L. Rubino
Imperial College
London
United Kingdom

Nanoparticle emissions from gasoline engine exhausts

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After-treatment of Nanoparticle Emissions from Gasoline Engine Exhausts

L. Rubino
Department of Mechanical Engineering, Imperial College, London, U.K.
Tel: +44 207 5947120 Fax: + 44 207 8238845 Email: l.rubino@ic.ac.uk

Introduction

Automotive particulate (PM) emission regulations are currently mass-based, with no dependency on particle size or number below 10 ìm size; they refer to diesel engines and no regulation exists for PM from gasoline-engined vehicles. However, new standards based on particle number or size, as well as mass, are under consideration in the U.S.A. and Europe, in order to address health concerns over particulate material (PM) in the ultrafine (< 100 nm) and nanoparticle (< 50 nm) size ranges. High numbers of ultrafine particles in ambient air have recently been associated with respiratory effects and deaths [1,2] and biological research suggests that particle surface area and chemistry are more important factors than mass; also, particles which are not toxic in micron sizes may be toxic as nanoparticles [3]. PM emissions from gasoline as well as diesel engines are therefore of growing concern, in view of the greater number of gasoline-engined than diesel-engined vehicles in use and evidence from laboratory and roadside measurements that they emit a higher proportion of nanoparticles than diesel vehicles at high speeds and loads [4, 5]. Gasoline PM emissions can be periodically unstable, showing spikes at sizes below 30 nm, and gasoline direct injection (GDI) engines have been found to emit higher numbers of particulates than modern port fuel injected (PFI) engines [6, 7].

The objective of the current research is to investigate techniques for possible use as after-treatment for control of gasoline nanoparticle emissions.

Diffusion and thermophoresis have been considered ineffective as mechanisms for particle transport to exhaust pipe walls but use of electrostatic fields appears to hold greater promise [8, 9]. Filtration can be a reliable particle trapping process provided that cost-effective solutions can be found for the problems of filter cleaning (regeneration) and increased engine back pressure. Exhaust after-treatment technologies such as diesel particulate filters (DPF) are a means of meeting future emission regulations. DPF concepts incorporate different filter media and geometric configurations and regeneration technologies, from continuously regenerating to catalyzed or chemically regenerated. Various studies have shown that filters reduce PM emissions by mass very effectively, with collection efficiency around 90 % or higher [10]. However, they may cause an increase in nanoparticle emissions by number, under certain engine operating conditions [11, 12].

In this presentation is reported the evaluation of the effect of a ceramic wall-flow filter on particle number concentration and size distribution for two situations: (a) a laboratory simulation of gasoline engine PM emissions using synthetic carbon particles generated by spark discharge from a carbon aerosol generator (CAG) in airflow; (b) tailpipe PM emissions from the exhaust of a GDI-engined passenger. Measurements of particle number concentration and distribution have been carried out using a TSI 3936 Scanning Mobility Particle Sizer (SMPS) for case (a) and a Dekati Electrical Low Pressure Impactor (ELPI) for case (b). The experimental arrangement for both experiments is presented.

For the simulation of gasoline engine PM, particle number concentrations as well as size distributions, measured upstream and downstream of the filter, are presented at 20°C and 400°C, for filter exposure time up to 20 h and for particle mass concentration within the range typical of gasoline engine exhausts. Wall-flow filters of identical type to the one used for the PM simulation have been fitted to the exhaust of a Mitsubishi Carisma passenger car with 1.8 litre GDI engine for comparison with the standard exhaust system. To date chassis-dynamometer experiments have been conducted with and without wall-flow filters in the exhaust, for two engine operating conditions: steady state at an equivalent road speed of 80 km/h (where fuel injection was in the stratified overall-lean mode, equivalence ratio ~ 2) and transient, over the European ECE+EUDC drive cycle. Some preliminary results are presented for both conditions. Particle number concentrations, in three selected size channels, are presented versus time at the steady condition with and without filter. A peak in particle number concentration is observed at cold start. After this, the number concentration with filter drops to a level an order of magnitude below the baseline (no filter) case. Over the ECE and lower-speed portion of the EUDC cycle, the filter reduced tailpipe number concentrations in the ultrafine range to values very significantly below the baseline levels. However, at the end of the EUDC cycle, spikes occurred where the post-filter particle numbers became similar to those without filter. This is associated with the maximum speed (120 km/h) portion of the cycle and investigations are in progress to identify the cause of this phenomenon. It is planned next to evaluate the filter at a steady vehicle operating condition where fuel injection is artificially held in the homogeneous (stoichiometric) mode. The investigation of wall-flow filter performance on PM nanoparticles from both the laboratory simulation and GDI-engined vehicle exhaust will be compared in the future to the performance of an alternative electrostatically-based after-treatment device under development.

Conclusions

Results from the PM simulation show: at ambient temperature, collection efficiency based on particle number increased with increasing particle mobility diameter in the 20–100 nm range, from modest values in the clean state to values generally exceeding 80% after a 20 h loading period. At 400°C, the change in efficiency with filter exposure time was much less marked and a falling trend in efficiency with particle size was observed, from ~80% at 20 nm to ~70% at 100 nm.

The same filter type was equally effective at reducing tailpipe particle number concentration in the exhaust of a GDI-engined passenger car, both at a steady 80 km/h in the stratified injection mode with an equivalence ratio of 2 and over the bulk of a European drive cycle. Only at the maximum speed of the extra-urban part of the cycle did particle number concentrations approach those measured in the absence of the filter.

