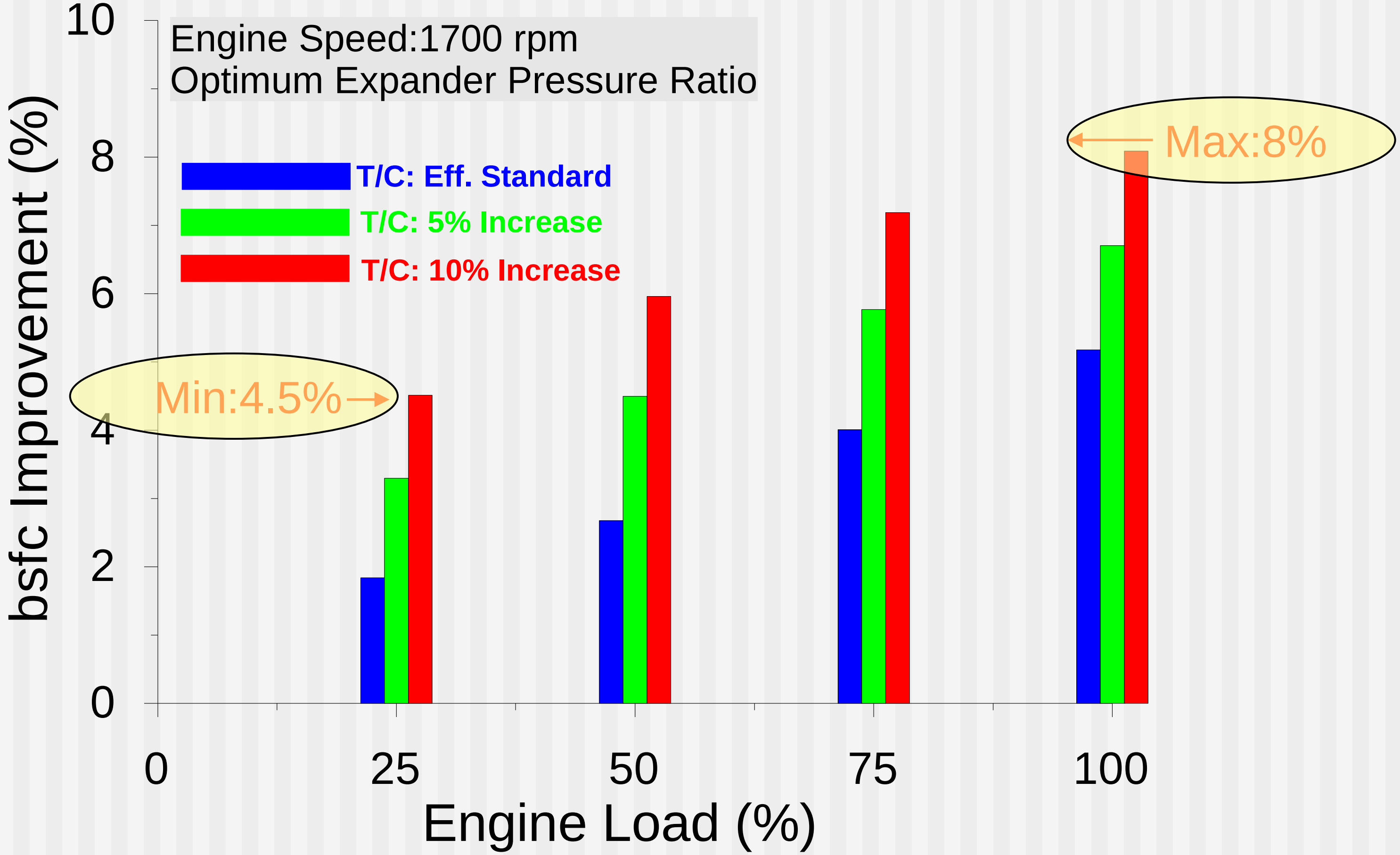
The objectives of our research are:

- **Research Motivation: Diesel engines still reject a considerable amount of fuel chemical energy (30-40% depending on engine load) to the environment through the exhaust gas. For this reason its utilization if possible can significantly improve engine overall efficiency.**
- **Exhaust Heat Recovery Technologies:**
  1) **Turbocompounding. The system uses a power turbine, which is located downstream to the T/C turbine. The power turbine is coupled with an electric generator.**
  2) **Rankine Cycle System using steam or organic as working media.**

