KTH ROYAL INSTITUTE
OF TECHNOLOGY

Experiences of airborne particulates from wear process

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Sweden's leading university of technology

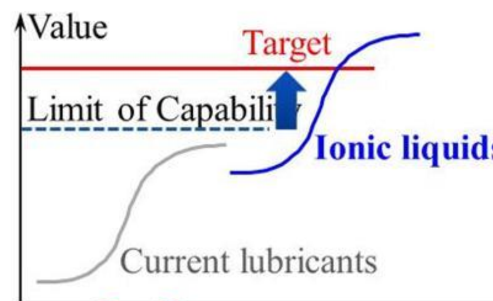
- Sweden's oldest and largest university of technology
- More than 12,000 full-time students
- More than 1,900 PhD Students
- Over 5,100 employees
- Five campuses in the Stockholm region
- Ranked as the 126th best university of technology in the world by THE

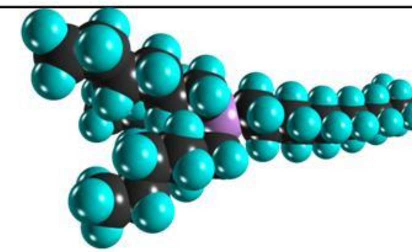
Tribology

From surface topography to system behavior

Modeling and simulation of friction and wear, with an overall perspective on the system effects of emissions, energy efficiency, material hygiene and design.

- Transmissions
- Particle emissions
- Adhesion
- Tactility
- Interface modularization
- New ionic liquids





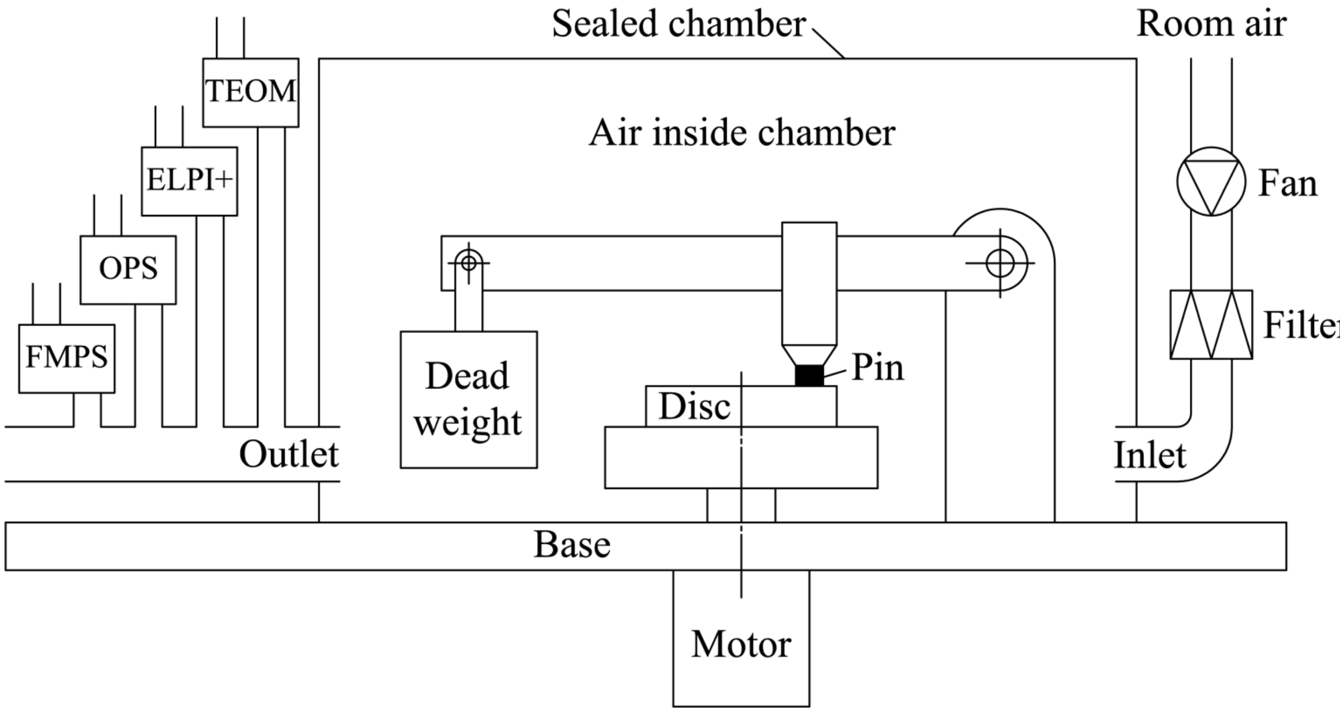
Airborne particulate research – PhD student projects

- 1 PhD project particle emissions from the tail pipe
- 3 PhD projects particle emissions from disc brakes
- 2 PhD projects particle emissions from rail vehicles

Two EU projects Rebrake and Lowbrasys plus three national projects from the Swedish National Transport Agency and Stockholm public transport

transition temperatures and particle density

Experimental setup



TEOM measures the mass concentration PM10 of particles smaller 10 µm;

FMPS classifies 0.0056–0.56 µm particles in 32 stages;

OPS classifies 0.3–10 µm particles in 16 stages;

ELPI+ separates 0.006–10 µm aerodynamic diameter particles in 14 stages

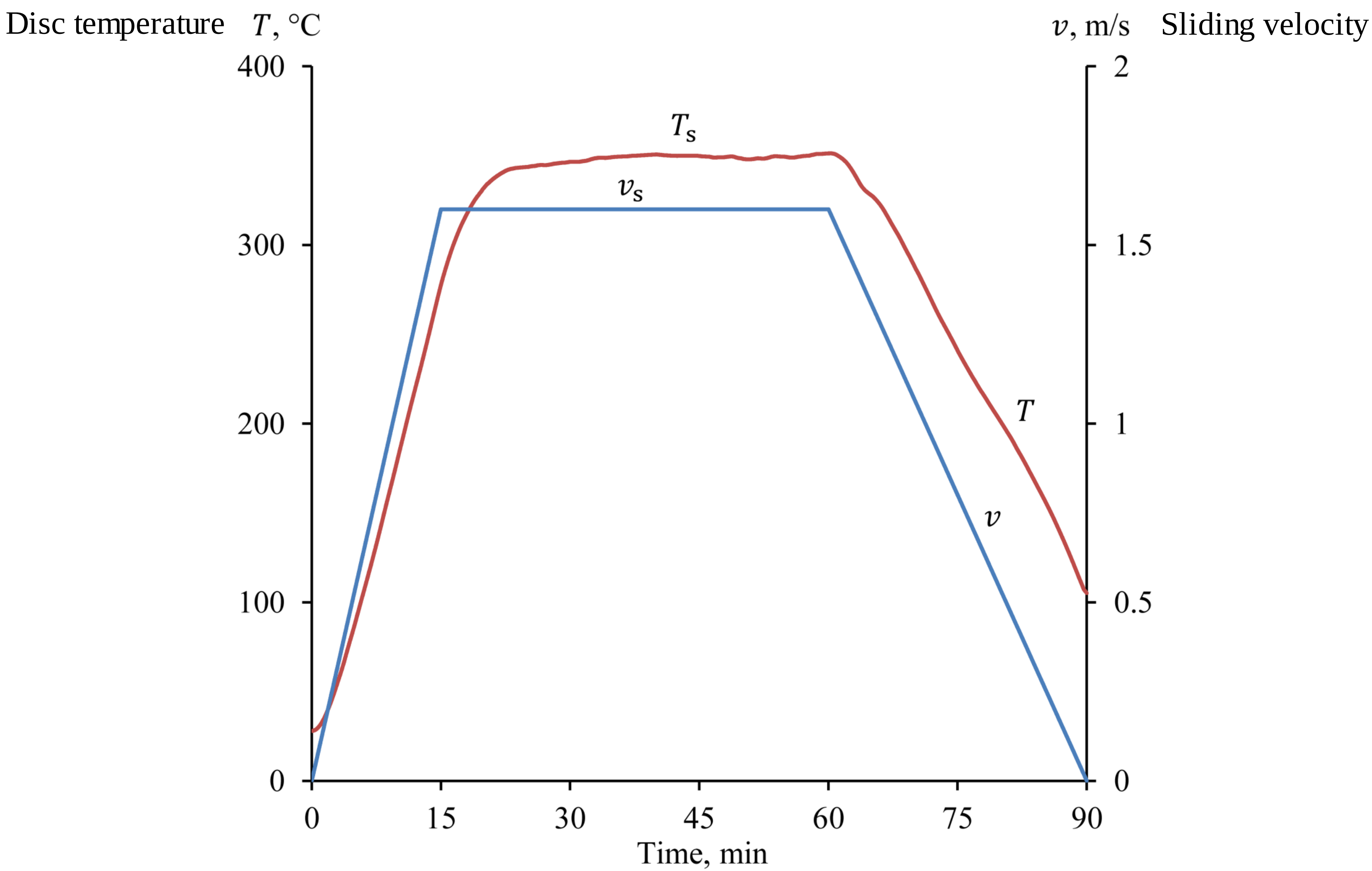
Friction materials

Friction pairs corresponding to those used in passenger car brakes were investigated. The disc was cast iron. Six different materials code-named M1, …, M6 were used as pin samples. Of these, five (M1, …, M5) were LM with phenolic resin as a binder and different reinforcements and abrasives. M6 was an NAO. The pin samples and discs were milled from real brake pads and discs. Their sliding surfaces remained unaltered during the milling.