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Lauretta Rubino

Mechanical Engineering Department

Imperial College of Science, Technology and Medicine

University of London

Supervisors:

Prof. C. Arcoumanis, Dr. R. I. Crane, Dr. J. S. Shrimpton

Outline

- Motivation
- Objective of the current research
- Particle capture mechanisms & possible techniques
- Experimental investigation on effects of wall-flow filters
  - Simulation of gasoline engine PM
  - PM from GDI-engined vehicle
- Conclusion & Future Work

Motivation

- Health concerns over ultrafine (d < 100 nm) and nano-sized (d < 50 nm) particles in the urban atmosphere

- Tightening regulations on automotive particulate (PM) emissions and future possible PM regulations by number or by size below O(1) μm

- Gasoline vehicles emit large number of nuclei mode particles at high speed/load and during transients, especially modern GDI engines (CONCAWE, 1998; Graskow et al., 1999; Hall et al., 2000)

- Diesel particulate filters (DPF) effectively reduce diesel PM by mass but may result in high number concentration of nanoparticles (Kruger et al., 1997; Andersson et al., 2000)

- Conventional 3-way or oxidation catalysts can oxidize part of the soluble organic fraction of PM but do not capture the solid carbonaceous fraction

Objective

- Investigation of techniques capable of reducing gasoline PM number emissions & development of an after-treatment device for gasoline-engined powered vehicles applications

DTLR "Foresight Vehicle" Link Programme

Imperial College and Johnson Matthey (JMTC)

Imperial College	Johnson Matthey (JMTC)
Experimental & numerical investigation of gasoline PM capture and deposition	Investigation of techniques for the elimination of the captured gasoline PM

Particle Capture Mechanisms & Possible Techniques

- Gravitational settling
- Inertial impaction & interception
- Diffusion
- Thermophoresis
- Electrostatic fields
  - make it possible to alter particle trajectories

Ceramic filters

Cooler ?? …but Thermophoresis plays an important role only in rather slow flows with strong grad T

Electrostatic precipitators (ESPs)

Experimental Investigation

- Simulation of gasoline engine particulates
  (control of variables can be difficult when source of PM is an engine)
  - Effects on particle number concentration and size distribution of:

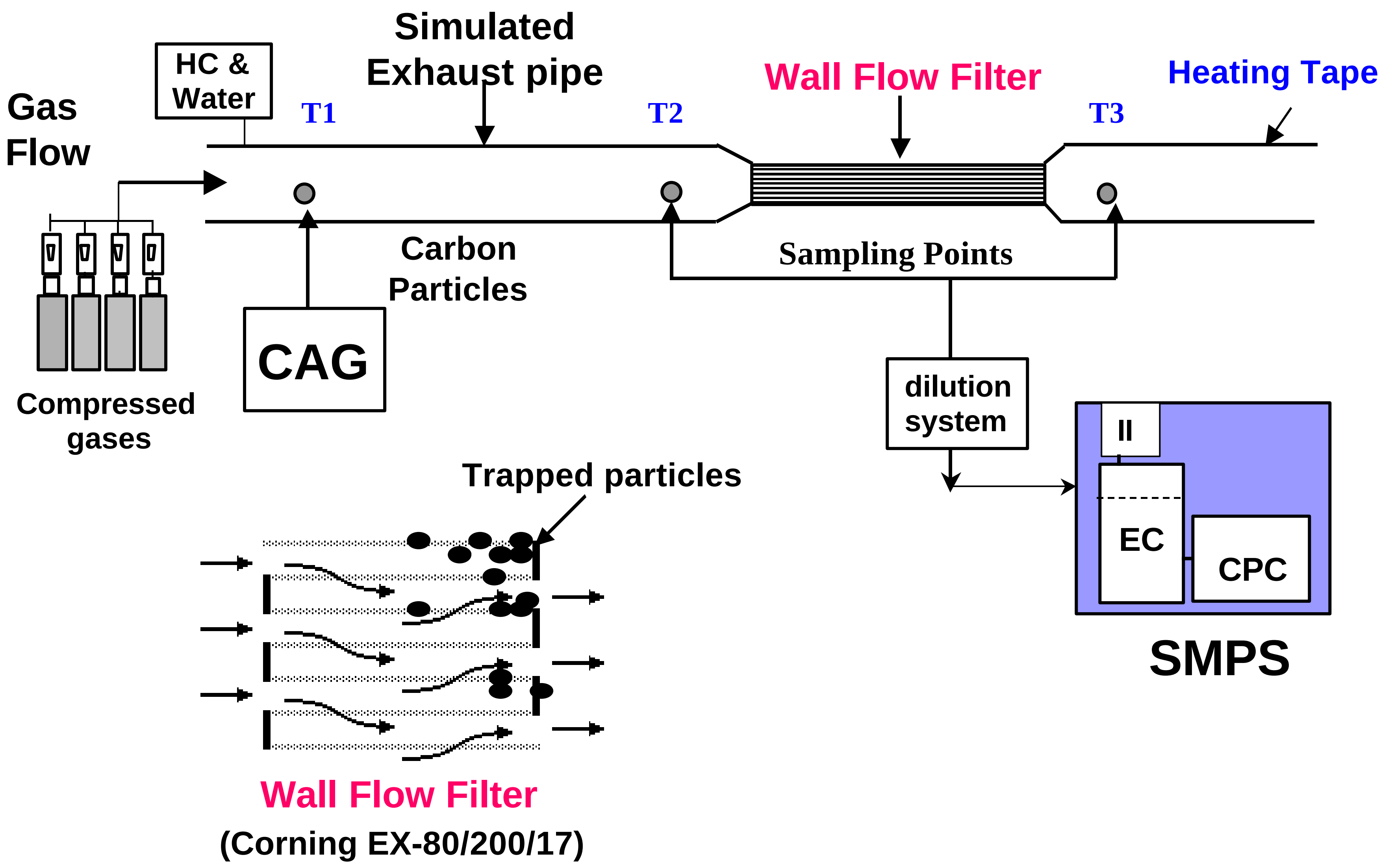
    Cordierite Wall-Flow Filter ←

    Wire-Cylinder Electrostatic Precipitator

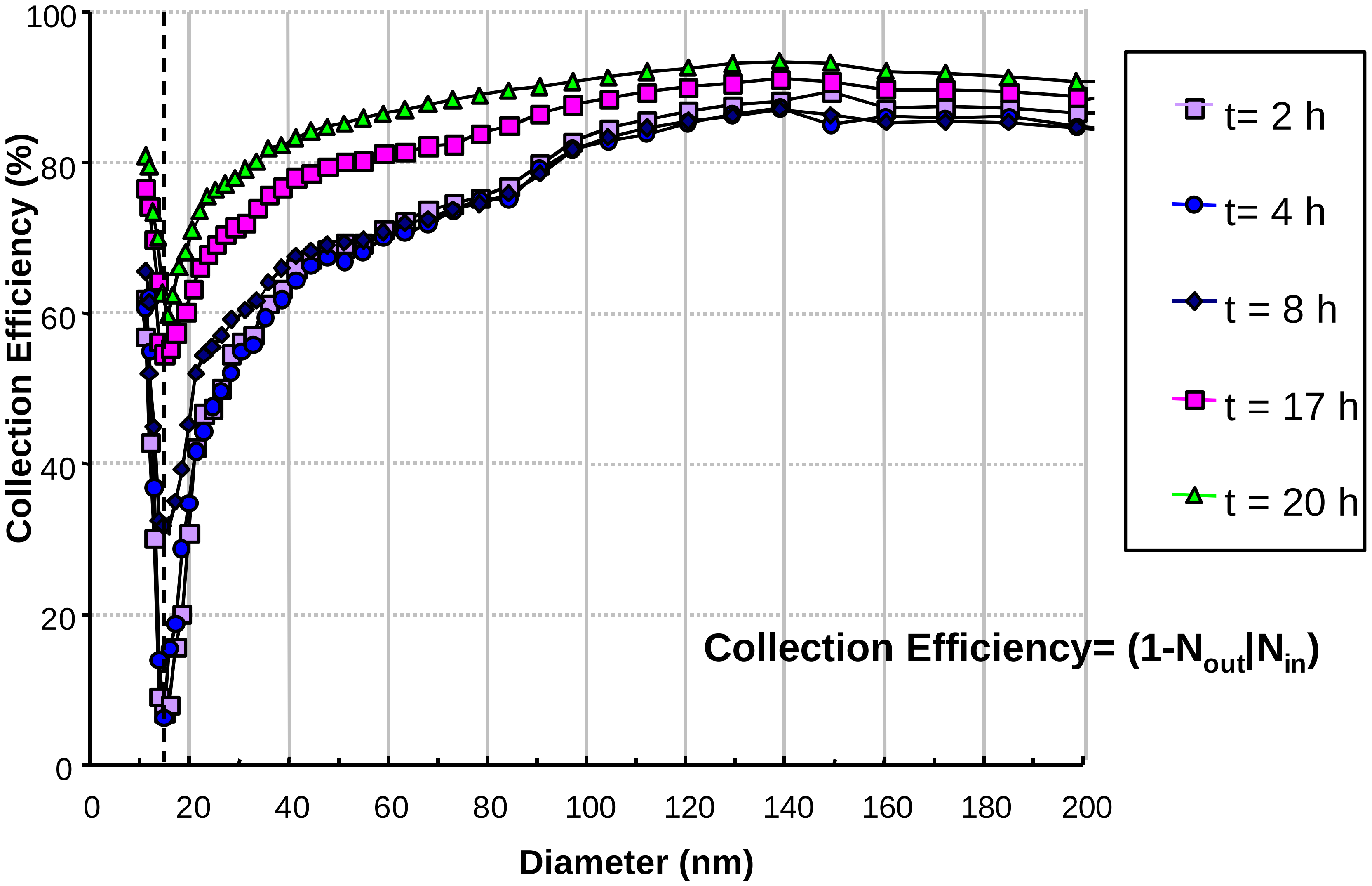
    (work in progress)

- Chassis-dynamometer experiments with a GDI-engined passenger car
  - Effects of Cordierite Wall-Flow Filter ←