ELECTRIC TURBOCOMPOUNDING

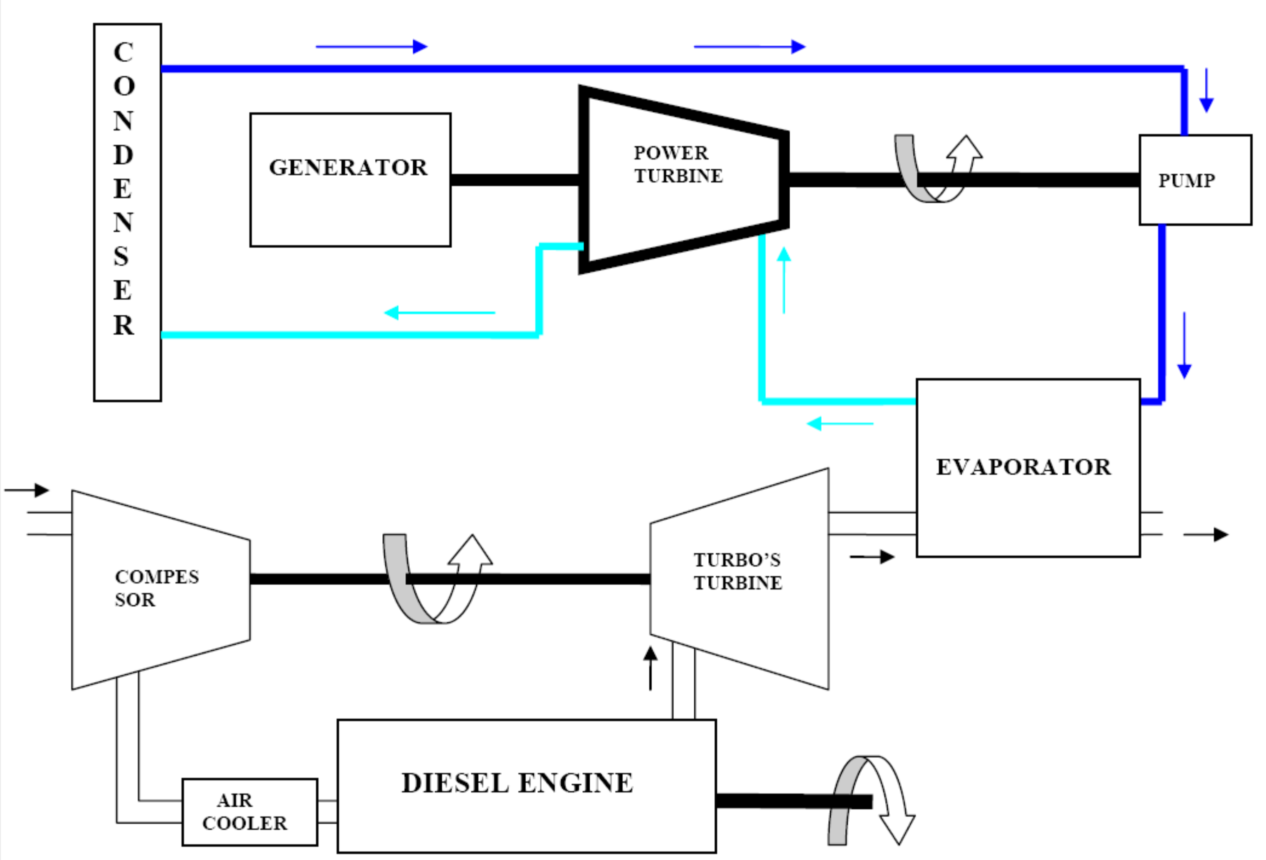


Electric Turbocompounding-Potential Efficiency Gain

