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The experimental evaluations and numerical simulation of NOx emissions by internal combustion engine, using test-bench GUNT CT 400.01 and RK-DIESEL software

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OBJECTIVES

- Investigate how fuel type and operating conditions affect NOx emission formation.
- Combine and compare the experimental data (GUNT CT 400.01) versus the RK-DIESEL simulation results.
- Validate simulation with measured data

INTRODUCTION

- Road transport → major source of air pollution (NO_x, CO, HC, PM).
- NO_x causes smog, acid rain, and health impacts.
- Tirana urban traffic worsens the air quality everyday.
- Aim: accurate experimental and numerical evaluation of NO_x behavior.

LITERATURE REVIEW

Key studies:

- NOx formation depends on temperature, pressure, and air–fuel ratio (Zeldovich 1946).
- Key references: Heywood (1988), Stone (2012), Cooper & Alley (2011).
- Gap identified: limited studies combining experimental and RK-Diesel validation and/or other simulation software.

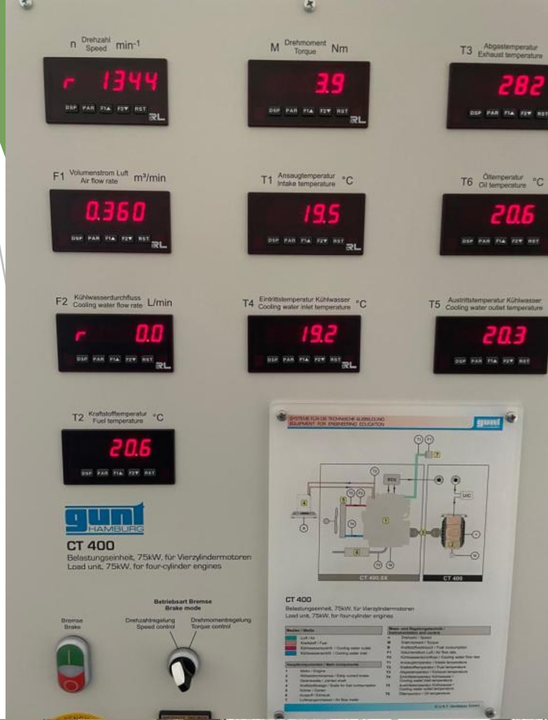
METHODOLOGY OVERVIEW

- Dual approach: Experiment + Simulation.
- Experimental setup: GUNT CT 400.01 test bench equipped with a 4-stroke petrol engine.
- Simulation: RK-Diesel simulation configured with real engine data for the same engine.
- Same rpm points (1000–3200) used for both methods.

EXPERIMENTAL SETUP

- Test-Bench: GUNT CT 400.01 equipped with an Engine: Ford MSG-425 EFI (electronic fuel injection).
- Parameters measured: Power, Torque, BSFC, NOx.
- Parental instruments used dynamometer and exhaust gas analyzer (NO, CO, HC).
- Each test point repeated 3 times for accuracy.

Test-bench GUNT CT-400.01 set-up



Data retrieved from GUNT-CT 400.01 test-bench.

Speed engine (in rev/min)	BP (in kW)	Torque (in Nm)	BSFC (in g/kWh)	NOx (in ppm)
1000	1.9	18.336	283.5	135
1200	6.726	54.0864	273.42	152.46
1400	11.324	78.0576	264.18	170.19
1600	15.694	94.656	255.78	188.19
1800	19.836	106.3488	248.22	206.37
2000	23.75	114.6048	241.5	224.82
2200	27.436	120.3552	235.62	243.54
2400	30.894	124.224	230.58	262.53
2600	34.124	126.6624	226.38	281.88
2800	37.126	127.9584	223.02	301.59
3000	39.9	128.352	220.5	321.66
3200	42.446	128.0064	218.82	342.09

SIMULATION SETUP

- Software: RK-Diesel configured with engine specifications.
- Inputs: Displacement, compression ratio, ignition timing, fuel data.
- Outputs: In-cylinder pressure, temperature, NOx formation rate.
- Calibrated to match real torque and power curves.

Data retrieved from RK-Diesel simulation

RPM	BP (in kW)	Torque (in Nm)	BSFC (in g/kWh)	NOx (in ppm)	SoC (in deg ATDC)	EoC (in deg ATDC)
1000	2	19.1	270	150	10	30
1200	7.08	56.34	260.4	169.4	10.42	30.02
1400	11.92	81.31	251.6	189.1	10.68	29.88
1600	16.52	98.6	243.6	209.1	10.78	29.58
1800	20.88	110.78	236.4	229.3	10.72	29.12
2000	25	119.38	230	249.8	10.5	28.5
2200	28.88	125.37	224.4	270.6	10.12	27.72
2400	32.52	129.4	219.6	291.7	9.58	26.78
2600	35.92	131.94	215.6	313.2	8.88	25.68
2800	39.08	133.29	212.4	335.1	8.02	24.42
3000	42	133.7	210	357.4	7	23
3200	44.68	133.34	208.4	380.1	5.82	21.42

