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INFLUENCE OF DILUTION CONDITIONS ON DIESEL ENGINE PARTICULATE EMISSION

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EXTENDED SUMMARY

Nanoparticles are not new developments in engine emissions. The new issues about them are their effects on our environment and by implication, our health. This has made their regulations a curious issue to authorities, researchers and engine manufacturers. Post 2010 engines in the US and Europe has met all requirements due to successful application of exhaust after treatment filtration technology and oxidation catalysts. However as health effects studies reveal, the mitigation of the nanoparticles especially within the ultrafine range remains a challenge. In every study, exhaust sample must be diluted in one way or the other to suite the capability of the measurement device but, the emergence of nanoparticles upon dilution is a sensitive issue in laboratory schemes. This is because of the many ways in which aerosol could be diluted according to the researcher's resources and intuitions. The difficulty in repeatability of results from different laboratories is majorly due to dilution effects since the nature of diluters and the dilution parameters, as well as artefacts can alter results [1, 2, 3 and 4]. Therefore, it becomes necessary to understand the dynamics of phase transformation of the volatile components from exhaust emissions and their subsequent transformations into accumulation mode in a given experimental technique. The primary objective of this work was to investigate the effects of dilution ratios and dilution gas temperatures on diesel engine exhaust samples obtained at two chosen engine operating conditions. This is in order to identify optimum dilution condition as measured in particle number and size distributions.

The experiments have been conducted at Brunel University's Centre for Advanced Powertrain and Fuels Research CAPF using a 2.0 Liter Ford Diesel Engine to generate exhaust samples at two engine load conditions of 2.5 bar BMEP and 5.0 bar BMEP; and measured with an Electrical Mobility Spectrometer EMS. This an Electrostatic measurement device using a combination of Vienna type Differential Mobility Analyzer DMA, automated to classify fine and ultrafine particles sizes from 4 to 600nm; and a Faraday Cup Electrometer FCE, which covers ideally the size concentrations obtainable from motor vehicle emissions even at small dilution ratios [4]. The dilution system is a closed loop type using filtered exhaust as dilution gas, measured according to the dilution ratio and directed back to the dilution probe via a feedback loop. The dilution ratios are governed by of set critical orifices as determined by the Flow Control Unit FCU. It is evaluated as percentage of aerosol in sample, values of which are dynamically calculated from the flow rate of the critical orifices (Co1 – Co6)

Table of Dilution Ratios as configured in our Measurement Device

Q_s (l/min)	**Ratio**	**Per cent of Q_{ae}**	**Aerosol Intake (l/min)**	**Orifice Combination**
2.57	31.5	3.17	0.08	CO1
2.57	24.7	4.05	0.10	CO2
2.57	16.4	6.11	0.16	CO3
2.57	10.8	9.28	0.24	CO1+CO3
2.57	8.0	12.45	0.32	CO4
2.57	5.4	18.56	0.48	CO3+CO4
2.57	4.5	21.98	0.56	CO5
2.57	3.2	31.26	0.80	CO1+CO3+CO5
2.57	2.0	49.42	1.27	CO6
2.57	1.4	71.15	1.83	CO1+CO3+CO4+CO6
2.57	1.0	100.00	2.57	

The dilution probe is in principle a mixing tube diluter whereby, filtered exhaust gas mixes with exhaust sample through perforations between the concentric tubes. The test matrix was set for the range of the device's dilution ratios for 100degC, 200degC and 300degC of dilution gas temperature for the various samples.