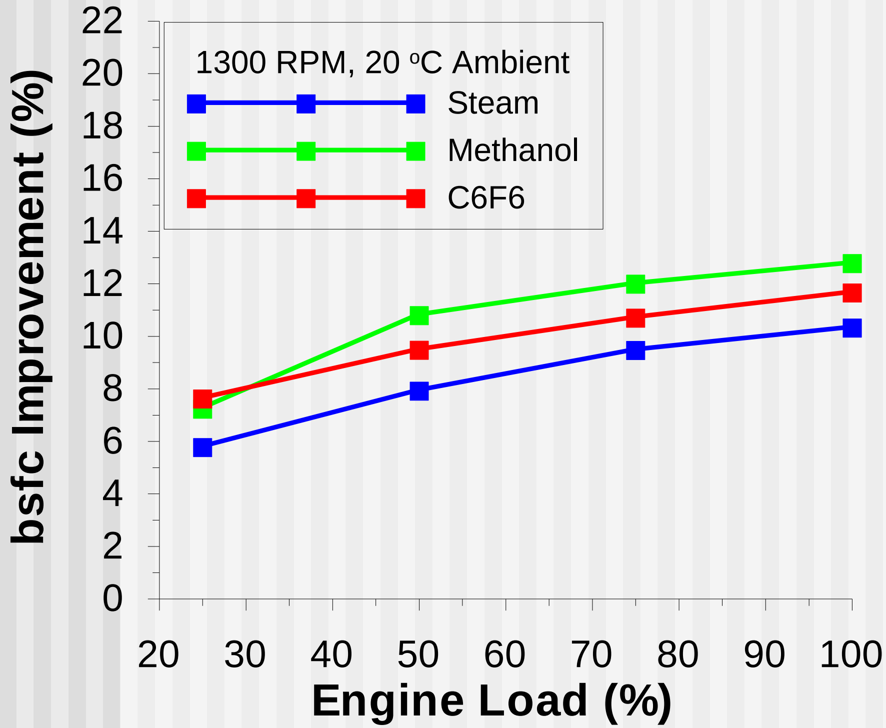


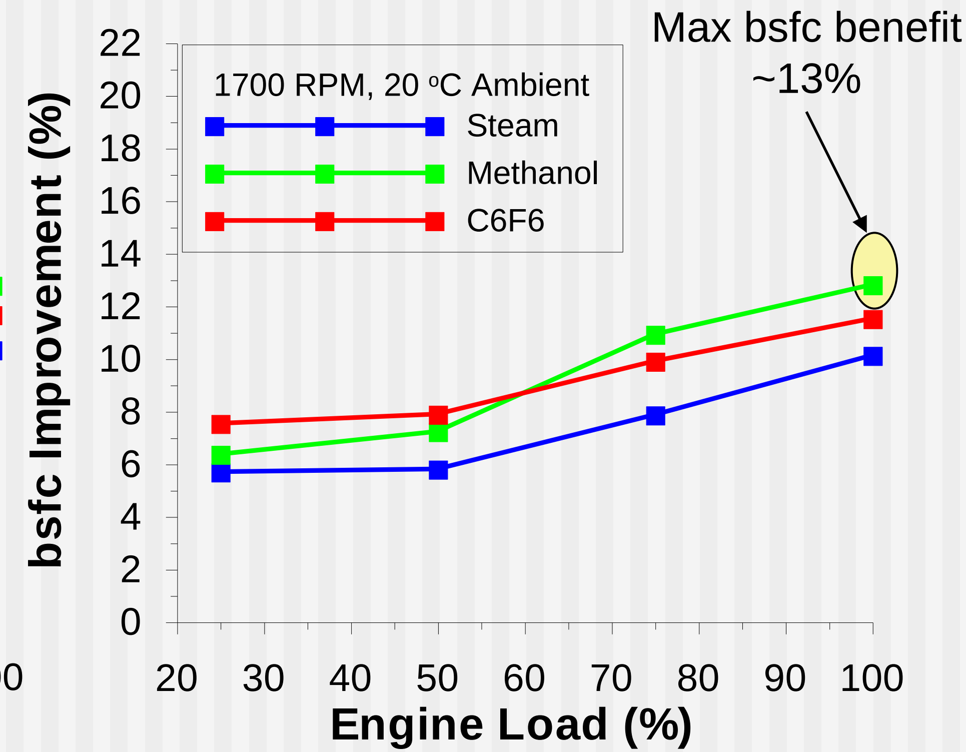
4.3 Results for Exhaust Gas Aftertreatment Technology (3)

