Exploring the Correlation between Soot Number Density and Combustion Duration in a GDI Engine at Part-Load Conditions

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Background

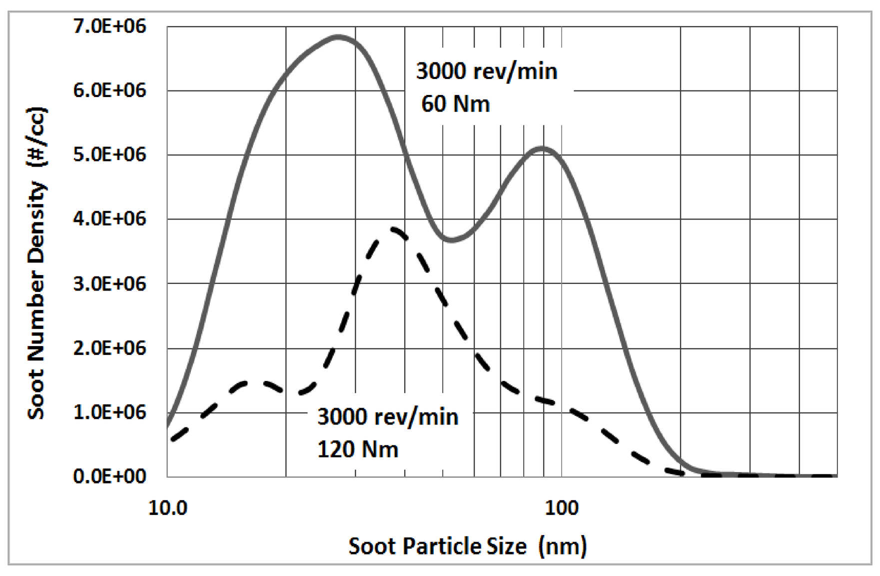
- Gasoline Direct Injection engines are more efficient than traditional PFI platforms (approaching 40% at part-load).
- Even in their latest generation (spray-guided), GDI platforms produce large numbers of ultra-fine soot particles (Euro 6 limit: 600 billion particles/km).
- An improved understanding of the soot formation processes is required to enable further design and combustion strategy optimisation.

Objectives

- Characterisation of exhaust soot at part-load.
- Correlation between soot number density and combustion characteristics.