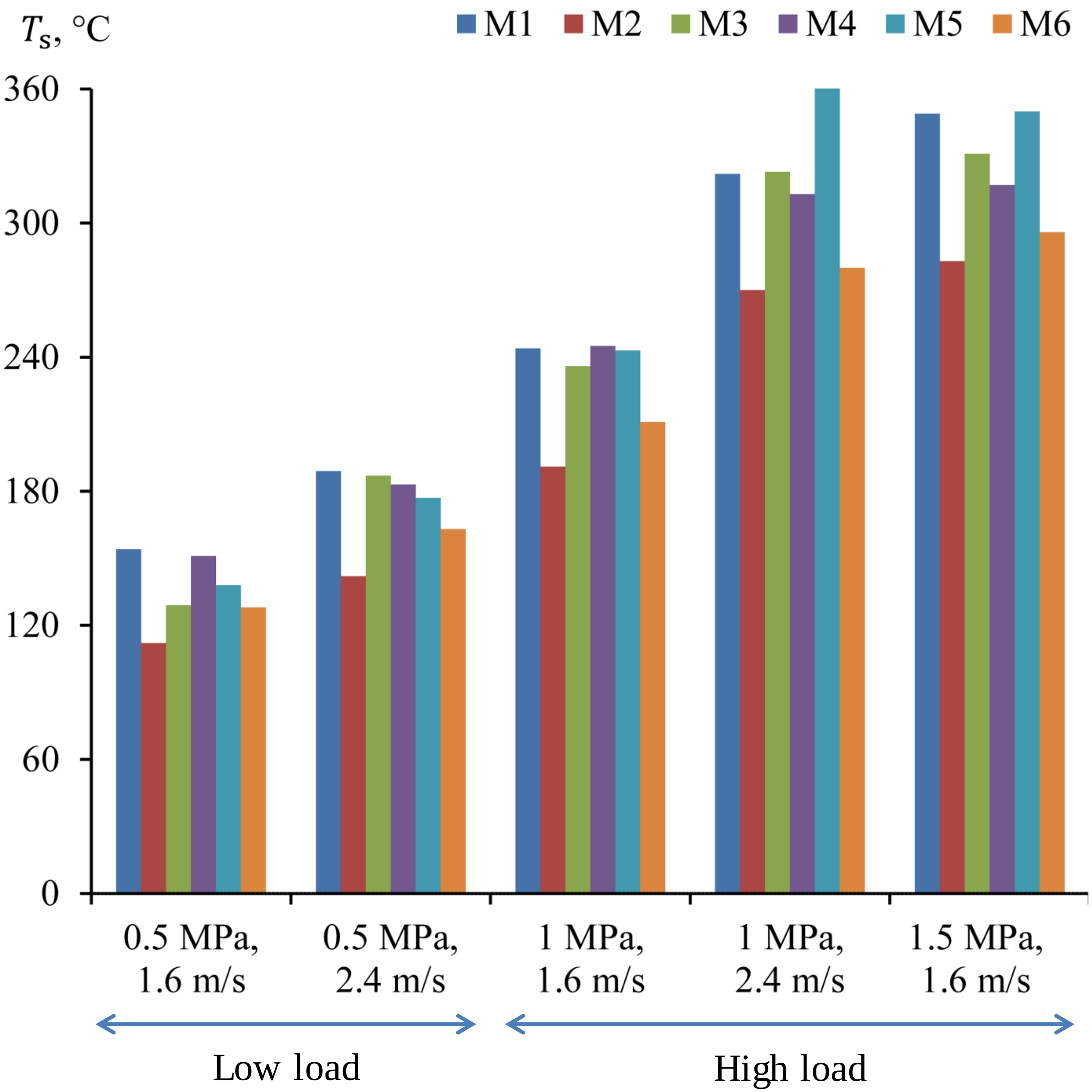
Pin sample

Cast iron disc

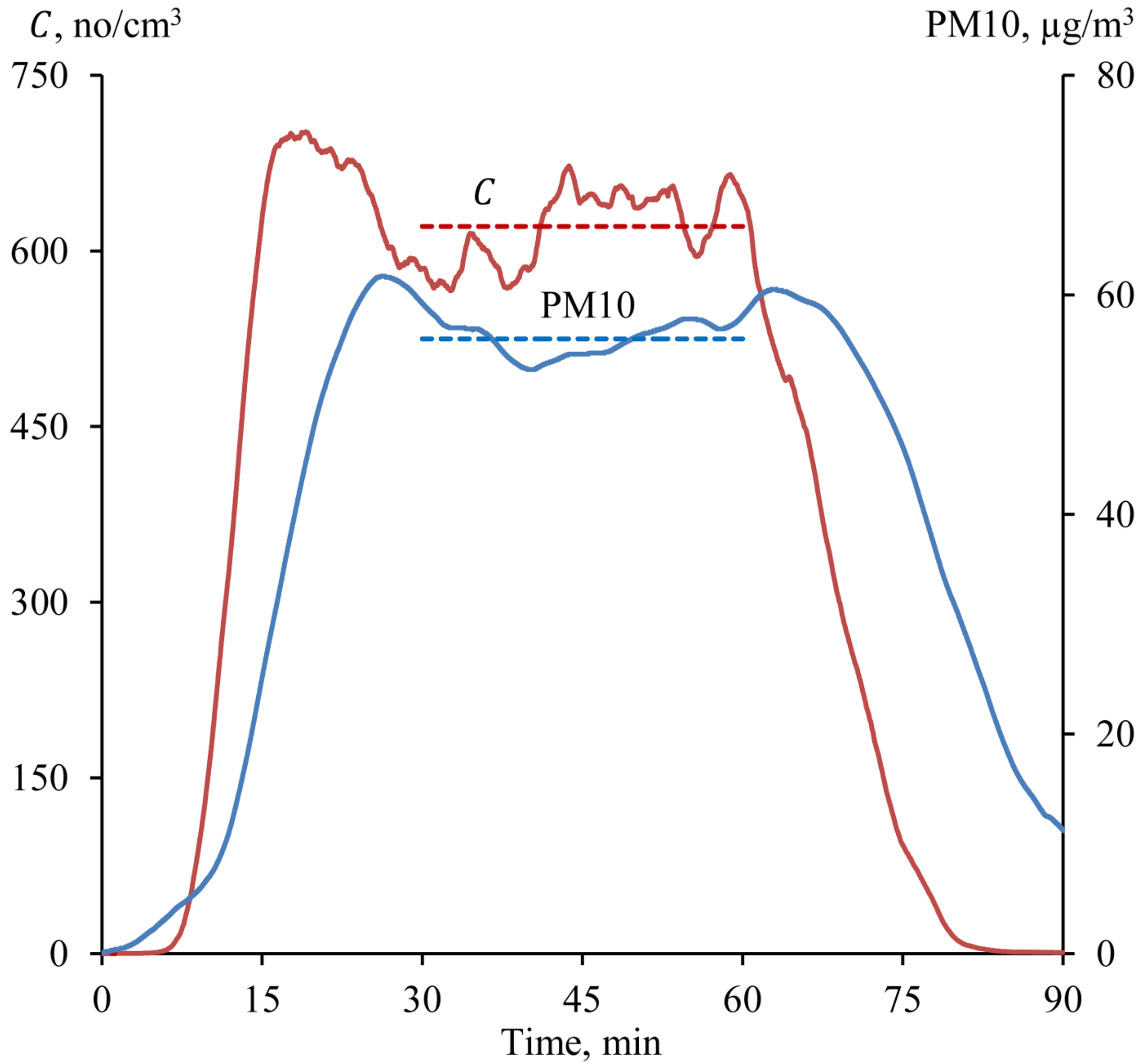
Friction conditions



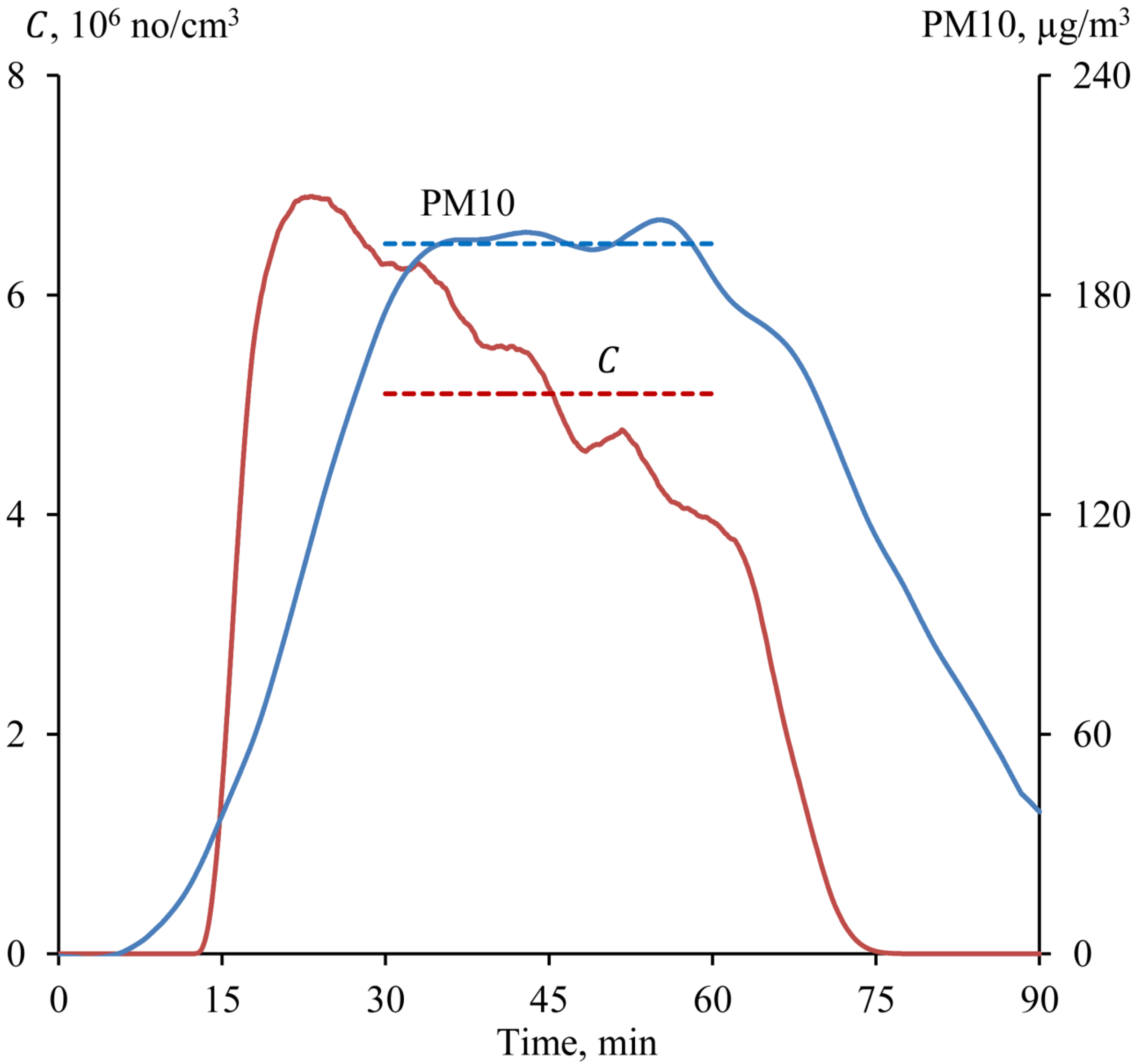
Stationary temperature T_s



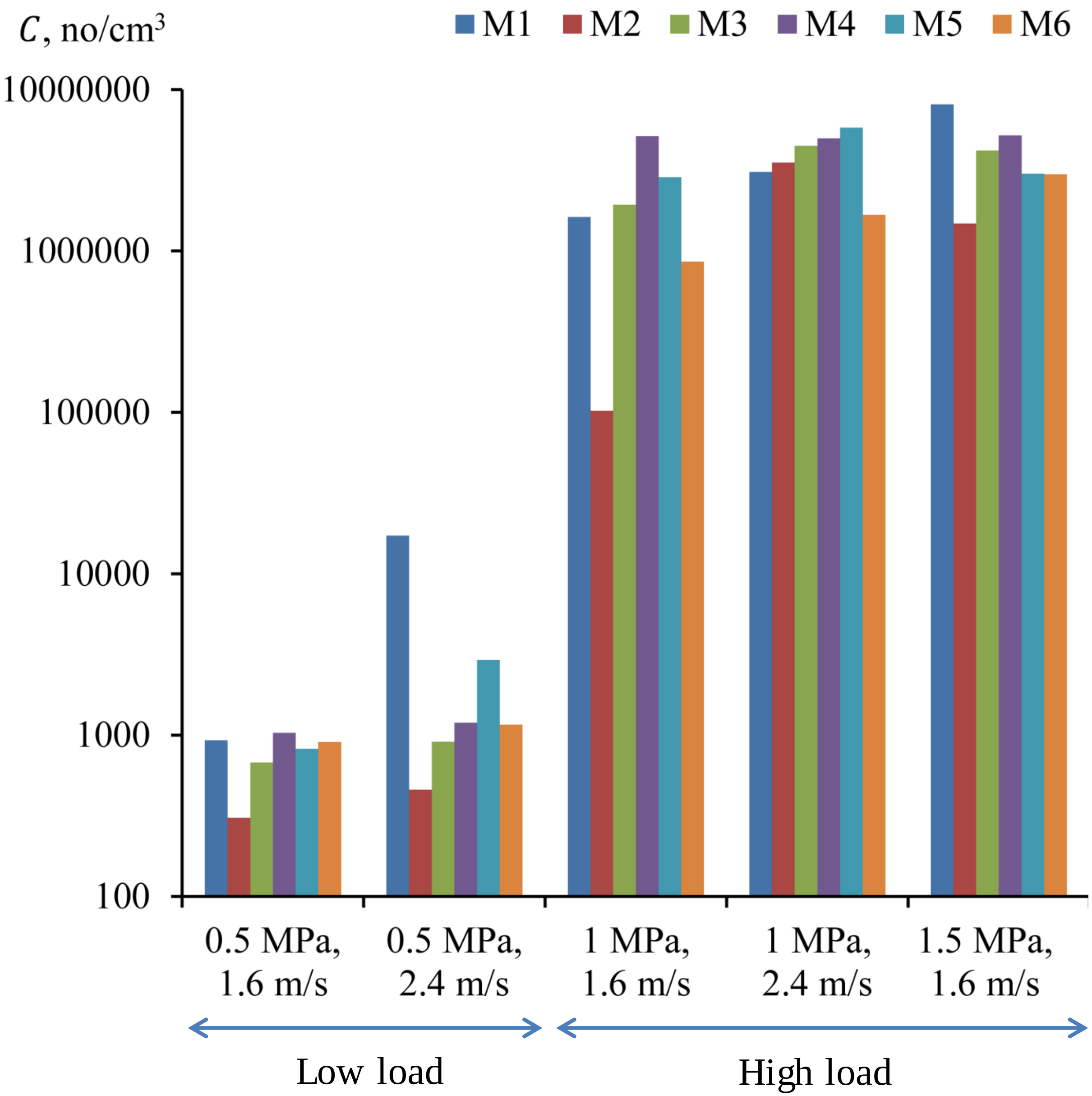