RANKINE CYCLE SYSTEM



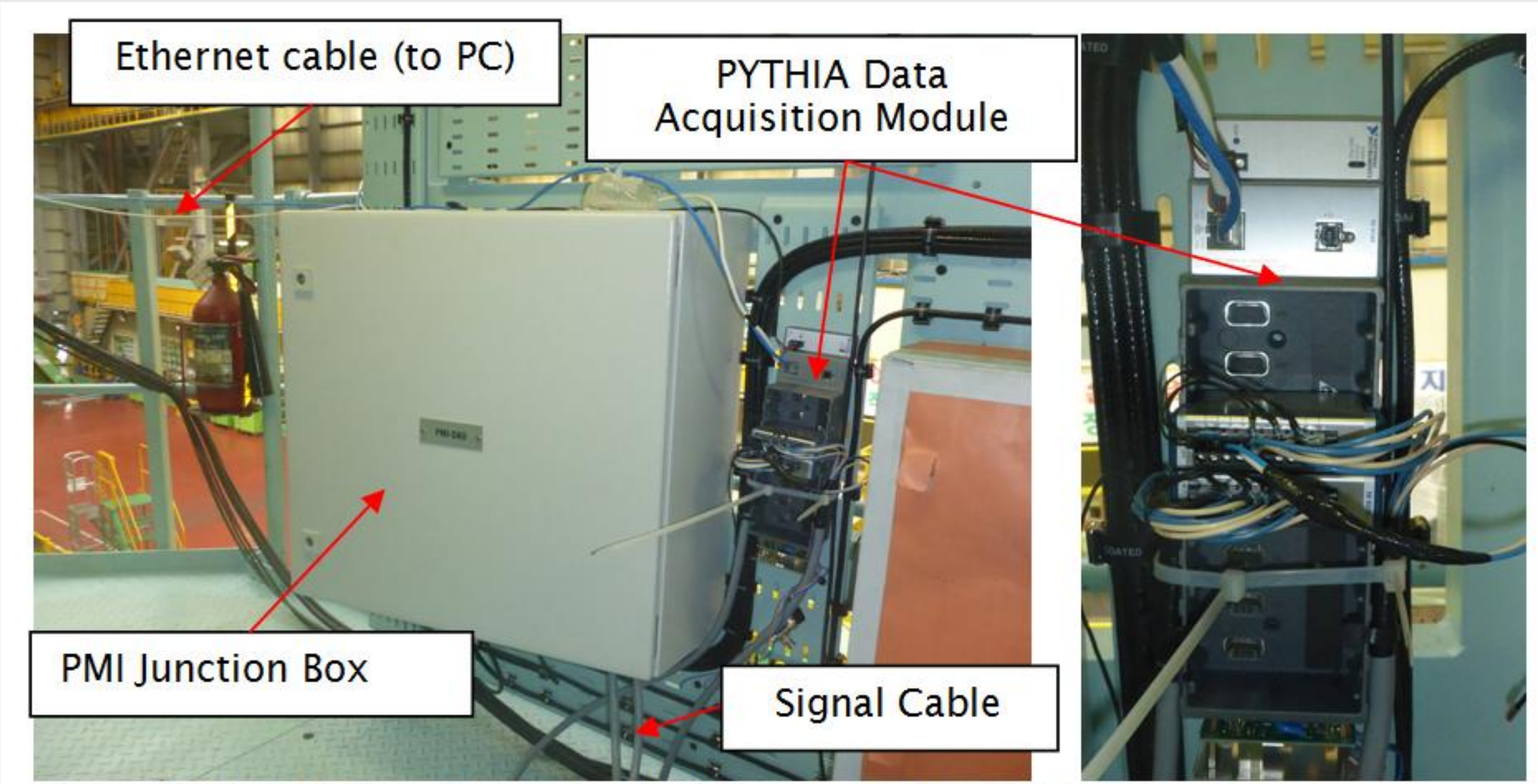
Rankine Cycle-Potential Efficiency Gain & Effect of Ambient Temperature