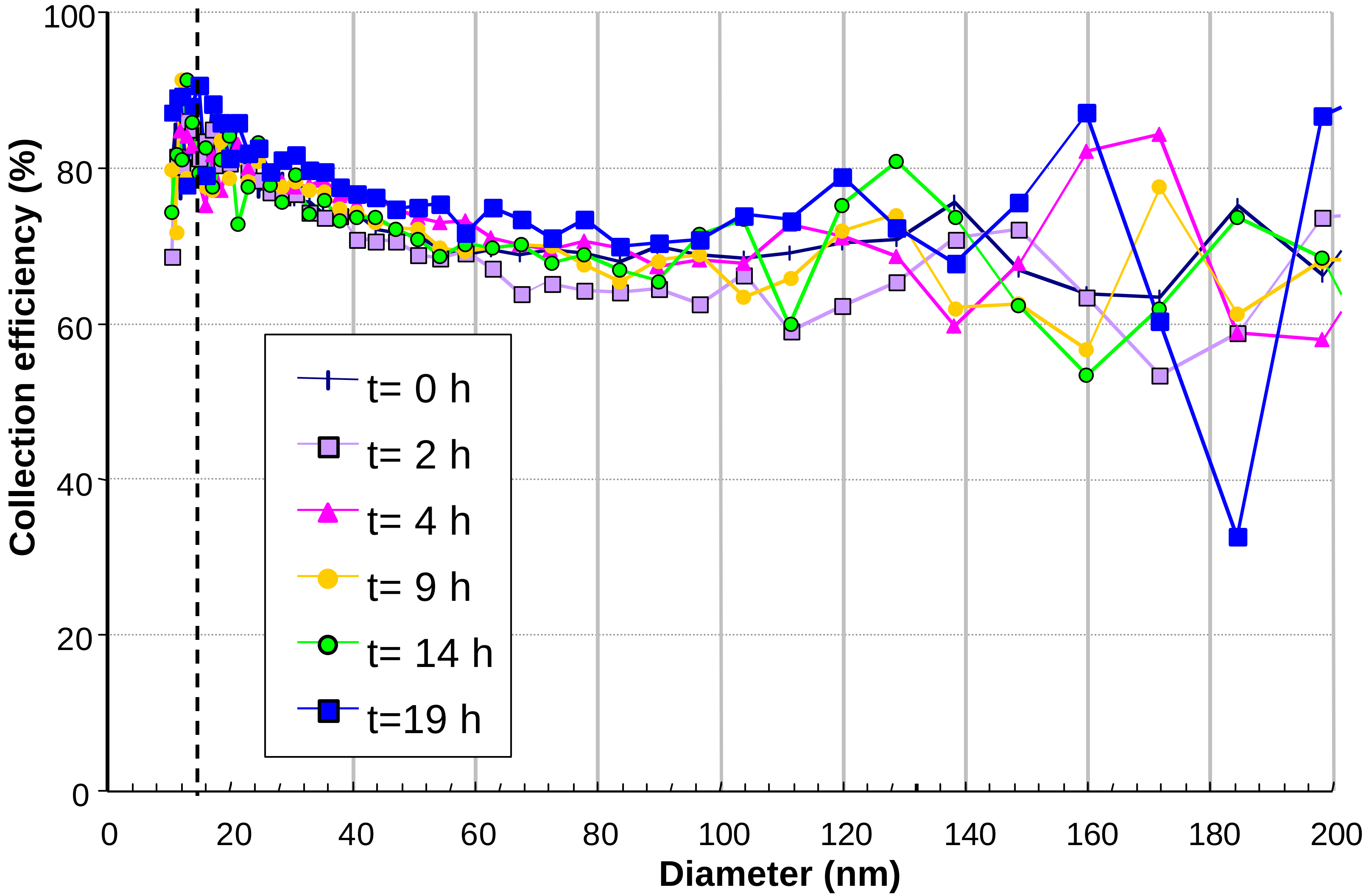
Simulation of gasoline engine PM



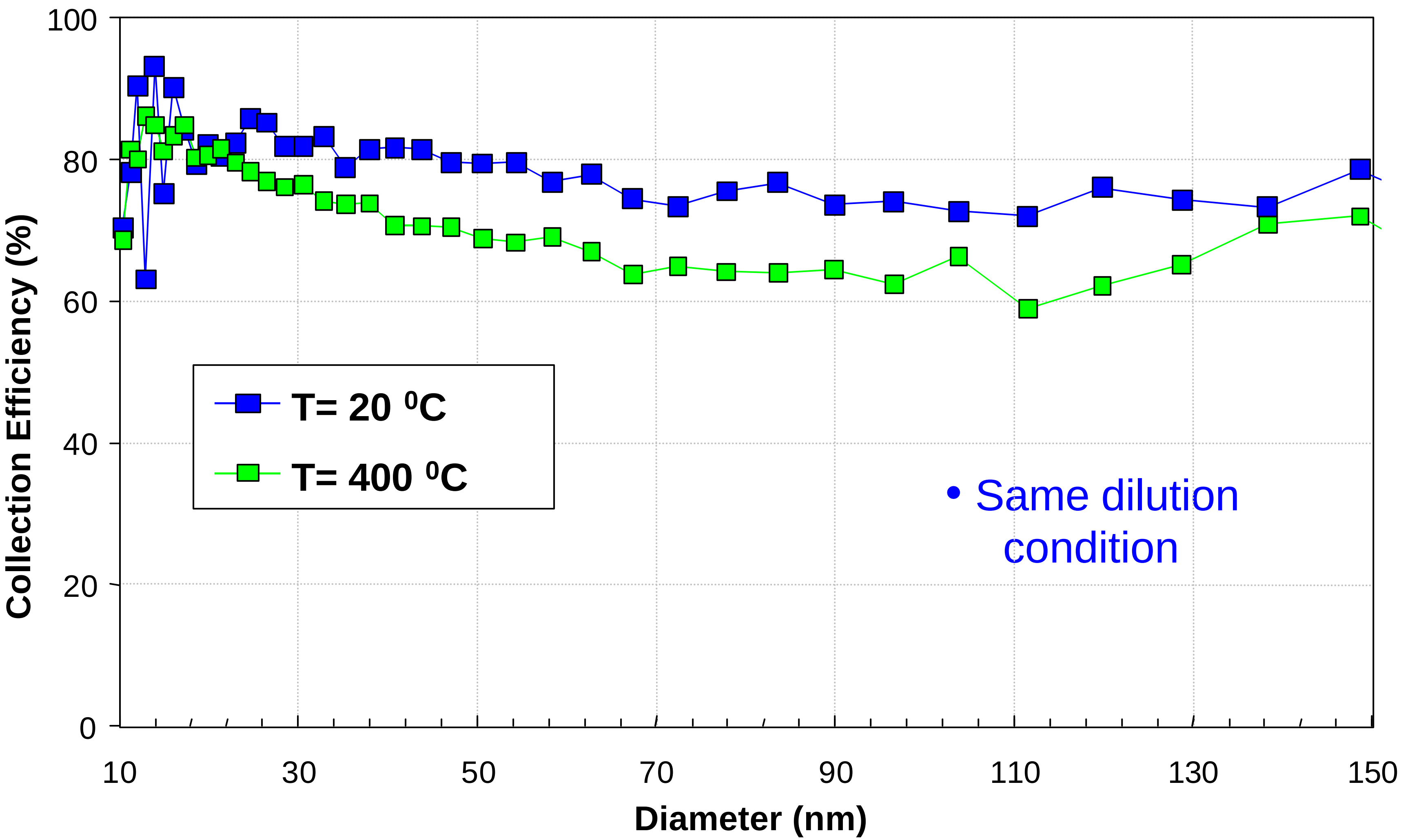
PM Simulation - Collection efficiency by number vs particle size, variation with time at 20°C



