Variable Valve Actuation-enabled Reactivity-Controlled Compression Ignition in a Medium Speed Marine engine: An Experimental Study

1. Background & motivation

- RCCI, dual-fuel concept, achieves high thermal efficiency (~55%) & ultra-low NOx and Soot and adapts various low or zero carbon fuels.
- **Challenges**: *limited-load range, combustion stability, difficult transient, poor exhaust thermal treatment*
- Adjusting blend ratio or pilot injection timing could mitigate some issues, but RCCI remains **sensitive to in-cylinder thermodynamic & mixing condition.**
- **Variable valve actuation (VVA)** adjusts these conditions flexibly which could extend the operation limits of stable and efficient RCCI operation.

- **What?** Investigating **two VVA strategies**: *early intake valve closing (**EIVC**)* and *negative valve overlap (**NVO**)* on biogas-diesel RCCI combustion
- **How?** Experimental investigation using **a large bore marine engine platform**
- **Objectives?**

O1. Evaluate the functionality of fully-flexible valve train (EHVA)

O2. VVA's impact on RCCI combustion / engine performance / emissions

2. Methodology

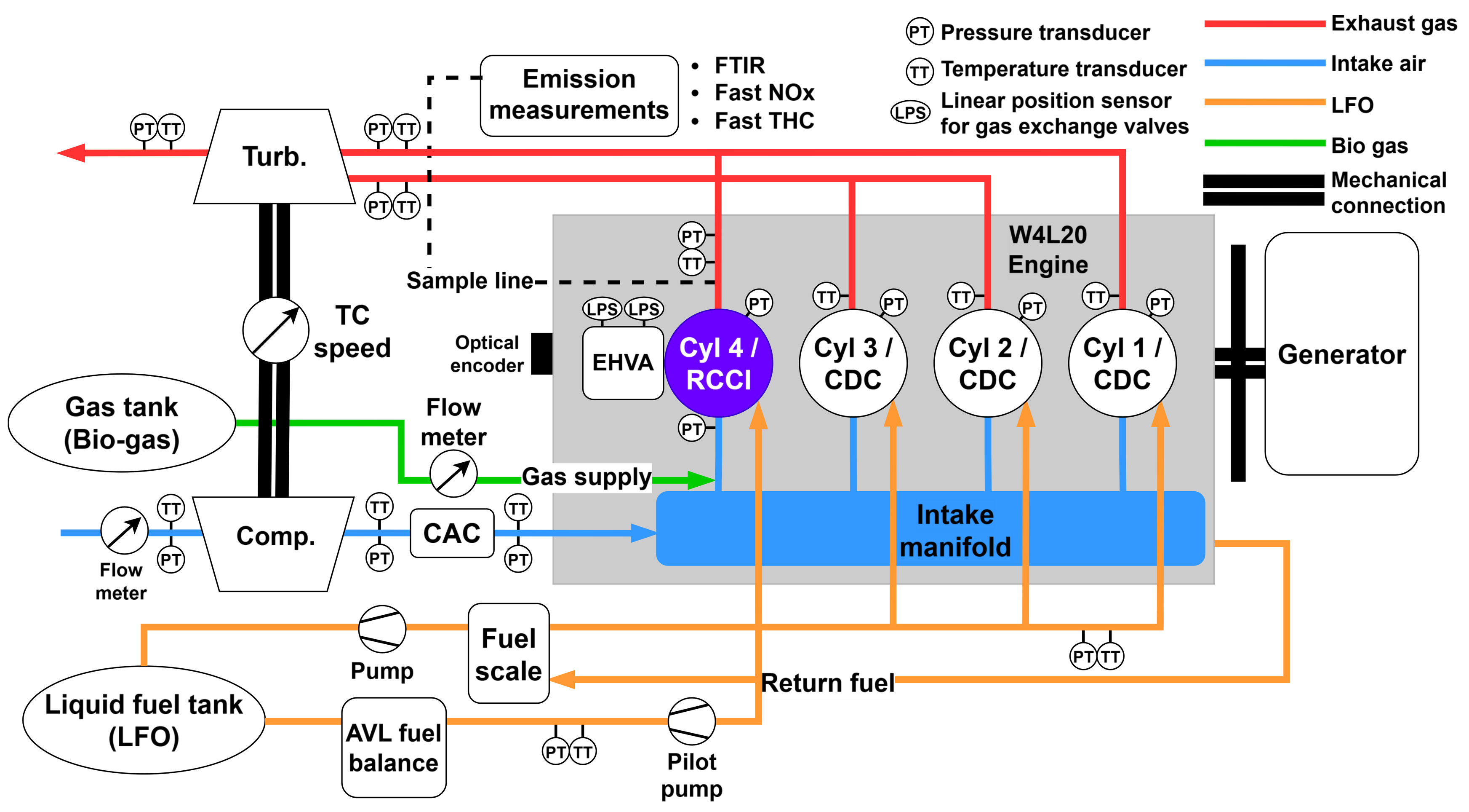
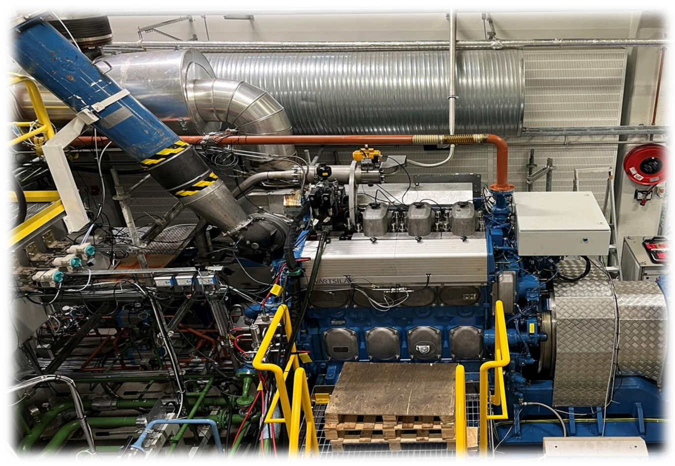