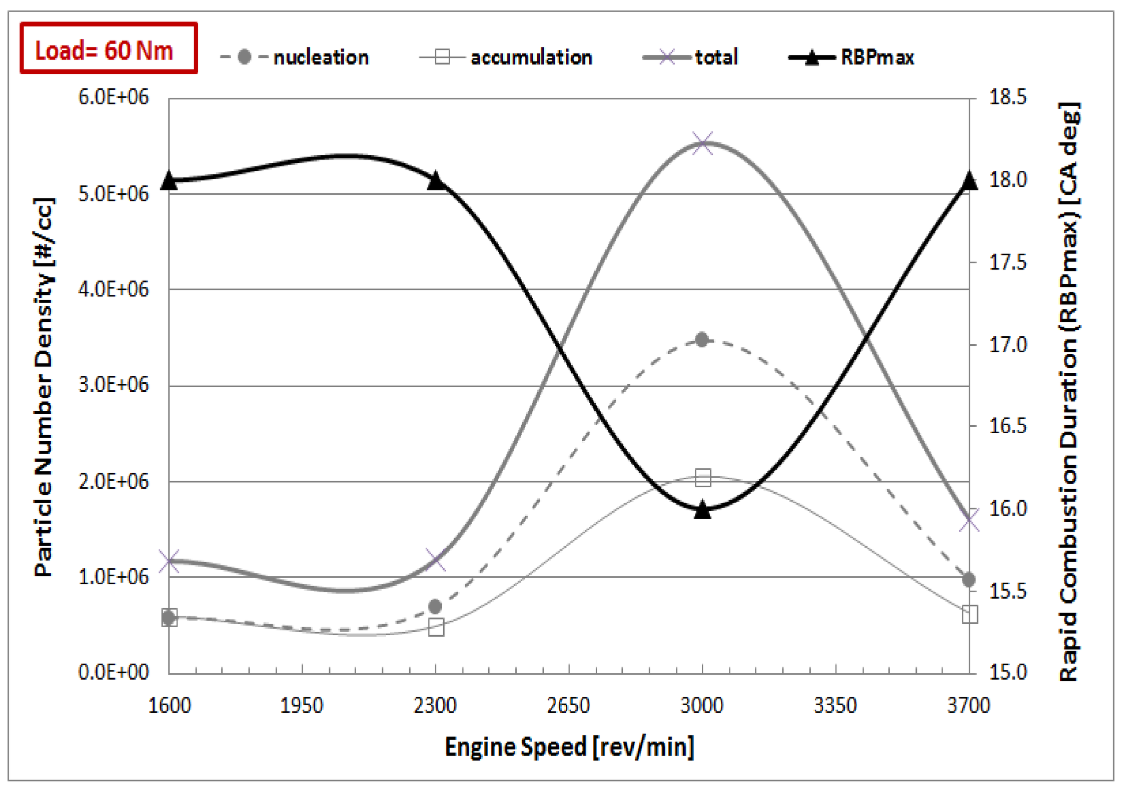
Methodology

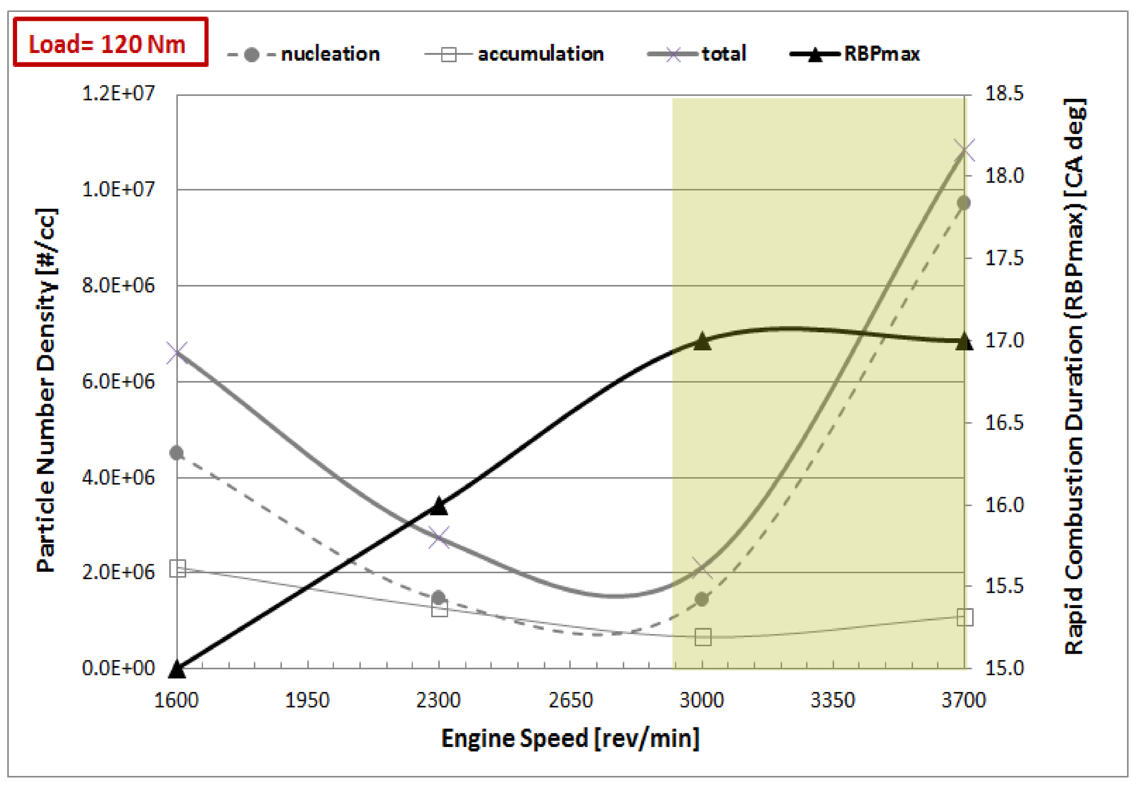
- Test Engine: Wall-Guided Spray, Gasoline Direct Injection (1.6 L, 4-cylinder).
- Test Conditions: steady-state, fully-warm, part-load conditions, in stoichiometric and theoretically-homogenous mode (early intake-stroke injection). Engine speed: 1600 to 3700 rpm; Torque: 60 and 120 Nm. Fuel: Single batch 95 RON gasoline.
- Size-resolved soot number density distribution measurements: Differential Mobility Spectrometer (DMS-500) from Cambustion.
- Combustion Analysis: modified Rassweiler and Withrow method to evaluate Mass Fraction Burned; iterative process to determine polytropic expansion index and EOC, along with zero-combustion pressure condition.
- Newly defined *Rapid Combustion Duration*, RBP_{max}: 10% MFB to Peak Pressure