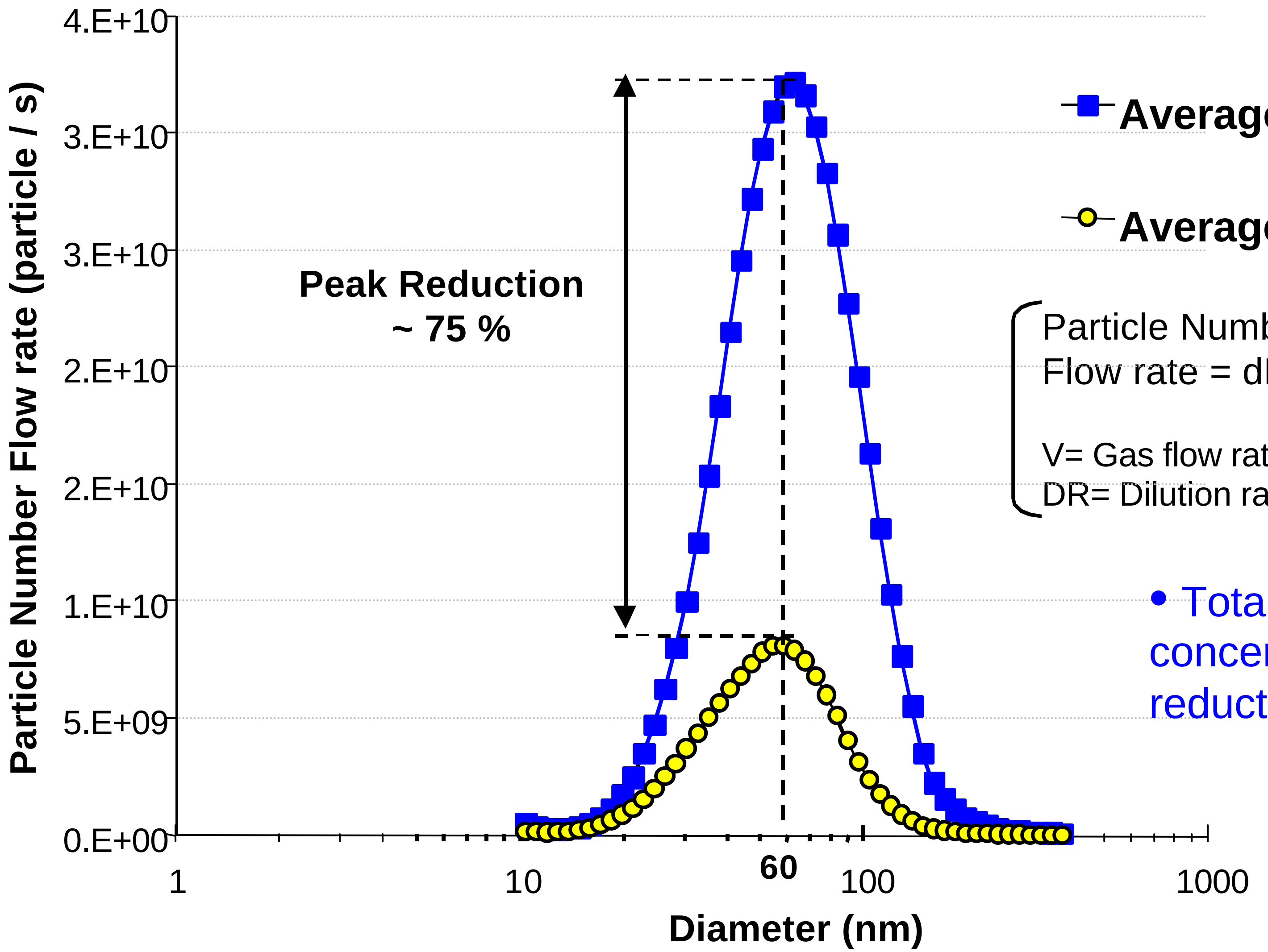
PM Simulation - Collection efficiency by number vs particle size, variation with time at 400°C



PM Simulation - Collection efficiency by number vs particle size, at 400°C & 20 °C



PM Simulation - Particle number flow rate upstream & downstream of filter after 8 h exposure at 20°C