Validation and data analysis

- Power & Torque vs RPM shows excellent agreement between measured and simulated performance curves.
- The maximum deviation in torque was less than 6 %, occurring near 2800 rpm where transient load variations were most pronounced.
- Brake power followed the same trend, with less than 5 % average error across the range.
- BSFC & NOx vs RPM demonstrates that both experiment and simulation capture the same tendencies:
  - **BSFC** decreases with engine speed, reaching a minimum near 2800-3000 rpm, reflecting improved efficiency.
  - **NOx emissions** increase monotonically with rpm due to higher combustion temperature and reduced residence time.

Data table summary

Engine speed (rev/min)	Brake power (in kW)	Torque (in Nm)	Brake specific fuel consumption (in g/kWh)	Emission of NOx (in ppm)
RK-Diesel				
1000	2	19.1	270	150
1200	7.08	56.34	260.4	169.4
1400	11.92	81.31	251.6	189.1
1600	16.52	98.6	243.6	209.1
1800	20.88	110.78	236.4	229.3
2000	25	119.38	230	249.8
2200	28.88	125.37	224.4	270.6
2400	32.52	129.4	219.6	291.7
2600	35.92	131.94	215.6	313.2
2800	39.08	133.29	212.4	335.1
3000	42	133.7	210	357.4
3200	44.68	133.34	208.4	380.1
GUNT CT-400.01				
1000	1.9	18.336	283.5	135
1200	6.726	54.0864	273.42	152.46
1400	11.324	78.0576	264.18	170.19
1600	15.694	94.656	255.78	188.19
1800	19.836	106.349	248.22	206.37
2000	23.75	114.605	241.5	224.82
2200	27.436	120.355	235.62	243.54
2400	30.894	124.224	230.58	262.53
2600	34.124	126.662	226.38	281.88
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3000	39.9	128.352	220.5	321.66
3200	42.446	128.006	218.82	342.09

Statistical deviation evaluation

- Quantitative validation through the mean absolute error (MAE) and the root mean square error (RMSE):

$$MAE = \frac{1}{n}\sum_{i=1}^{n} | x_{exp,i} - x_{sim,i} |;$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (x_{exp,i} - x_{sim,i})^2}$$

Parameter	RMSE		Max Deviation	Validation Result
Brake Power (kW)	0.61		5.1 %	Acceptable
Torque (Nm)	3.1		6.0 %	Acceptable
BSFC (g/kWh)	4.2		4.8 %	Good
NOx (ppm)	34		9.6 %	Good

- All major indicators remain within ±10 % deviation, confirming strong agreement between experimental and simulated datasets.

Discussion and Recommendation

- All major indicators remain within **±10 % deviation**, confirming strong agreement between experimental and simulated datasets.
- RK-Diesel effectively reproduces engine performance and emission behavior under steady-state operation.
- Minor discrepancies in NOx prediction arise from simplified heat-transfer and kinetics models.
- Validation confirms the simulation’s reliability for engineering and academic applications.
- Recommended: refine sub-models and extend study to alternative fuels and transient conditions for improved accuracy.

Recommendations

- **Model Refinement:**
  Introduce advanced sub-models in **RK-Diesel** for transient heat-transfer and real gas effects. Improve residual gas fraction and wall temperature modeling to reduce deviations.
- **Alternative Fuel Analysis:**
  Extend testing to biodiesel, bioethanol, and natural gas to study NOx–efficiency relationships. Lower flame temperatures of these fuels may yield significant NOx reductions.
- **Operational Parameter Optimization:**
  Investigate ignition timing, equivalence ratio, and cooling rate to find the optimal balance between efficiency and emissions.
- **Extended Experimental Validation:**
  Validate under partial-load and transient regimes to better represent real driving conditions.
- **Integration with Environmental Assessment:**
  Link measured NOx data with urban air-quality models for Tirana to quantify real-world impacts

Future work

- Future research should explore alternative fuels biodiesel, ethanol, and natural gas and their potential to further reduce NOx emissions.
- Additionally, investigations into the long-term effects of combustion emissions on air quality and public health are crucial.
- Advanced Simulation Models are need to integrate the detailed combustion kinetics and wall-temperature effects into RK-Diesel or coupled CFD tools.
- Environmental correlation, linking engine emissions data with ambient air quality measurements to assess urban impact.
- These conclusions underscore the study's contribution to understanding and mitigating NOx emissions from internal combustion engines, particularly in urban settings like Tirana, where air quality is increasingly compromised.

Acknowledgements and contact

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- Thanks to my supervisors and laboratory coo-worker
- Thank YOU ALL FOR LISTENING!

For further question do not hesitate to contact me:

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Never forget: "…we are the first generation to feel the effect of climate change and the last generation who can do something about it…" Barack OBAMA.