The results show that dilution affects size distributions and number concentrations differently at different dilution ratios and dilution gas temperatures. This also depends on the nature of the sample used. The characterization of the samples was carried out in another experiment and as such, it was known that, at 2.5 bar BMEP (low load), samples were laden with more volatile fractions compared to samples collected at 5.0 bar BMEP (high load) which were composed of more dry soot particles. Assuming adiabatic dilution and for a given residence time, effect of dilution was more on samples from low load engine operation compared to those from high engine load for various dilution gas temperatures. Dilution in effect, displayed twofold attributes of mixing and cooling whereby mixing affects the partial pressure of component species in the aerosol sample while temperature dictates the saturation pressure. This is deducible by considering the saturation ratio of constituent species in the aerosol as they condense preferentially upon cooling, according to their boiling points. This explains the dynamics of phase change from volatile state to particle nuclei formation as well as the transformation of nucleation mode particles to accumulation mode. The saturation ratio could be derived from first principles is based on Clausius - Clapeyron relation as:

$$S = (Y_{HC}/D) \exp((-hfg/R\,(1/Tmix - 1/Tbp)) \qquad (1)$$

Mixing temperature could be determined from interpolation of exhaust temperature and dilution gas temperature with respect to dilution ratios; assuming constant specific heats and adiabatic dilutions.

$$T_{mix} = T_{exh}\,(1/D) + T_{gas}\,(1-1/D) \qquad (2)$$

Measurement results show that at low loads, there are more nucleation mode particles compared to that measured at high load Conversely, there is more accumulation mode at high load compared to low load. Diluting at lowest temperature gave rise to highest particle formation and growth into accumulation mode. Integration of particle number concentrations show a maximum trend curve at all dilution temperatures with respect to dilution ratio.| This show that there is a dilution range favorable to condensation .

This point to the fact that when comparing results of different groups, measurement parameters for dilution must be known

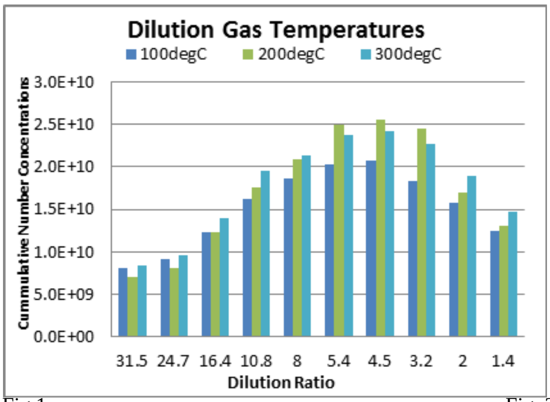

Fig.1

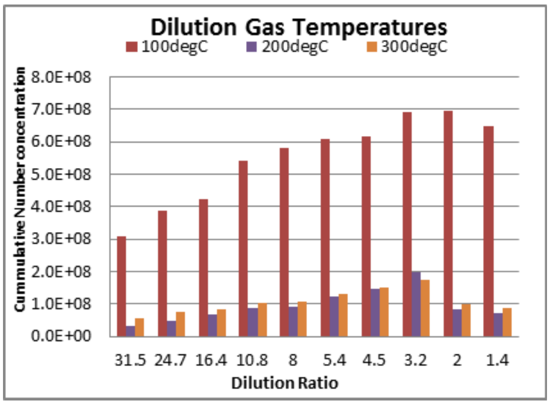

Fig. 2

Fig.1 Cumulative number concentrations for Nucleation mode particles; Fig.2 Cumulative number concentrations for Accumulation mode Particles (for various dilution ratios and dilution gas temperatures at low engine load operation)

References

1. Eastwood, P. (2008) Particulate Emissions from Vehicles. Wiley – PE Publishing Series. west Sussex PO19 8SQ, England
2. Kasper. M. (2004) The Number Concentration of Non-Volatile Particles – Design Study for an Instrument according to PMP Recommendations SAE - 2004 – 01 – 0960
3. Khalek, I. A., Kittelson, D. B., and Brear, F. (2000). The Influence of Dilution conditions on Diesel Exhaust Particle size Distribution measurements. SEA - 1999-01-1142
4. Reischl, G.P. (2006). Characterization of Particulate Motor Vehicle by Emissions Electrostatic Measurement Techniques. 'International Colloquium on Measurement and Characterization of diesel and other Particulate Matter' Kyoto, Japan, 2006.