3. Participation in Shop Tests and Sea Trials of Marine Engines in Korea, China etc

Engine Testing at Hyundai Shipyard-Ulsan: Elctronic Engine



Installation prepared by engine maker after submitting instructions

3. Participation in Shop Tests and Sea Trials of Marine Engines in Korea, China etc… Continued

Engine Testing at Hyundai Shipyard-Ulsan: Electronic Engine

Development of New Measurement Procedure

5. Participation in Shop Tests and Sea Trials of Marine Engines in Korea, China etc … Continued

Engine Testing at Hyundai Shipyard-Ulsan: Electronic Engine

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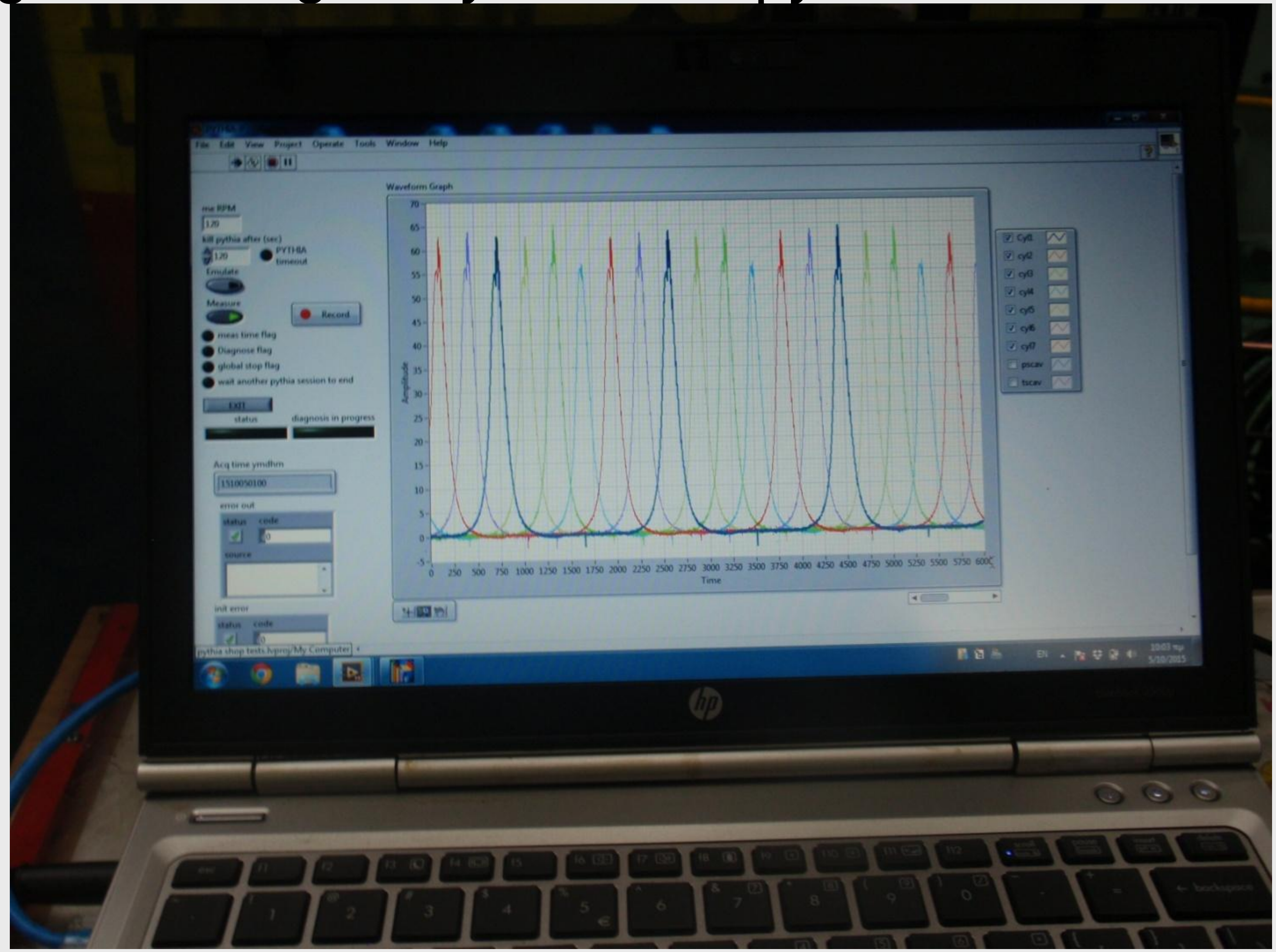
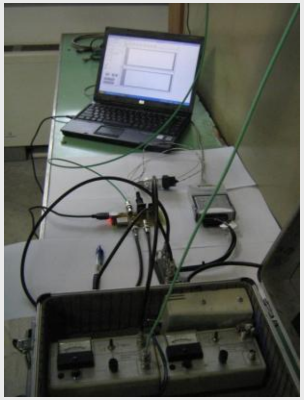
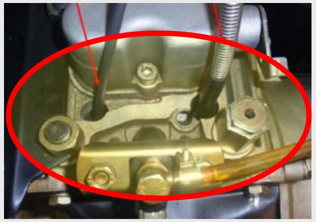