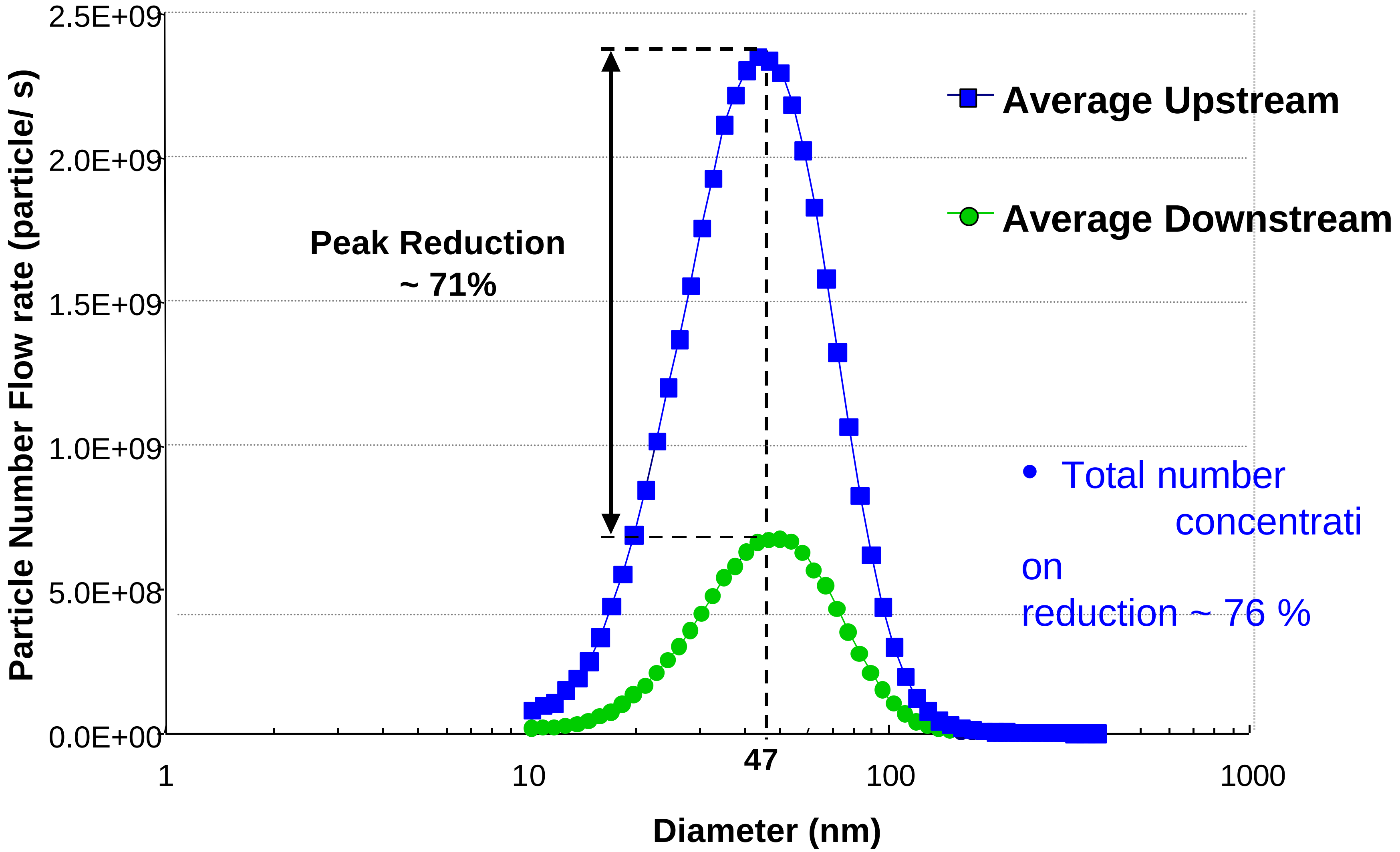


Particle Number Flow rate = $dN/dLog(D_p)$* V * DR

V= Gas flow rate (cm^3/s)
DR= Dilution ratio

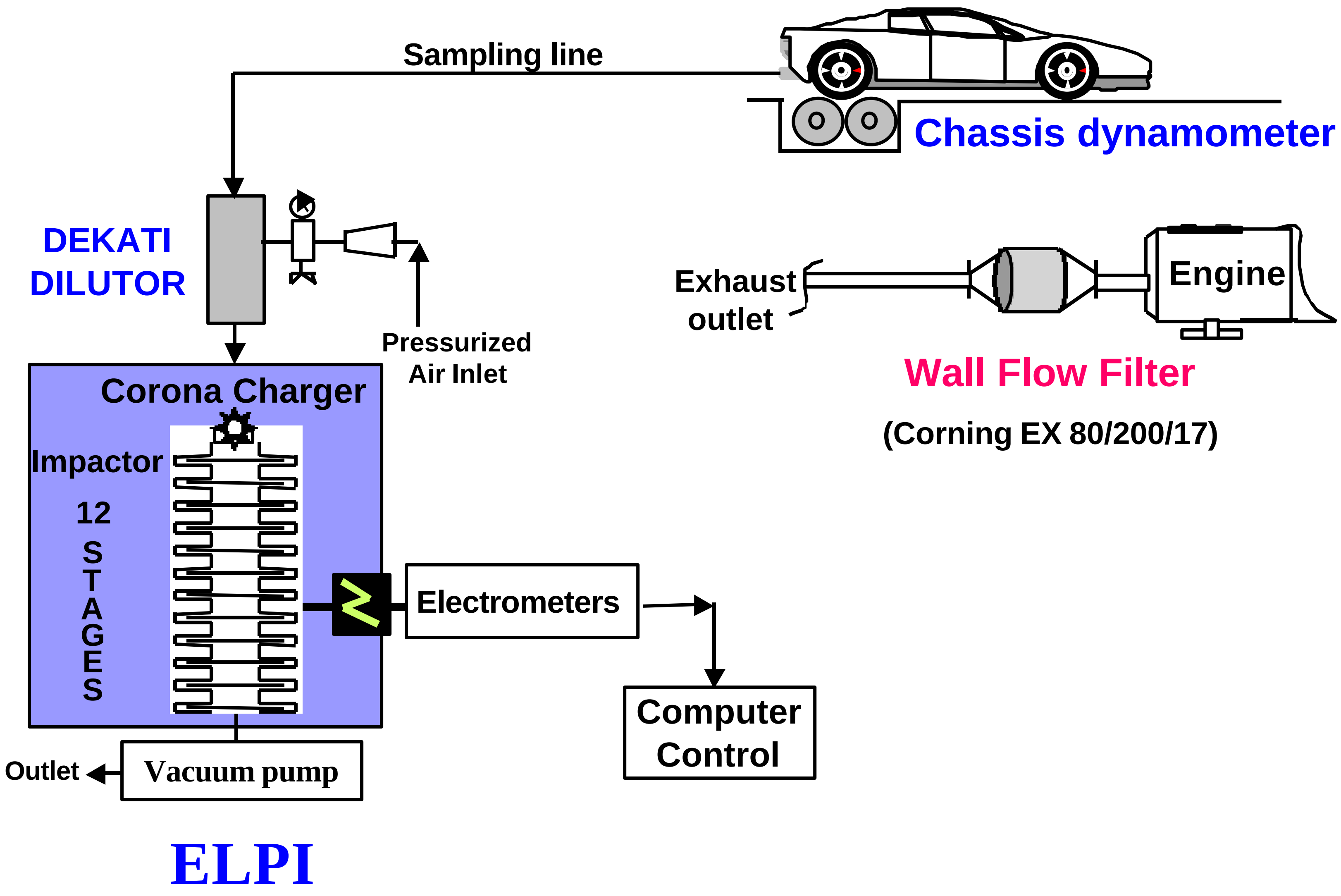
- Total number concentration reduction ~ 80 %

PM Simulation - Particle number flow rate upstream & downstream of filter after 19 h exposure at 400°C