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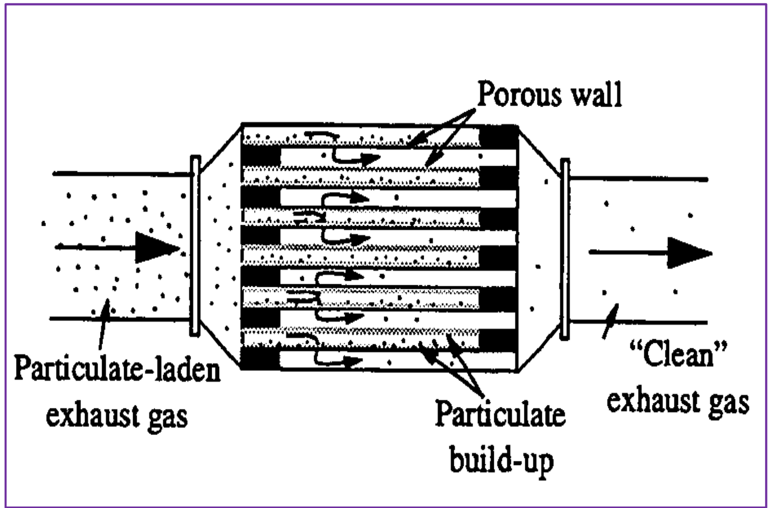
INTRODUCTORY BACKGROUND

DIESEL ENGINE:
THE INCREDIBLE POWER HAWK!

BENEFITS	EMISSION ODDS
Power output	Particulate matter
High efficiency	Nitrogen Oxides
Fuel economy	Noise
Less maintenance	Odour

CONTROL OF PARTICULATE MATTER



DESIGN OPTIONS	AFTER TREATMENT
Optimised Injection schemes	Use of Particulate Filter (DPF)
In-cylinder Flows & Chamber Designs	Oxidation Catalyst (DOCs)

EMISSIONS CHALLENGE

- THE NANOPARTICLES!

ISSUES OF ENGINE NANOPARTICLE EMISSIONS

- Aerosol in nature
- Constitute of Solid and Volatile Fractions
- Laboratory measurement require dedicated instruments and necessitates sample dilution
- **Dilution!** The hallmark of sample conditioning