Number concentration C and mass concentration PM10 of airborne wear particles at low load



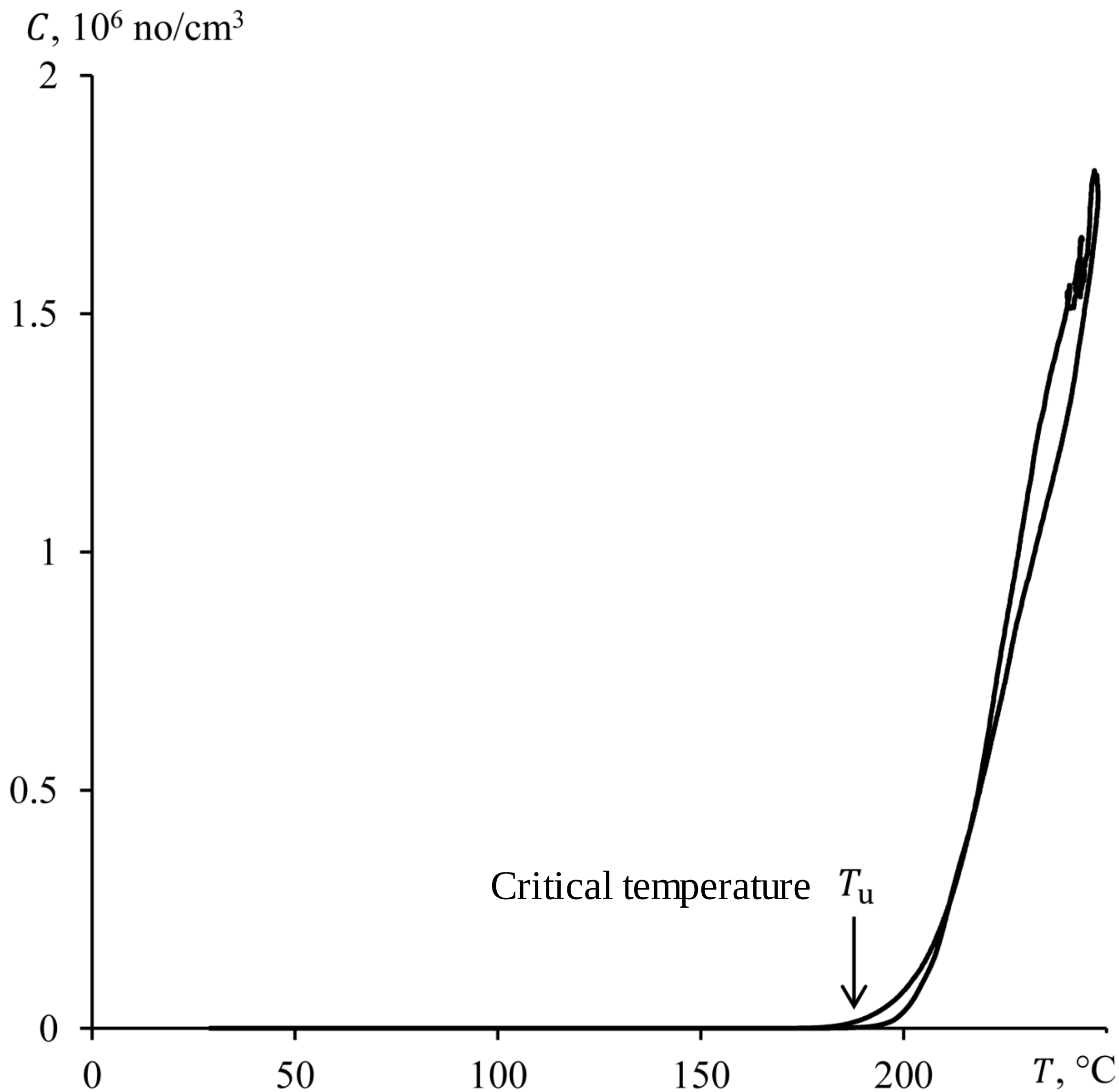
Number concentration C and mass concentration PM10 of airborne wear particles at high load