Figure1. Schematic diagram of multi-cylinder research engine platform

Table1. Specifications of the Wärtsilä 4L20 research engine with RCCI-Cyclops retrofit

Engine	Wärtsilä 4L20 Diesel	RCCI-Cyclops
Configuration	4-cylinder, inline	Semi-decoupled 1-cylinder with common airpath and individual fuel paths
Bore / stroke	200 mm / 280 mm	
Displacement & speed	8.8 L / cylinder & 1000 rpm	
Compression ratio	15.8	13.44
Diesel fuel system	ISO 8217 LFO; CRDI	ISO 8217 LFO; CRDI – independent
Gas fuel system	-	Bio-gas (MN=99), PFI 20 bar
Valvetrain	Cam-driven fixed, 4 valves / cylinder	Fully-flexible EHVA, 4 valves / cylinder
Engine & EHVA control	Rapid prototyping platform (Speedgoat)	



3. Experimental results

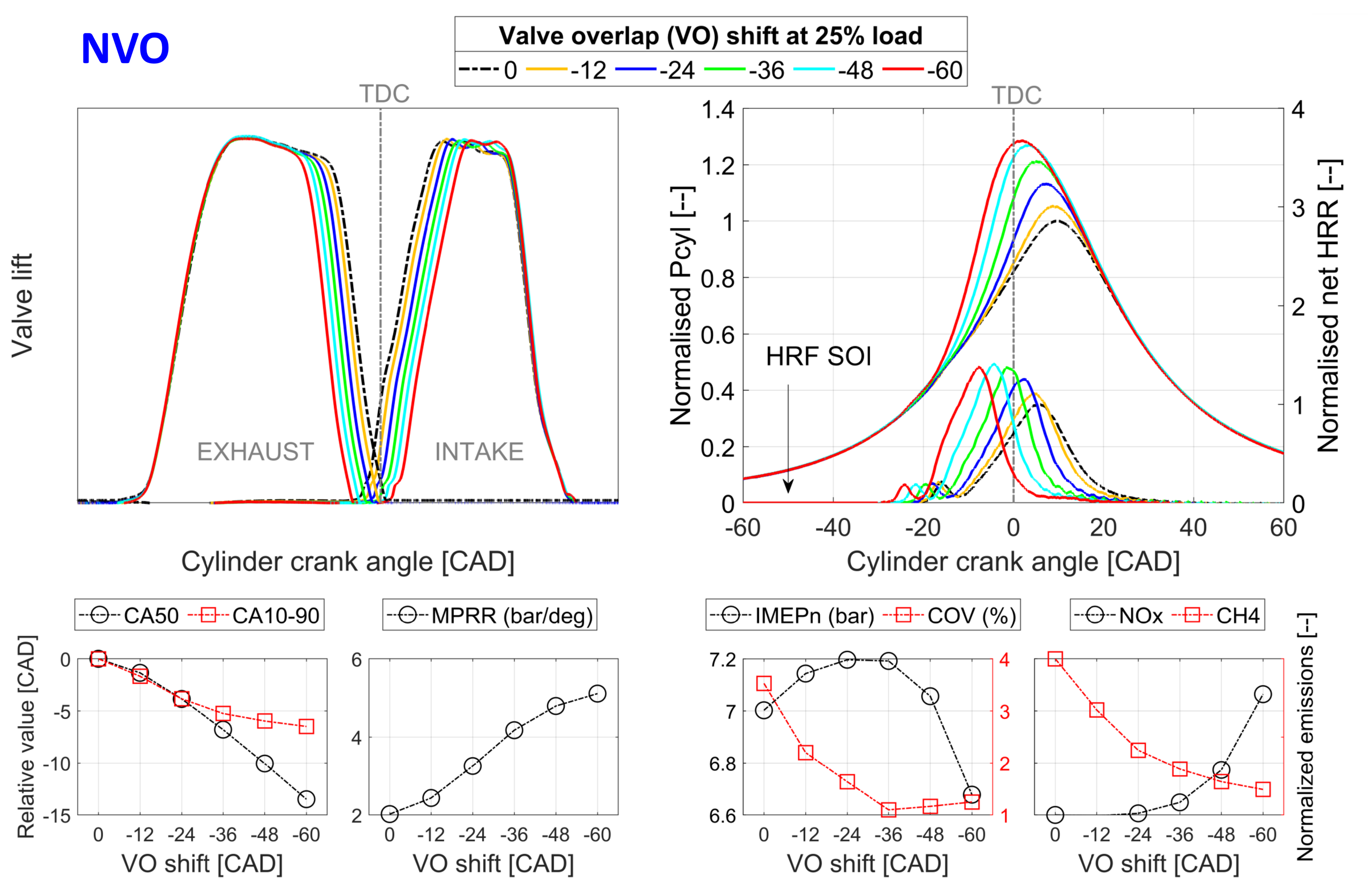


Figure2. Experimental results of NVO at 25% load: valve lifts, cylinder pressure, HRR, CA50, CA10-90, MPRR, IMEPn, COV-IMEP, NOx, CH4

