Volumetric Expanders for Waste Heat Recovery in Heavy-Duty Trucks

KTH CCGEX

Sandhya Thantla

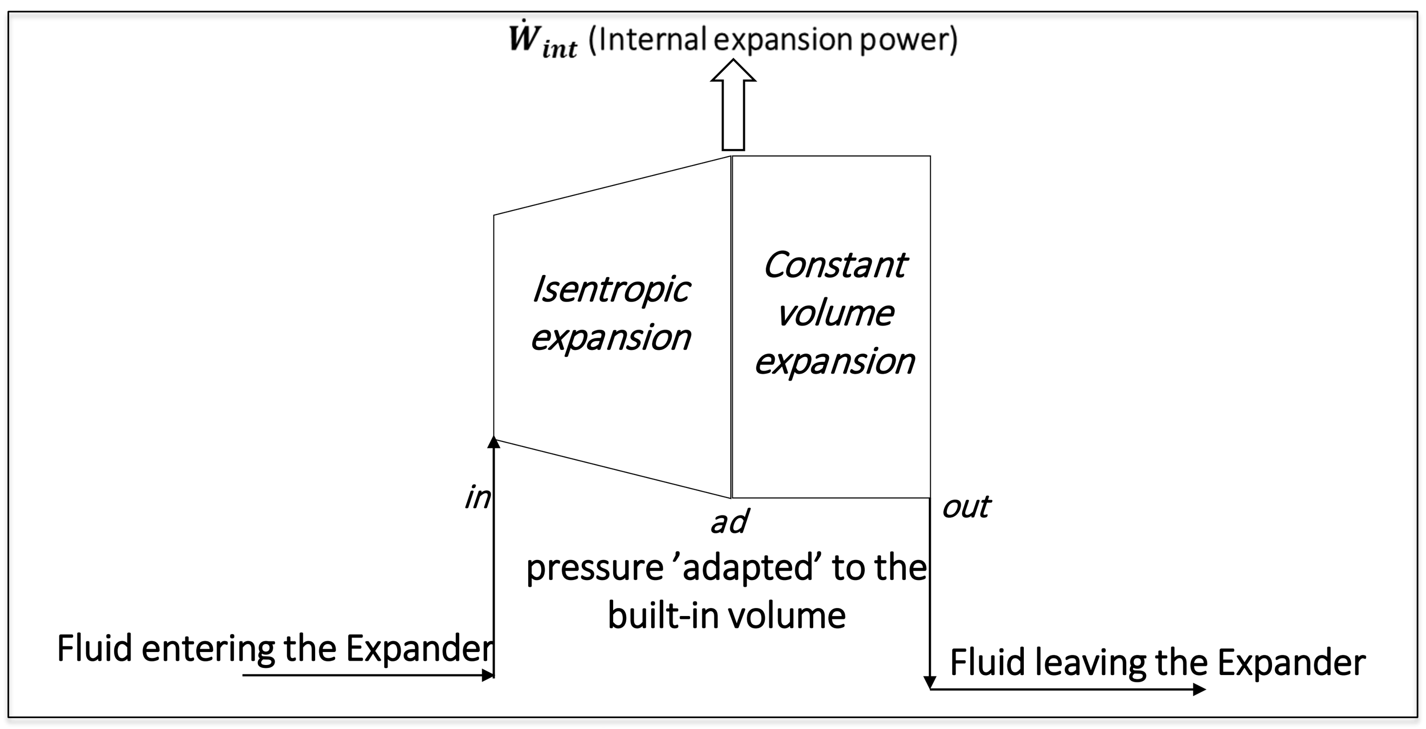
sandhyat@kth.se

Recovering waste heat from Heavy Duty (HD) truck engines is beneficial in improving fuel economy and reducing emissions. Waste Heat Recovery (WHR) is being implemented in HD truck engines using the Organic Rankine cycle (ORC) system that comprises of Heat exchangers, Pump and an Expansion machine/Expander. WHR from these type of engines is challenging due to their transient behaviour including changes in vehicle speed and load, road profile, ambient conditions, etc. To handle this behaviour and to achieve effective heat recovery, it is necessary to study the adaptability of the components of the ORC system, in particular, of the Expanders. The aim of this work is to analyze the performance of a Volumetric Expander at different boundary conditions, with respect to its built-in volume ratio.

Introduction and Motivation:

The transient behaviour of a HD truck engine lays constraints on the evaporating and condensing boundary conditions which in turn affect the performance of the Expander used. Based on the geometry, every volumetric Expander has a built-in volume ratio ($r_{v,in}$), that is, the ratio of volume of the fluid before discharge (V_{ad}) to the volume of the fluid before expansion (V_{in}). The built-in volume ratio has a corresponding Design Pressure Ratio (DPR) defined by the formula, $\frac{P_{in}}{P_{ad}} = \left(r_{v,in}\right)^{\kappa}$, where κ is the specific heat ratio of the fluid. In transient conditions of a typical HD truck engine, it is not always possible to maintain an operating pressure ratio (OPR) that matches the DPR. Therefore, it is necessary to analyse the performance of a volumetric Expander having a fixed volume ratio, at different boundary conditions, to identify the zones of efficient operation. In this work, a semi-empirical model representing a Scroll Expander using R123 as the working fluid is implemented to analyse the Expander's performance characteristics at various built-in volume ratios with different boundary conditions imposed to the Expander.