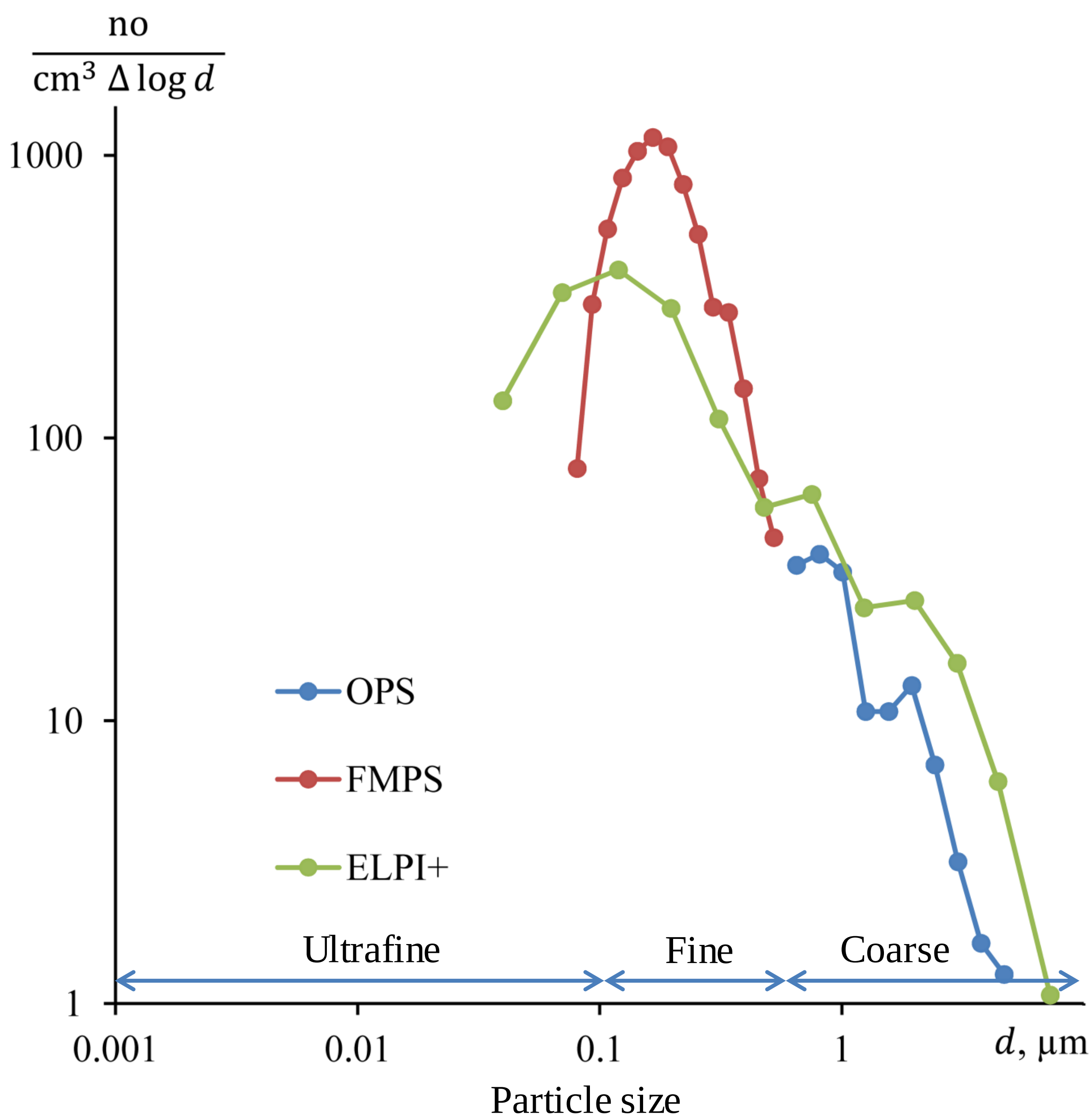
Number concentration C of airborne wear particles



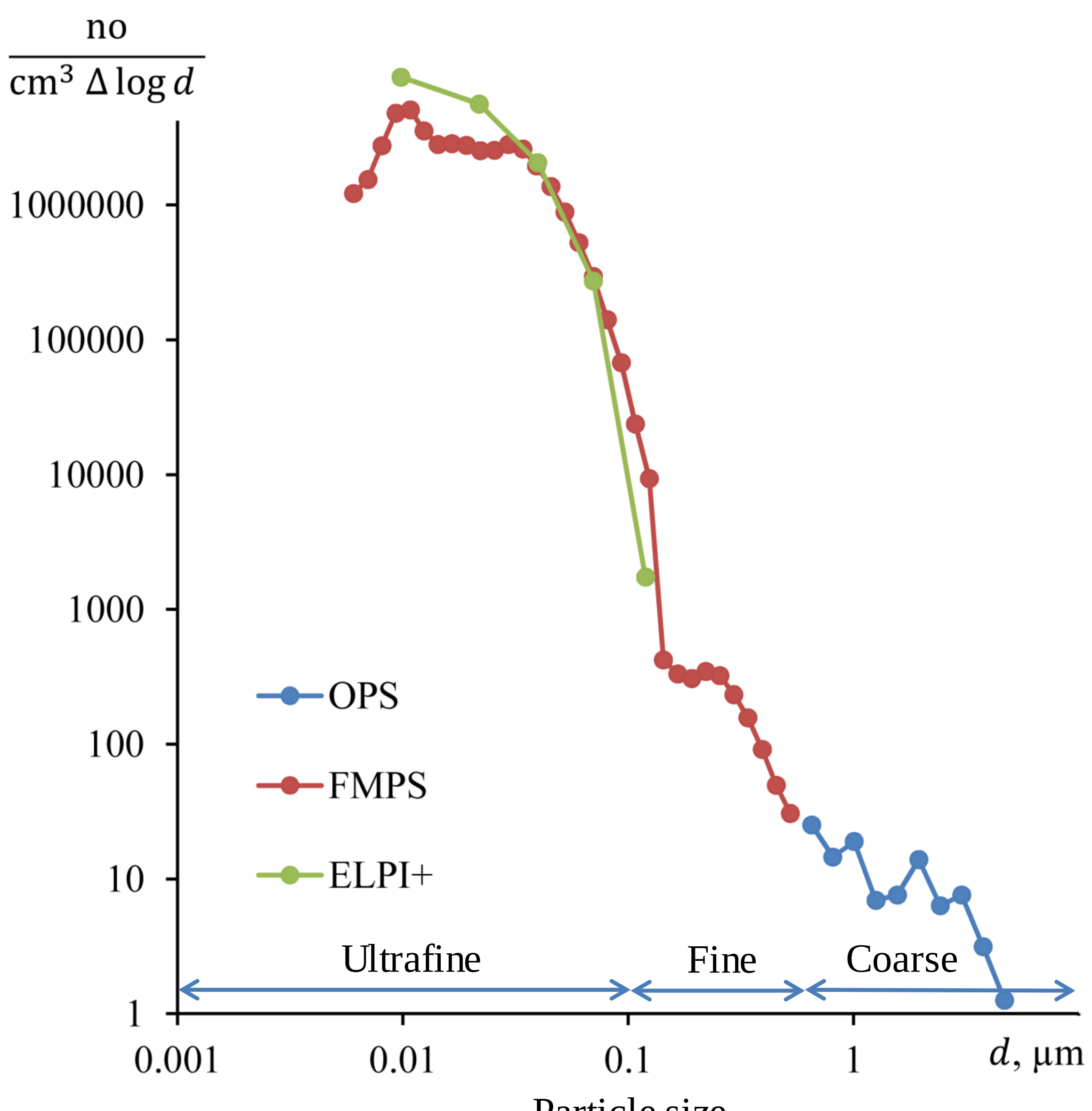
Relation between the temperature T and number particle concentration C