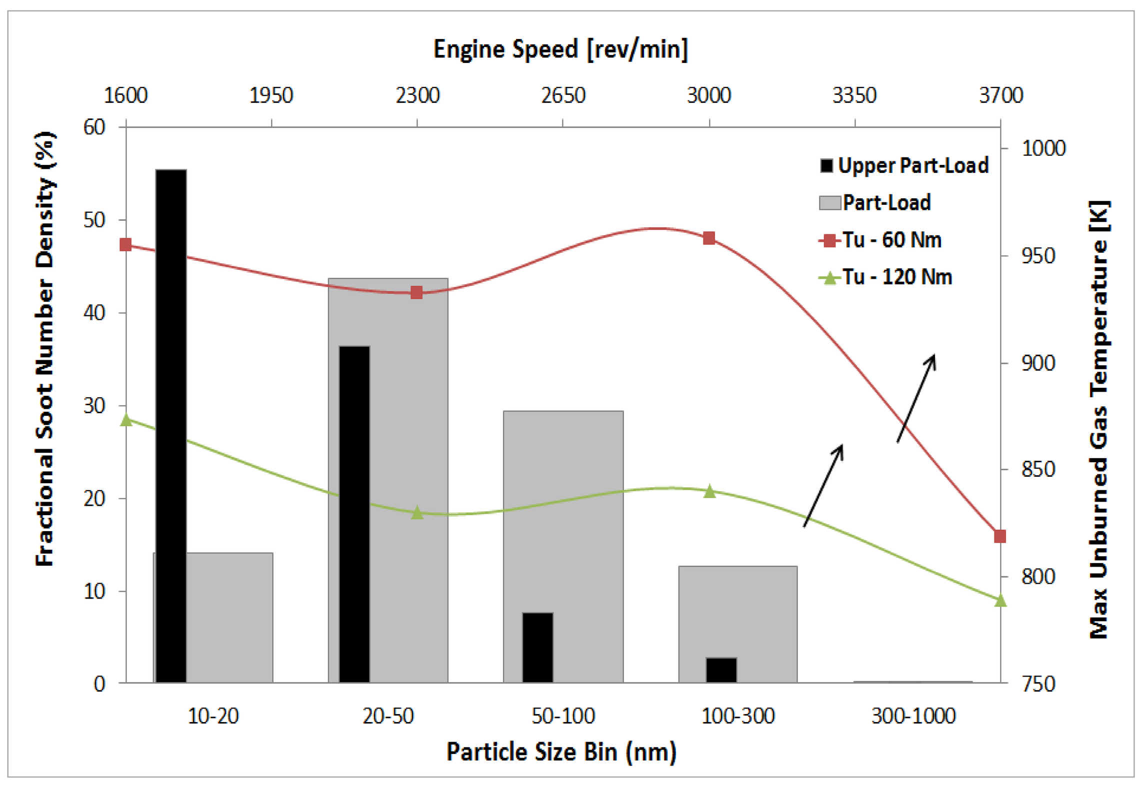
- Bi-modal distribution at lower load
  - Nucleation mode: mostly primary particles formed during combustion (mostly non-volatile material).
  - Accumulation mode: agglomerates, formed also after combustion, non-volatile and volatile condensed fraction (organics, nitrates, sulfates).
- Single-mode distribution at higher load

Results/Discussion





- Most soot particles emitted in nucleation mode (< 50 nm); at higher engine load, speed-resolved size trend almost solely driven by nucleation mode.
- Bar *upper part-load* region (green band), higher total particle number density invariably correlated to faster rapid combustion RBP_{max} (inverse linear correlation).
  - Lengthening rapid duration of 4 CA deg associated to six-fold reduction in total number density.
  - The correlation does not stand for nucleation or accumulation modes separately.
- Longer rapid burning duration leaves more time for mixture preparation → soot loading reduces.
  - Greater fraction of combustion takes place in the expansion stroke, at reduced unburned gas temperature → soot loading reduces.
- Upper part-load (3700 rev/min; 120 Nm): greater fuel flow, greater injection pressure and earlier SOI (318 to 321 CA deg BTDC) induce extended spray-wall impingement, charge stratification and greater / smaller size soot loading (possibly from *pool-fire*).



Part-Load

- Asymmetric distribution, typical of GDI engines at part-load.
- 55% of soot emitted in nucleation mode.
- Higher unburned gas temperature would enable some accumulation mode.
- Size much lower than typical 130 nm soot agglomerates from diesel engines (possibly more volatile hydrocarbons).

Upper Part-Load

- Monotonic distribution; only 8% emitted in accumulation mode (> 50 nm).
- Owing to late-cycle oxidation, higher exhaust gas temperature (not shown) may contribute to smaller size (GMD≈ 23 nm).
- Lower unburned gas temperature would discourage agglomeration.