Schematic depiction of the model representing the expansion process inside the Scroll Expander

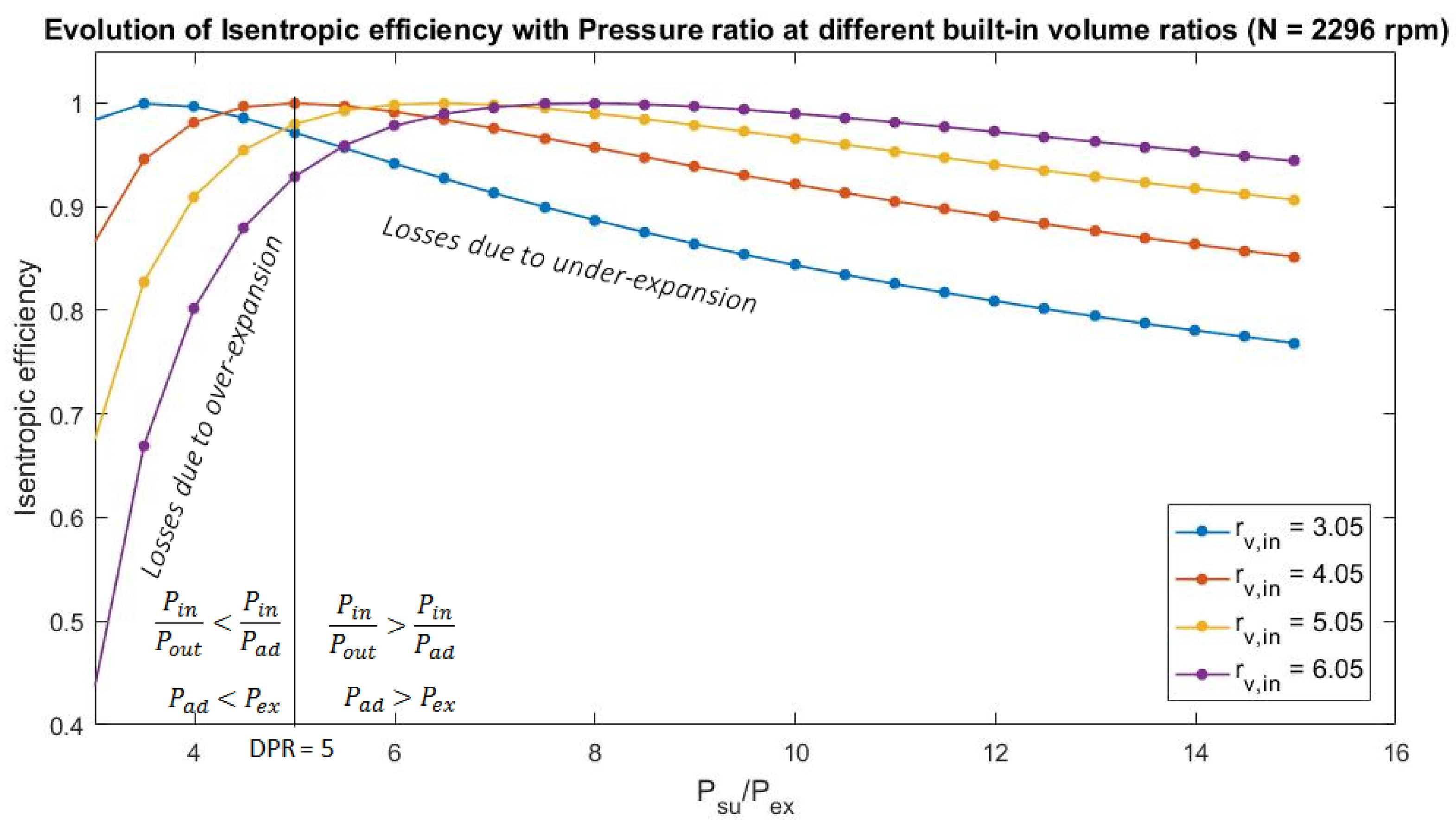


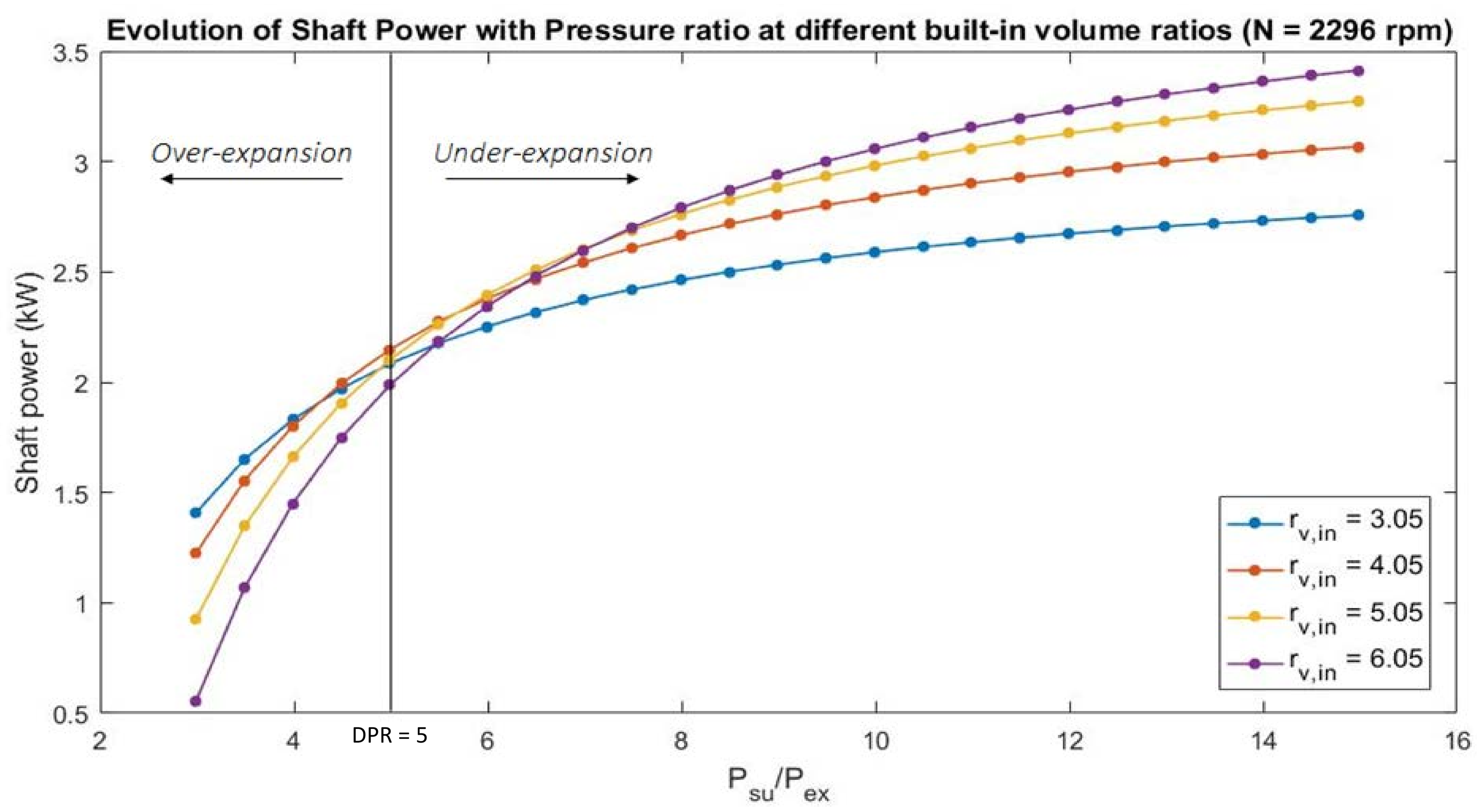
Internal expansion power (W), $\dot{W}_{int} = \dot{m}_{fluid}(h_{in} - h_{out})$;

Isentropic efficiency, $\eta_{is} = \frac{\dot{m}_{fluid}(h_{in} - h_{out})}{\dot{m}_{fluid}(h_{in} - h_{out,s})}$

where, h – enthalpy, s – isentropic, $\dot{m}_{fluid}$ - mass flow rate of the working fluid, W - watt

Results:





- When the OPR deviates from the DPR,
  - Expander's Isentropic efficiency decreases gradually due to under-expansion losses, but, decreases abruptly due to over-expansion losses.
  - Shaft power decreases during the over-expanded operation, but increases during the under-expanded operation.
- With the increase in built-in volume ratio, the peak efficiency of the Expander shifts to higher Design Pressure Ratios.

Summary and Conclusion:

- Choosing a Scroll Expander with a built-in volume ratio whose Design pressure ratio falls in the under-expanded region, leads to wider operating ranges with less loss in efficiency compared to the losses in the over-expanded region.
- Increasing the built-in volume ratio aids in increasing the Expander's Shaft power and Isentropic efficiency with a compromise on Expander's volume and weight.
- Applying the concept of variable built-in volume ratio in volumetric Expanders would help achieve peak efficiencies with increased Shaft power.

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