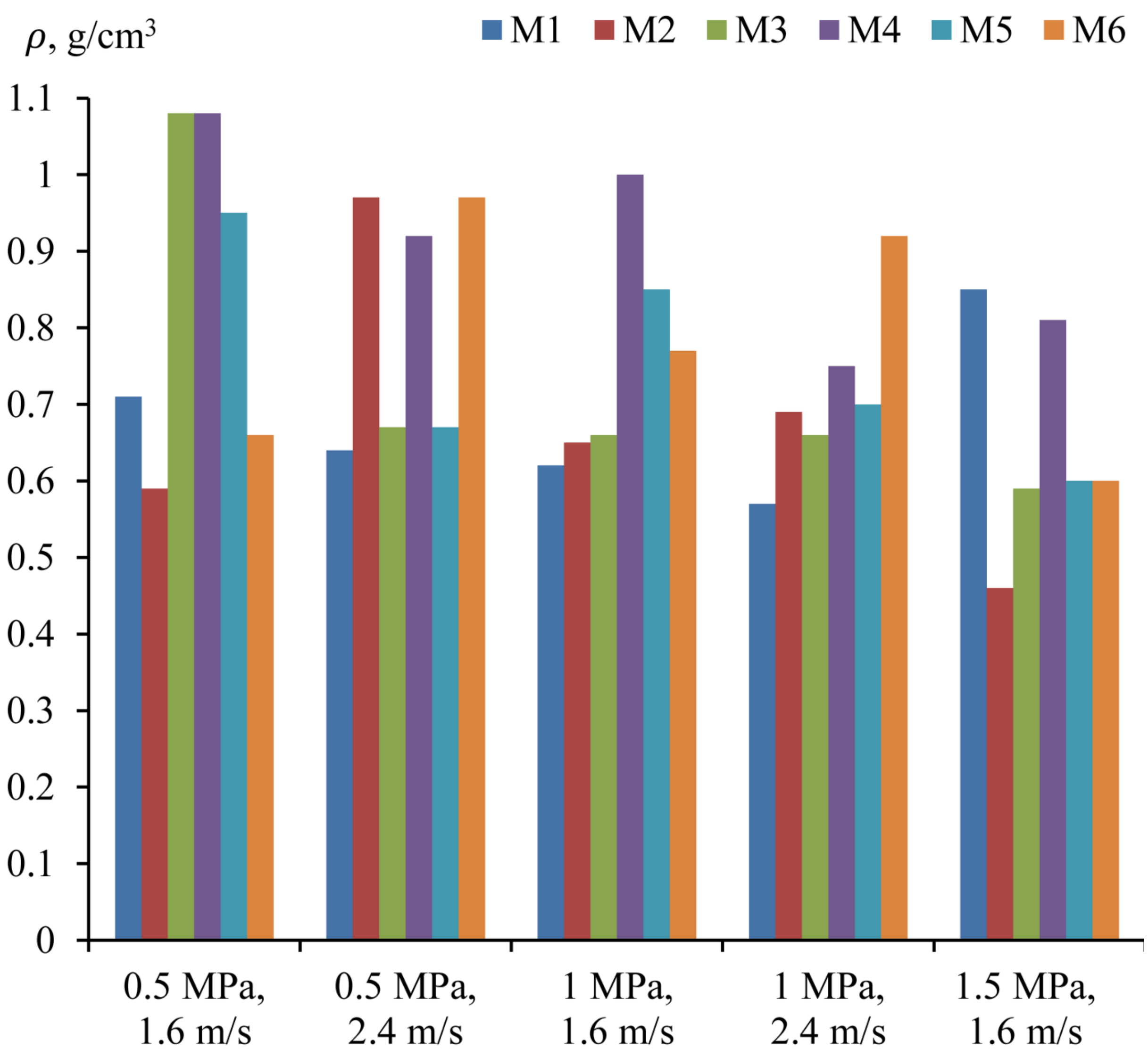
Particle size distribution at low load



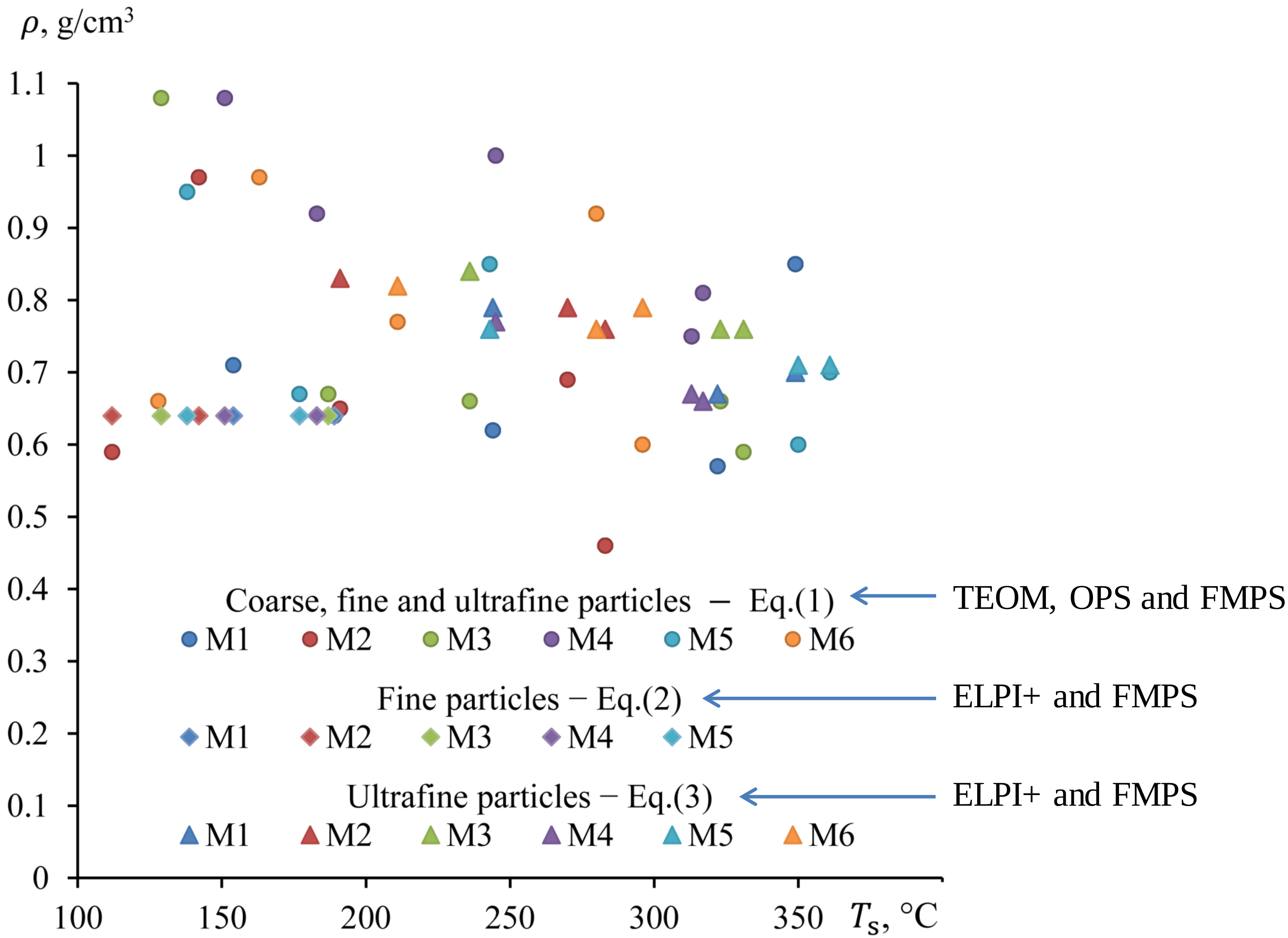
Particle size distribution at high load



Particle density ρ based on measurements by TEOM, OPS and FMPS



Relation between the particle density ρ and stationary temperature T_s

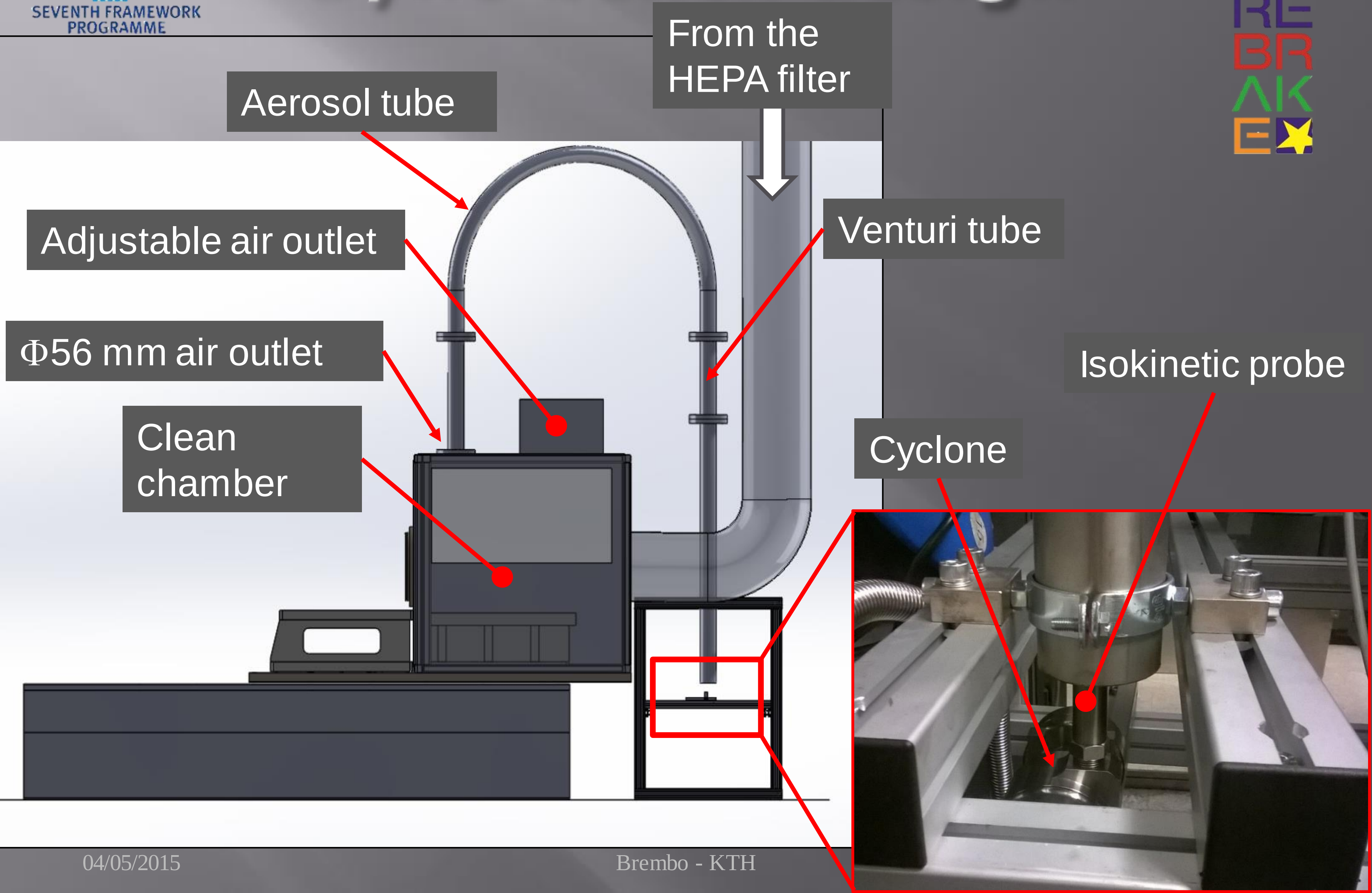


A proposed dyno-bench test cycle to study particle emissions from disc brakes

Main design aims

- Control of the cleanness of the incoming air.
- Assurance of isokinetic sampling.