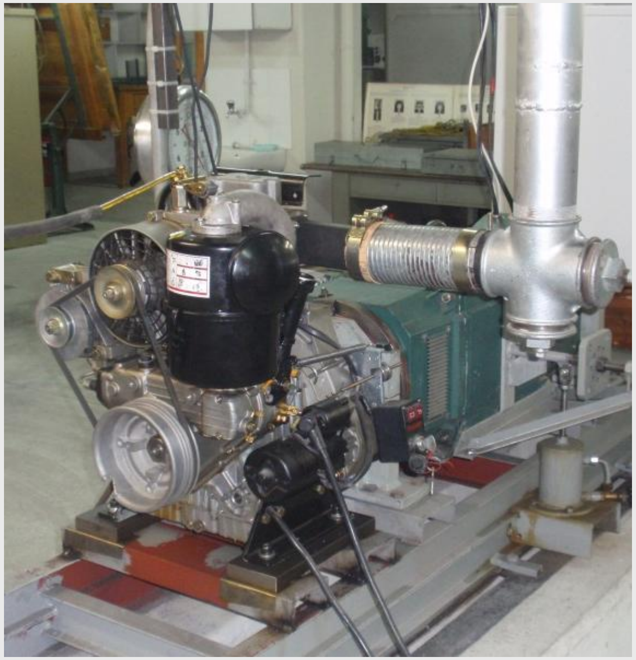
On-Line Cylinder Pressure Data Acquisition from Engine Control System