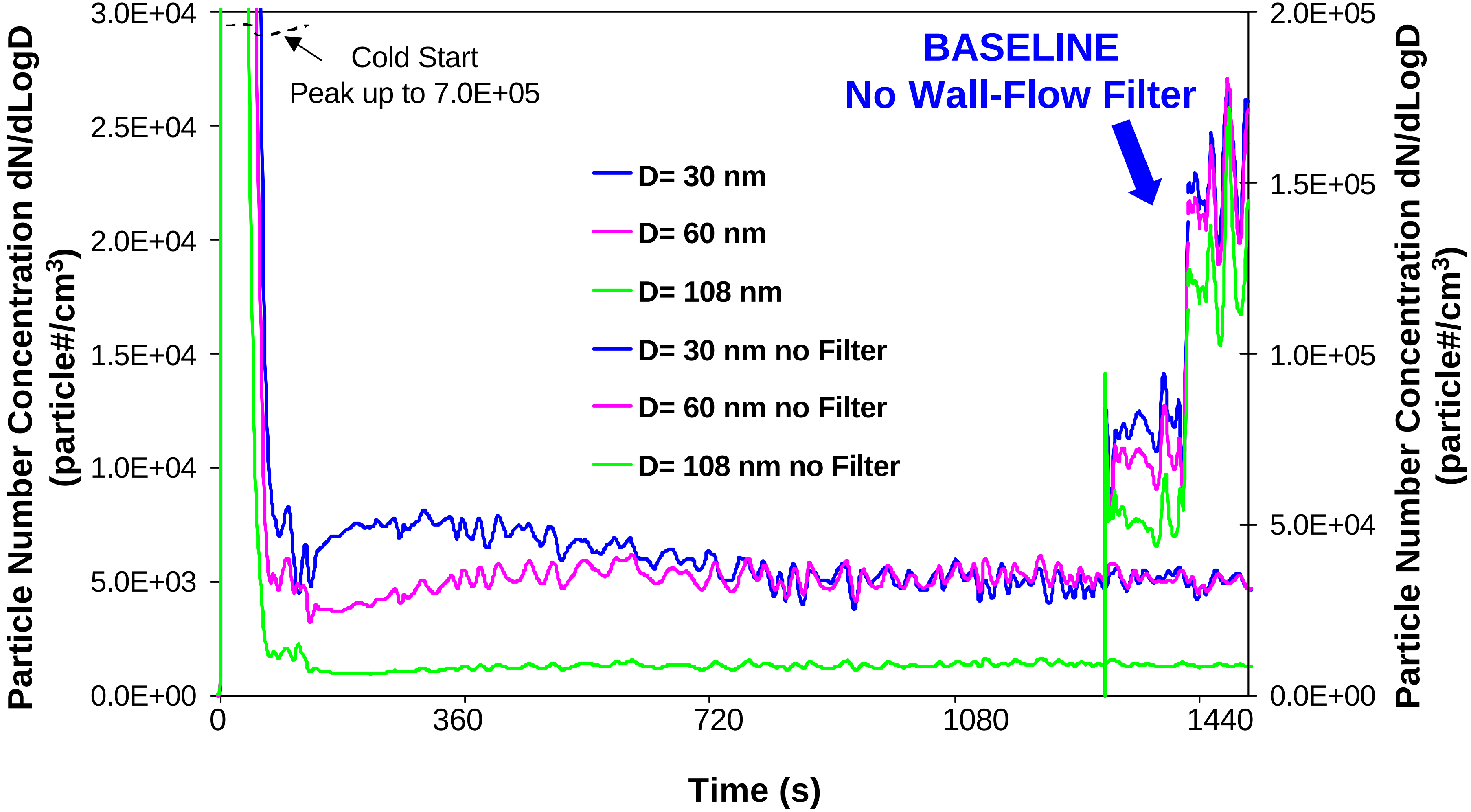


- Total number concentration reduction ~ 76 %

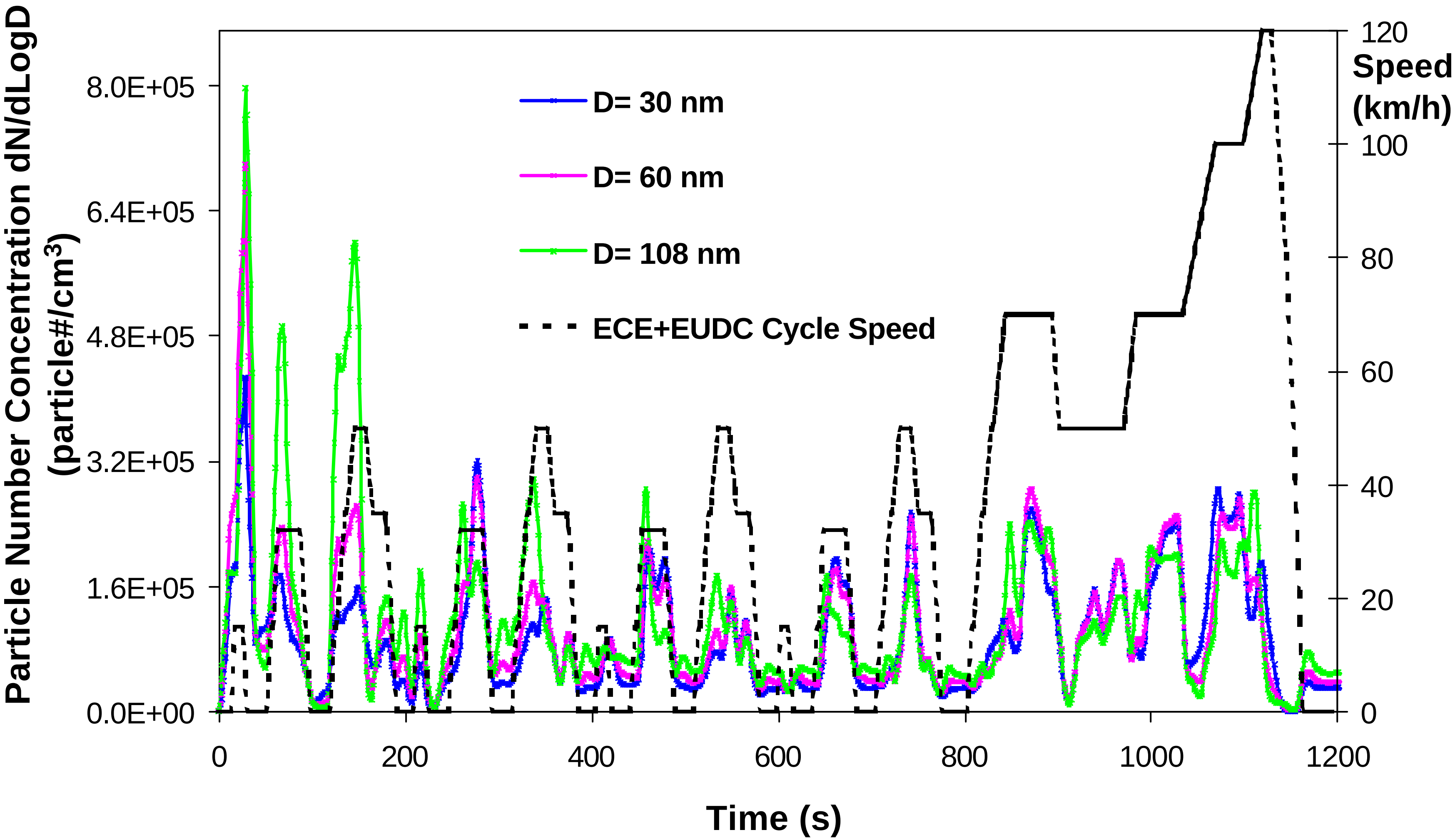
PM from a GDI-engined passenger car (Mitsubishi Carisma 1.8 litre)