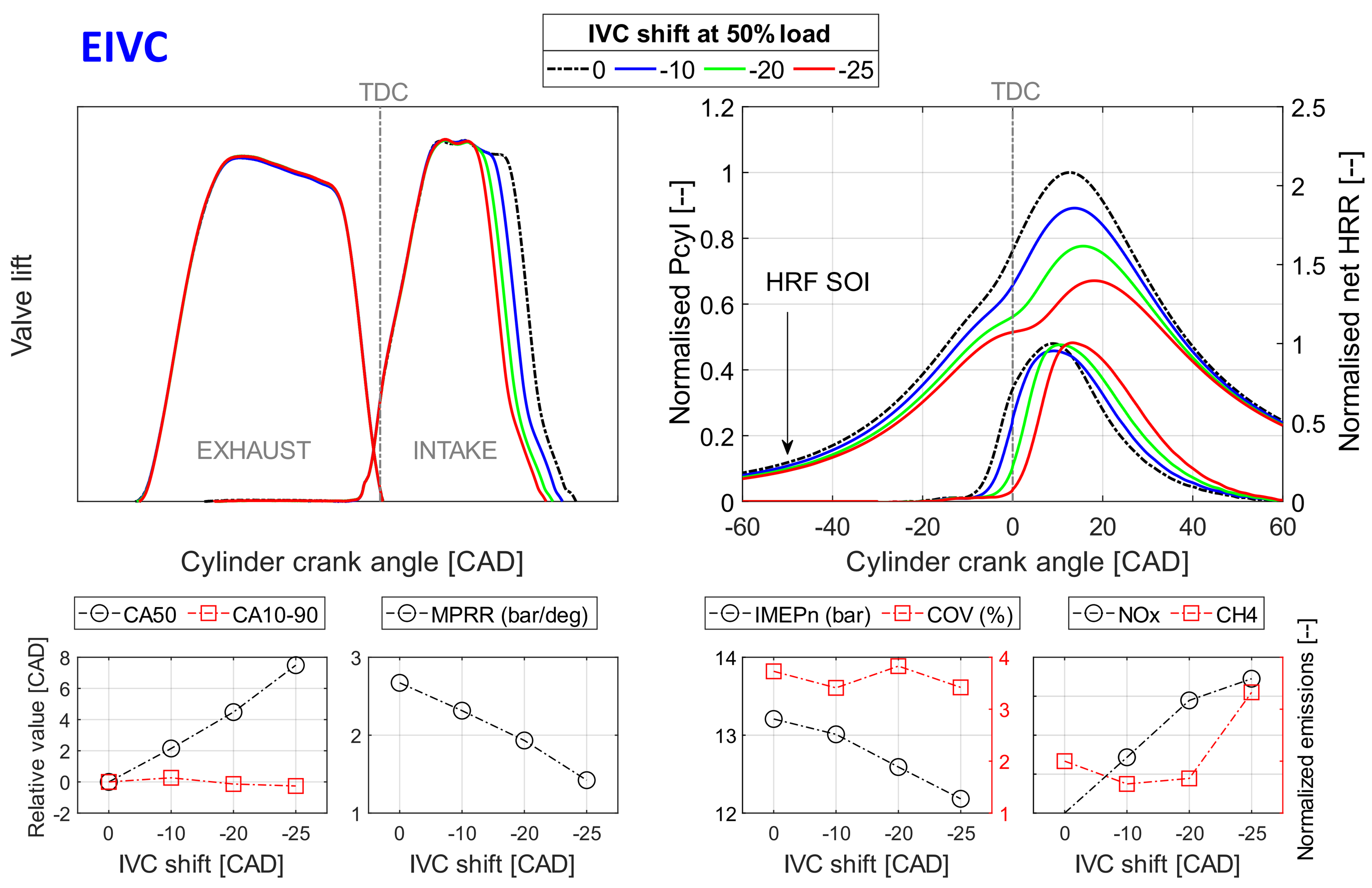


Figure3. Experimental results of EIVC at 50% load: valve lifts, cylinder pressure, HRR, CA50, CA10-90, MPRR, IMEPn, COV-IMEP, NOx, CH4

Key findings of NVO sweep:

- Increased internal-EGR → elevate in-cylinder temp (T_{ivc}) → short ignition delay (HRF) / accelerate chemical reaction → advance combustion onset & rapid combustion
- Promote complete combustion (low methane slip) / improve stability at low load
- Excessive NVO: high pumping losses + intake charge reduction ← high boost!
- NVO with HRF injection enables in-cylinder fuel reforming (control in-cylinder reactivity)

Key findings of EIVC sweep:

- Reduced effective compression ratio (ECR) / trap mass → lower compression temp (T_{ivc}) → long ignition delay (HRF) → retard combustion onset
- P_{max} / pressure rise rate (PRR) is reduced → effective for high load extension
- Excessive EIVC: intake charge reduction + slower chemical reaction → misfire

4. Conclusions

- Fully-flexible valvetrain enables fast in-cylinder thermal management / combustion control → extends operational limit of RCCI
- Better low/high load performance when these VVA strategies are combined with blend ratio control for maintaining optimum combustion phasing

5. Future works

- Further investigation on various VVA strategies (2EVO, NVO with fuel reforming) on RCCI
- Examine VVA's potential on bio-gas and H_2 blend-diesel RCCI
- Systematic optimization with VVA: ultra-efficient RCCI operation towards 55% of ITE
- Calibrate and validate predictive RCCI combustion model (in-house developed physic-based chemical kinetic multizone model)

6. Acknowledgments

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