Dyno bench design



Dyno bench design

Brake assembly

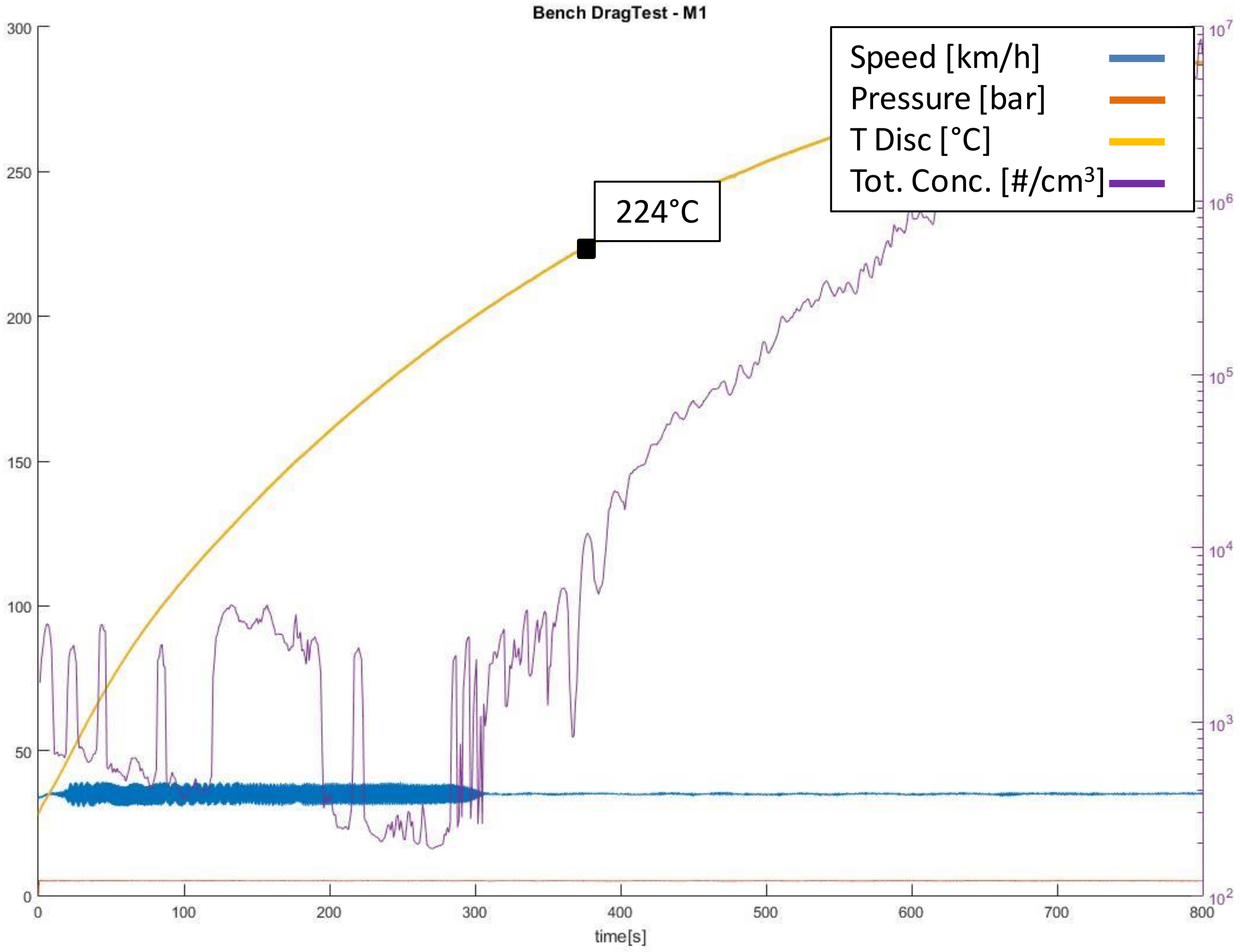
Impactor

Test conditions

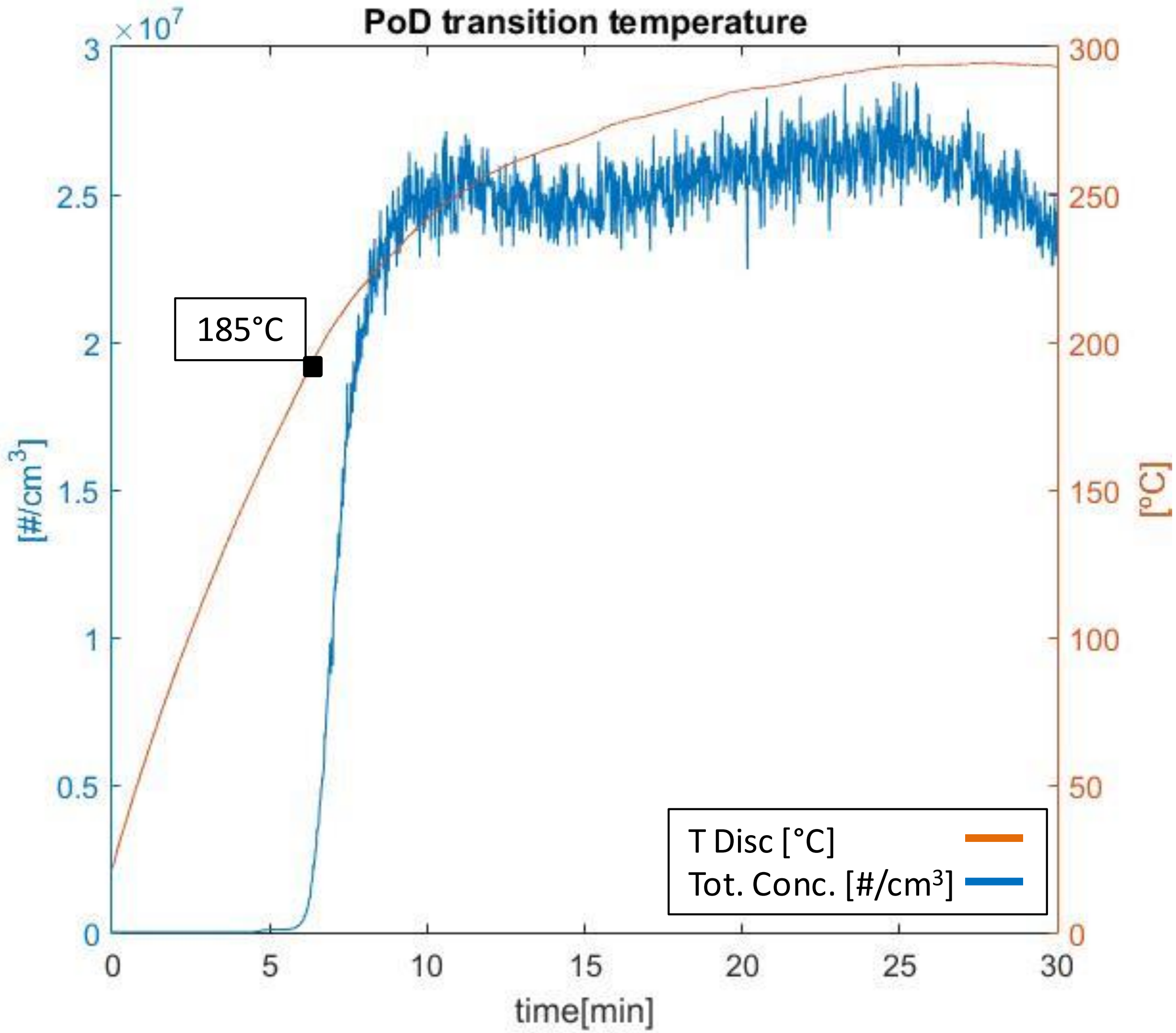
ACQUIRED DATA:

- ❑ Particulate emissions – Dekati ELPI+ (1Hz)
- ❑ Pad and disc temperatures
- ❑ Torque/ Pressure – Transducer (50 Hz)
- ❑ Velocity / Friction coefficient – calculated