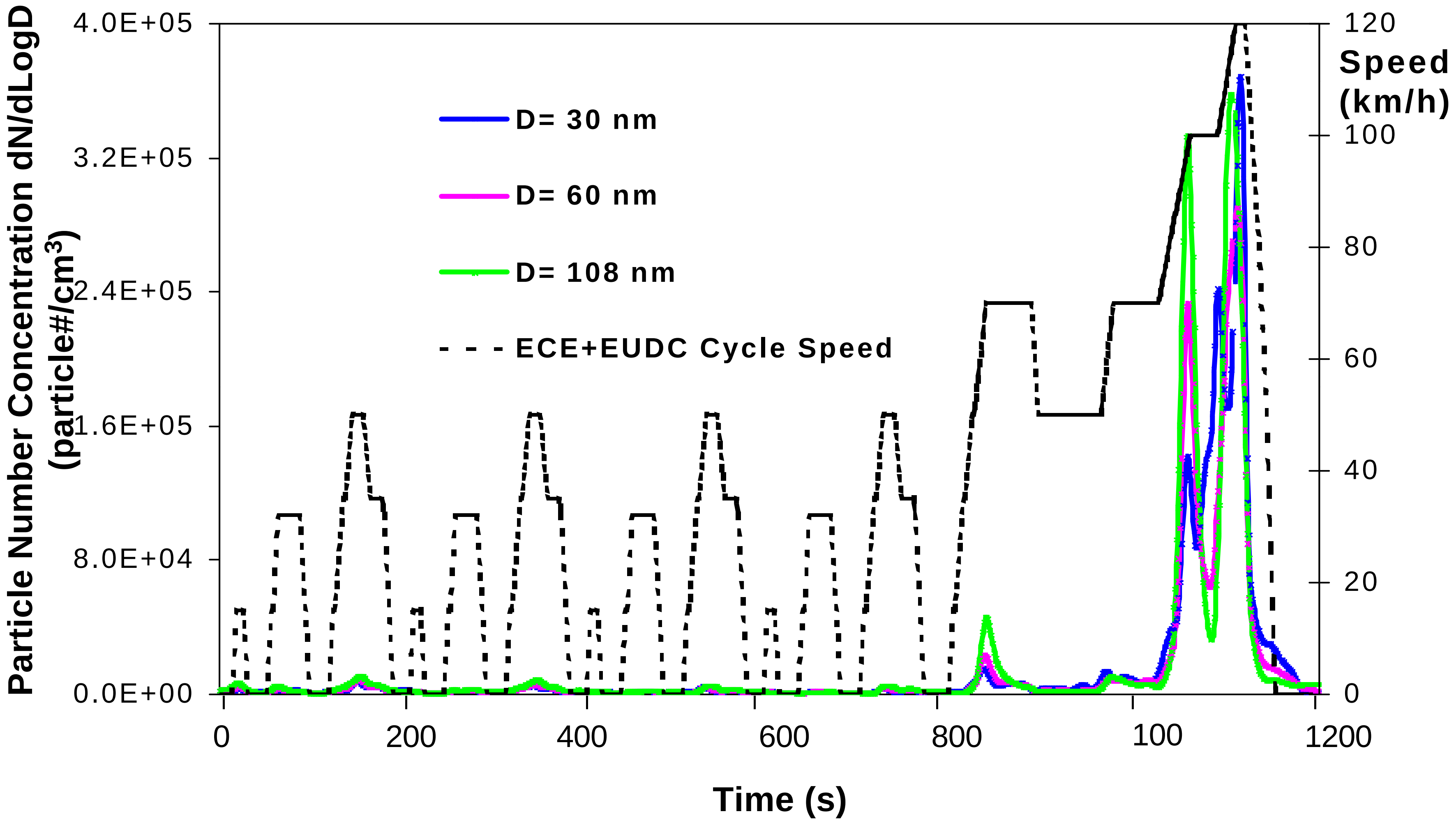
GDI vehicle on chassis dynamometer
Steady-state 80 km/h



GDI vehicle on chassis dynamometer
No Wall-Flow Filter
European Drive Cycle (ECE + EUDC)



GDI vehicle on chassis dynamometer with Wall-Flow Filter European Drive Cycle (ECE + EUDC)



Conclusions

Results from PM simulation for exposure times up to 20 h:

- at 20°C, collection efficiency by number increased with time for all particle sizes and in particular for d_p < 100 nm
- at 400°C, a slight decrease in collection efficiency with particle size in the range 20 nm – 100 nm, unchanged on increasing the exposure time

Results from GDI vehicle:

- effective reductions in particle number concentration both at a steady 80 km/h in the stratified injection mode (equivalence ratio ~2) and over the bulk of a European drive cycle
- at the maximum speed (120 km/h) of the EUDC cycle, post-filter particle number concentrations peak to values measured in the absence of the filter

Current and Future Work

- Further investigation of the effect of Wall-Flow Filters on PM emissions from GDI and PFI engine exhausts
- Simultaneous measurement of particle number concentration & size distribution using both SMPS and ELPI during steady-state engine operating conditions
- Testing of prototype of wire-cylinder ESP on simulated gasoline PM emissions
- Modeling of nanoparticle transport and deposition in the ESP prototype, to determine optimum ESP operating conditions for high efficiency capture
- Comparison of results obtained using wall-flow filters and prototype ESP, leading to development of an after-treatment device for gasoline engined vehicles