6. Brief Description of Lab Facilities for testing & Development

Development – Lab Tests



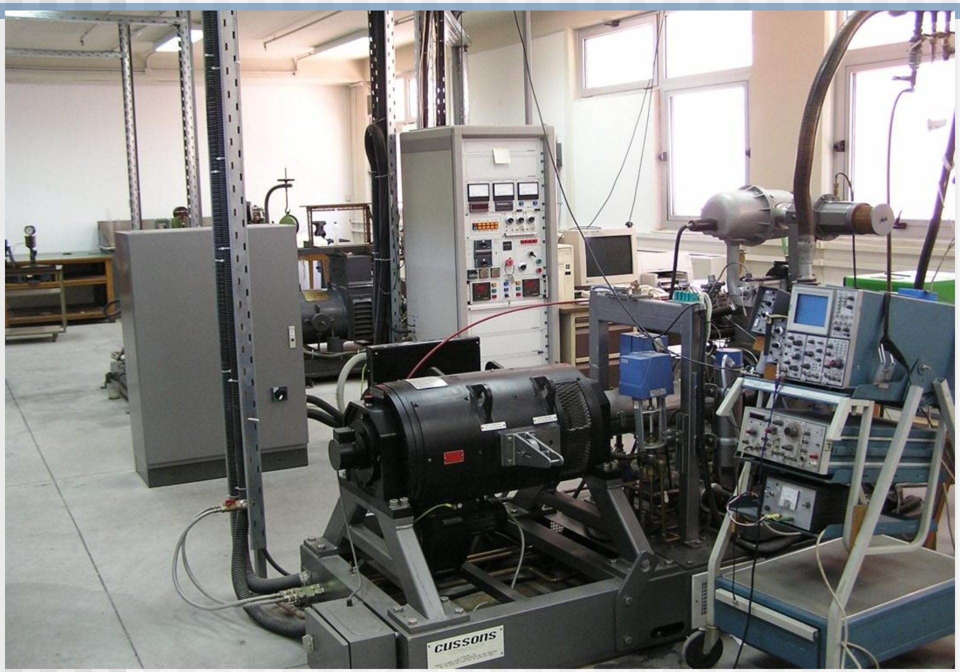


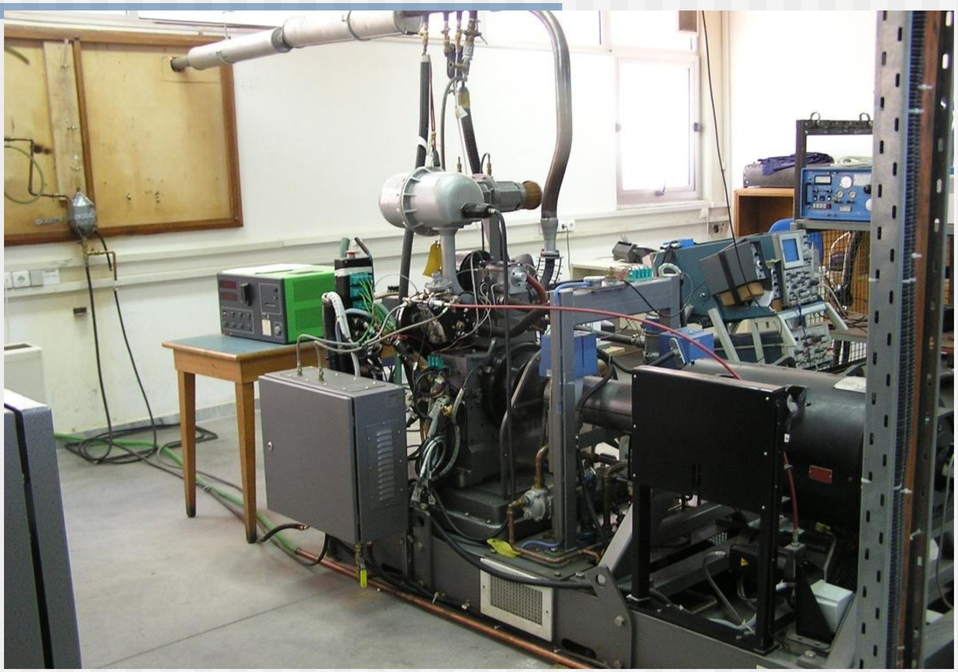


Development – Field Tests

6.1 Indicative Facilities-Multi Cylinder Engines

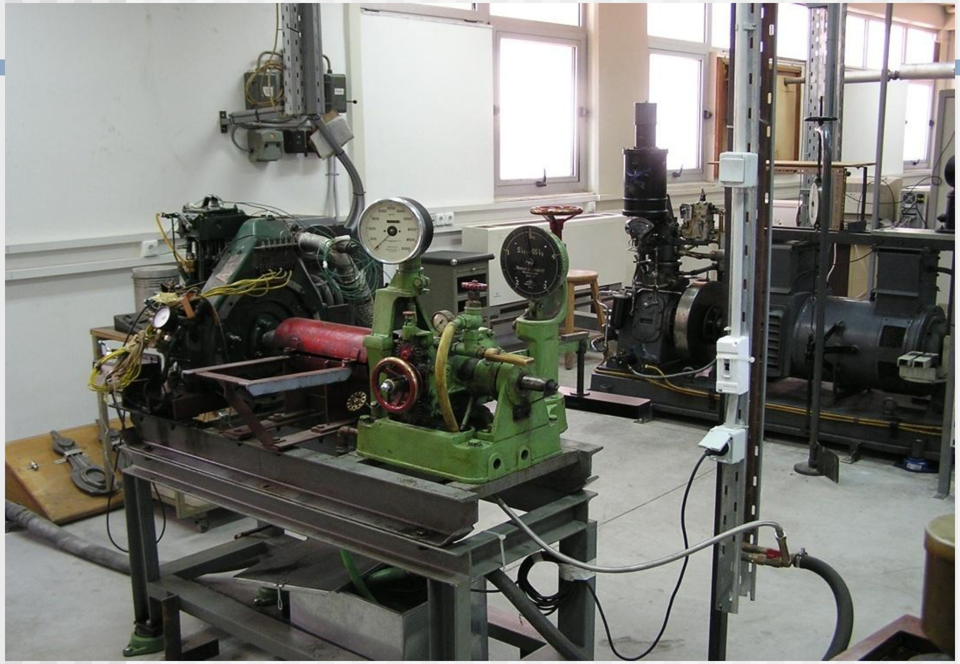
6.2 Indicative Facilities-Single Cylinder Hydra Engine





6.3 Indicative Facilities-Gas Analyzers-Ricardo E-6 Engine

6.4 Indicative Facilities: Dual Fuel Single Cylinder Engine & Fuel Injection System Test Bench



6.5 Indicative Facilities-Single Cylinder Test Engines

6.6 Indicative Facilities-Roller Dyno for Vehicle Testing