Transition temperature: Dyno



Transition Temperature: PoD

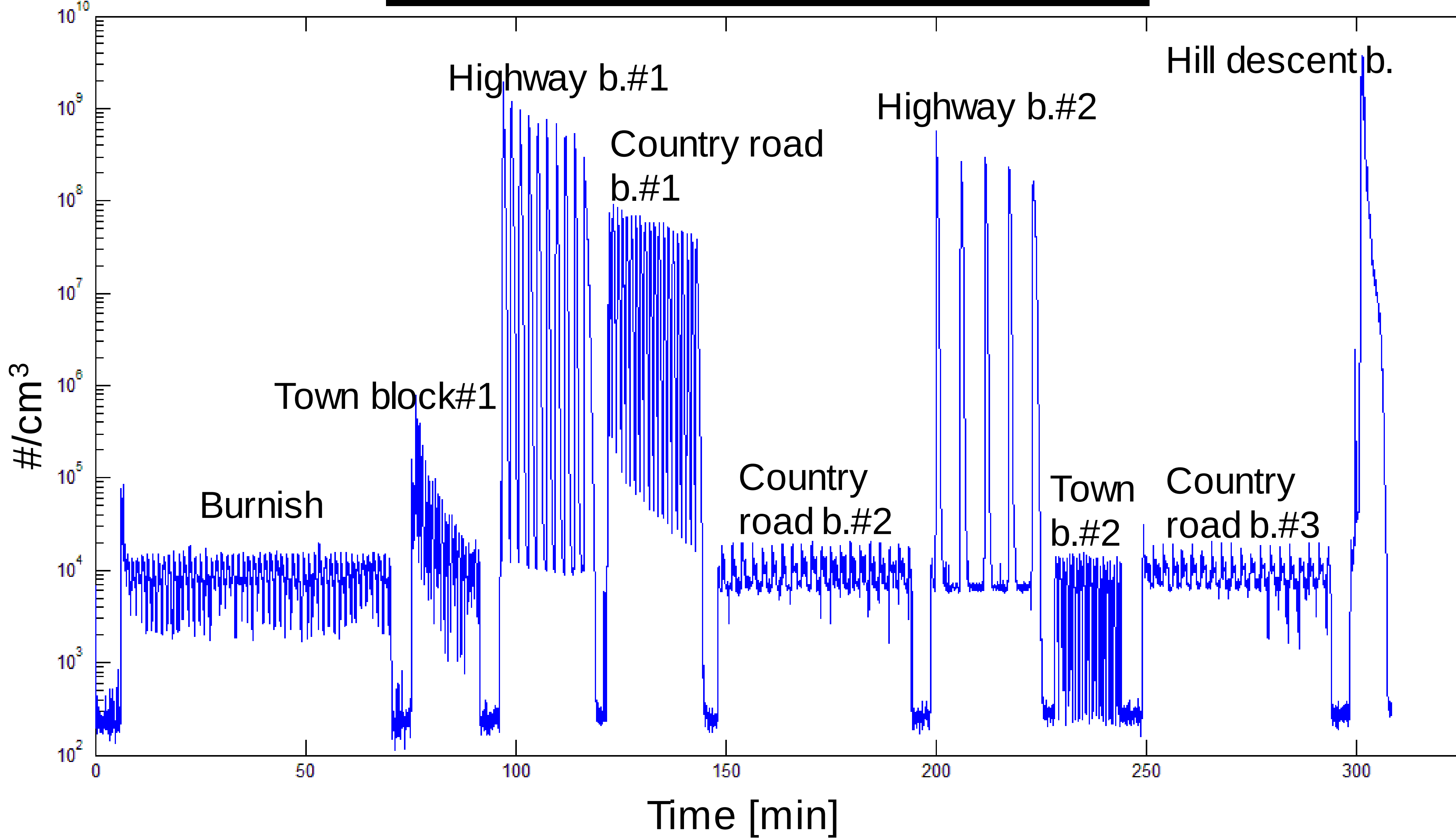


Test conditions

#	Section	Initial speed [km/h]	Final speed [km/h]	Initial disc brake temperature [°C]	Braking deceleration [g]	Number of stops [N]	Number of stop in present test [#]
	5’ Cleaning						
1	Burnish	50	4	100	0.25	100	50
	5’ Cleaning						
2	Town block #1	50	4	150	0.25	200	20
	5’ Cleaning						
3	Highway block #1	150	80	150	0.4	100	10
	5’ Cleaning						
4	Country road block #1	80	4	200	0.35	200	20
	5’ Cleaning						
5	Country road block #2	100	4	125	0.4	200	20
	5’ Cleaning						
6	Highway block #2	180	80	100	0.5	50	5
	5’ Cleaning						
7	Town block #2	50	4	150	0.25	200	20
	5’ Cleaning						
8	County road block #3	100	4	125	0.4	200	20
	5’ Cleaning						
9	Hill descent block	80	4	350	0.35	50	5
	5’ Cleaning						

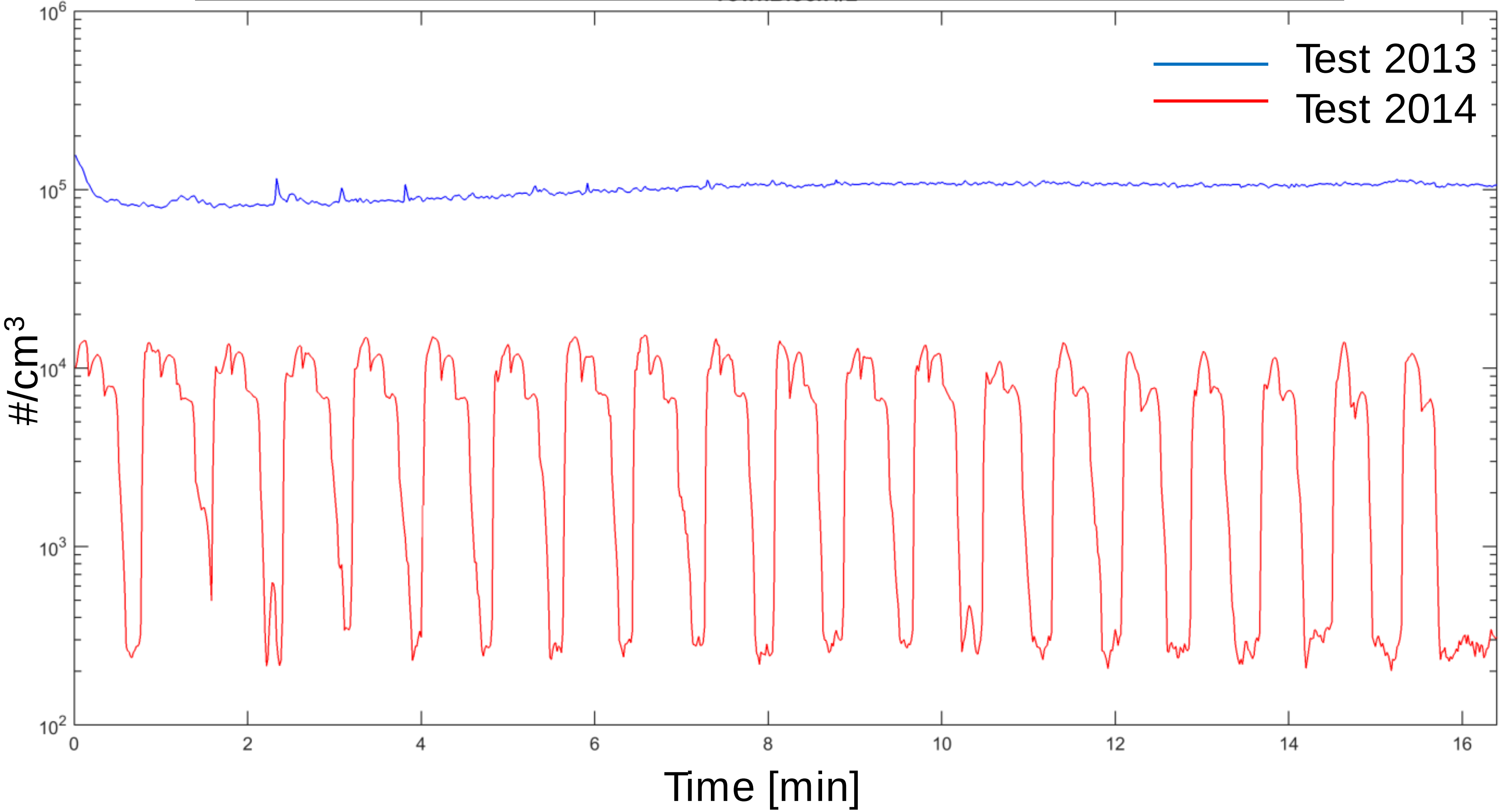
Results

Particle total concentration



Results

Particle total concentration: Town block #2



Road Test: Set-up

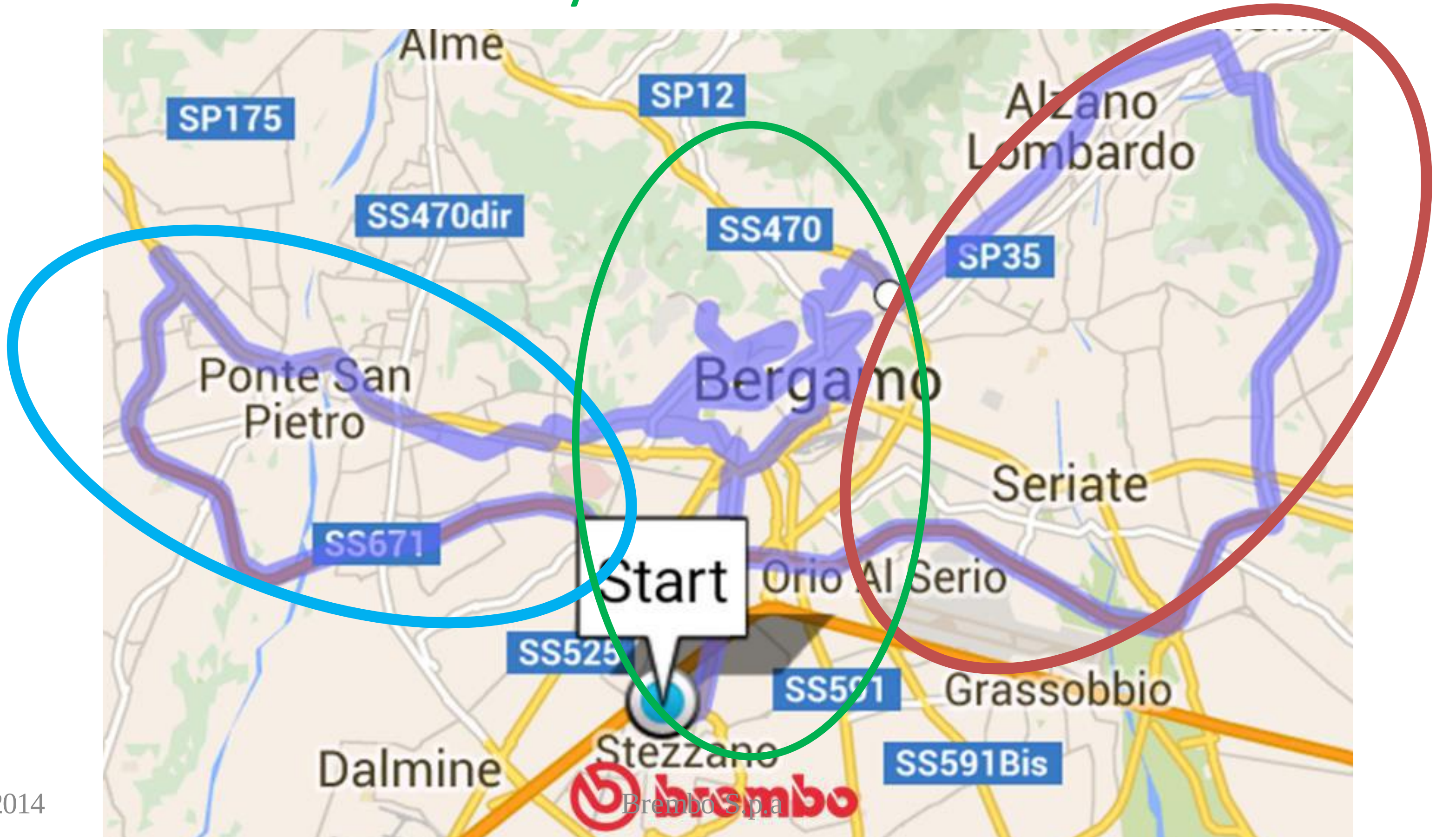
In order to define the typical urban driving brake system parameters the reference car was equipped as follows:

- 2 k-type thermocouples each pad
- 2 k-type thermocoupes each disc
- GPS speed
- Wheel speed
- Pressure transducer

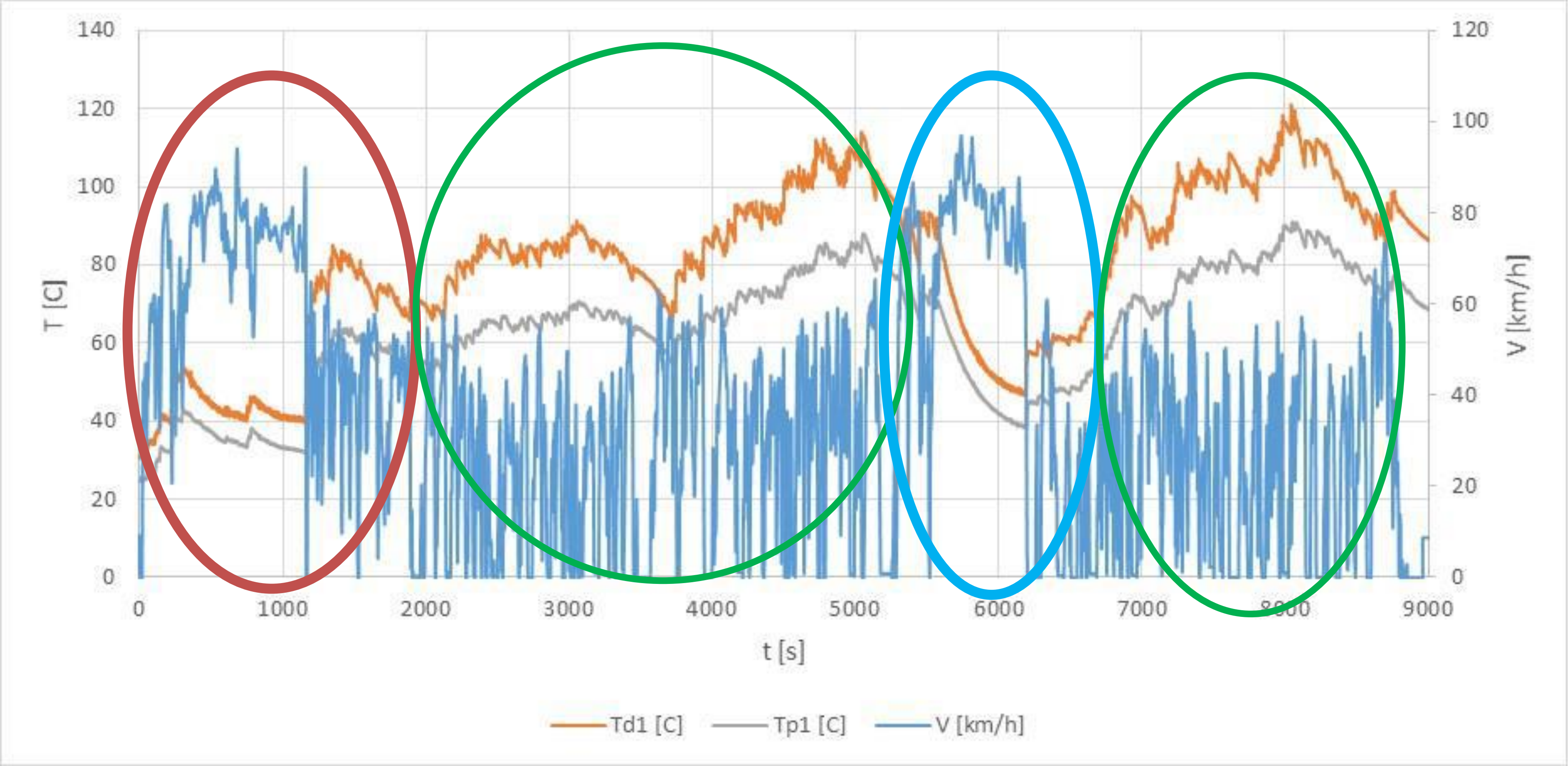
Road Test: Track

The defined track involved 4 phases, for a total of 74km:

- Initial system **warm-up**
- **1st city** cicle
- System **cool down** phase
- **2nd city** cicle



Road Test: Results example



Future developement

- Rank different brake materials
- Calculation of emission factors
- Road tests - updated dyno cycles (transition temperatures)
- Simulation models on local and global scale

REBRAKE Workshop 3: Modelling and simulation of wear and particle emissions

KTH Royal Institute of Technology, Stockholm, Sweden
Department of Machine DesignMonday
October 26th 2015
Contact: Anders Söderberg aes@md.kth.se

Preliminary programme

09:15 – 09:20 Welcome and opening

09:20 - 09:30 Overview of the modelling and simulation activities in REBRAKE and LOWBRASYS
(Anders Söderberg, Dept. of Machine Design, KTH Royal Institute of Technology)

9:30 - 10:00 Introduction to numerical wear simulations
(Anders Söderberg, Dept. of Machine Design, KTH Royal Institute of Technology)

10:00 - 10:15 Coffee break

10:15 - 11:00 Wear simulation using finite element analysis
(Giorgio Valota, Brembo SpA)

11:00 – 11:45 Simulation of local contact situation using cellular automaton
(Jens Wahlström, Dept. of Machine Design, KTH Royal Institute of Technology)

11:45 – 12:00 Open-discussion and closure of the morning session

12:00 – 13:15 Lunch

13:15 – 13:20 Opening of the afternoon session
(Anders Söderberg, Dept. of Machine Design, KTH Royal Institute of Technology)

13:20 - 13:50 Measurement of wear and particle emissions in pin on disc tribometer
(Mattia Alemani, Brembo SpA)

13:50 – 14:20 A computational fluid dynamic study of gas-particle system with the application to the laboratory tests of particle emissions
(Hailong Lu, Dept. of Material Science, KTH Royal Institute of Technology)

14:20- 14:30 Coffee break

14:30 – 15:00 Particle density estimation
(Oleksii Nosko, Dept. of Machine Design, KTH Royal Institute of Technology)

15:00 – 15:30 Copper in brake materials and related environmental issues
(Giovanni Straffelini, Dept. of Industrial Engineering, University of Trento)

15:30 – 16:00 Open discussion

16:00 Closure