OBJECTIVES

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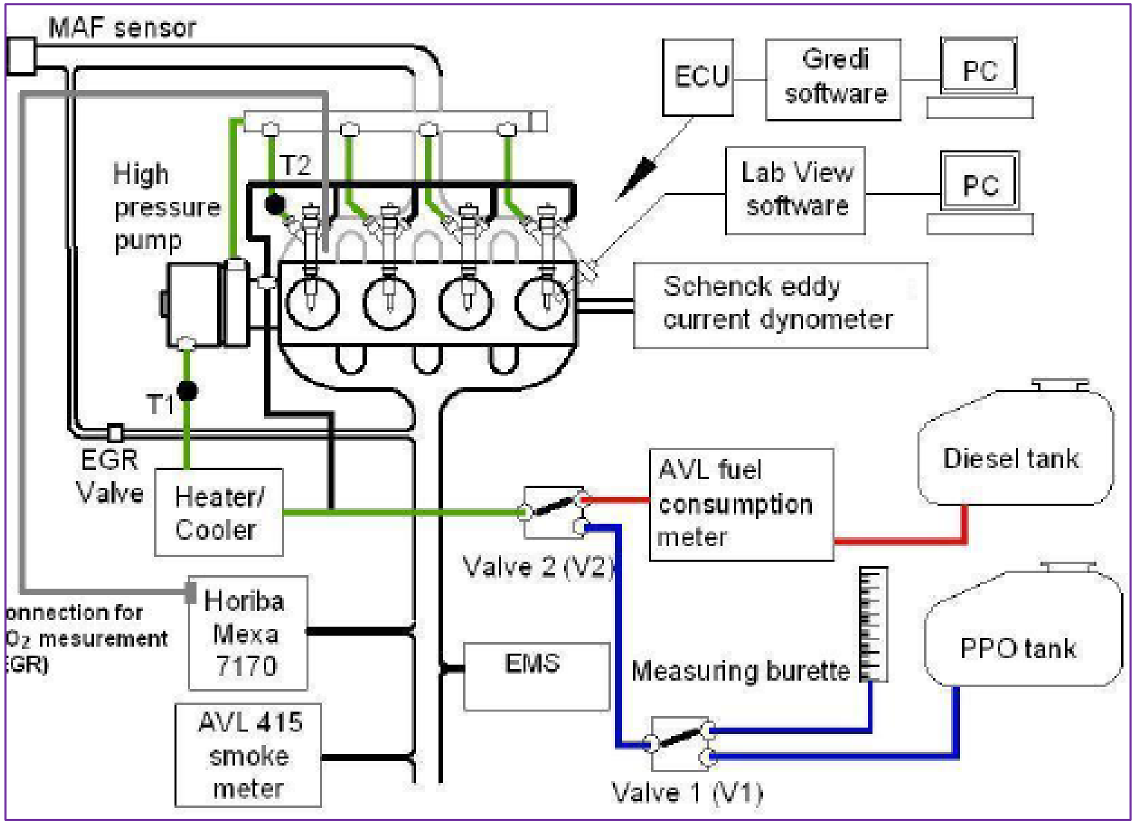
- **Primarily** to investigate the influence of dilution and dilution gas temperatures using samples from two engine load conditions
- To understand the dynamics of phase conversion of the volatile components
- To investigate dilution effect on nanoparticle growth
- To identify optimum dilution conditions using our device.

EQUIPMENT SET UP AND METHODOLOGY

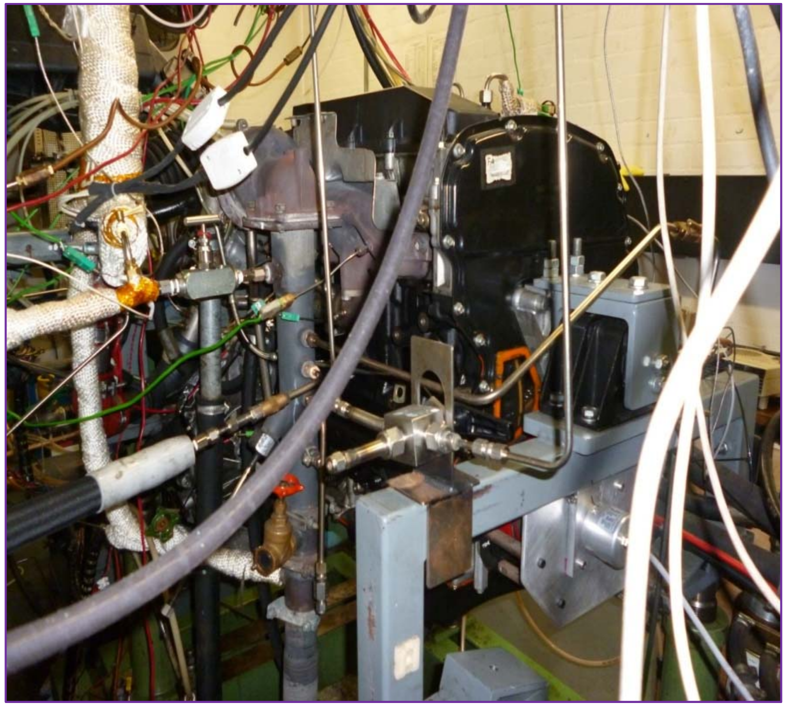
RESEARCH FACILITIES

[Sketch of Brunel University Engine Test Cell]



DIESEL ENGINE GENERATED EXHAUST SAMPLE

Laboratory sampling Point



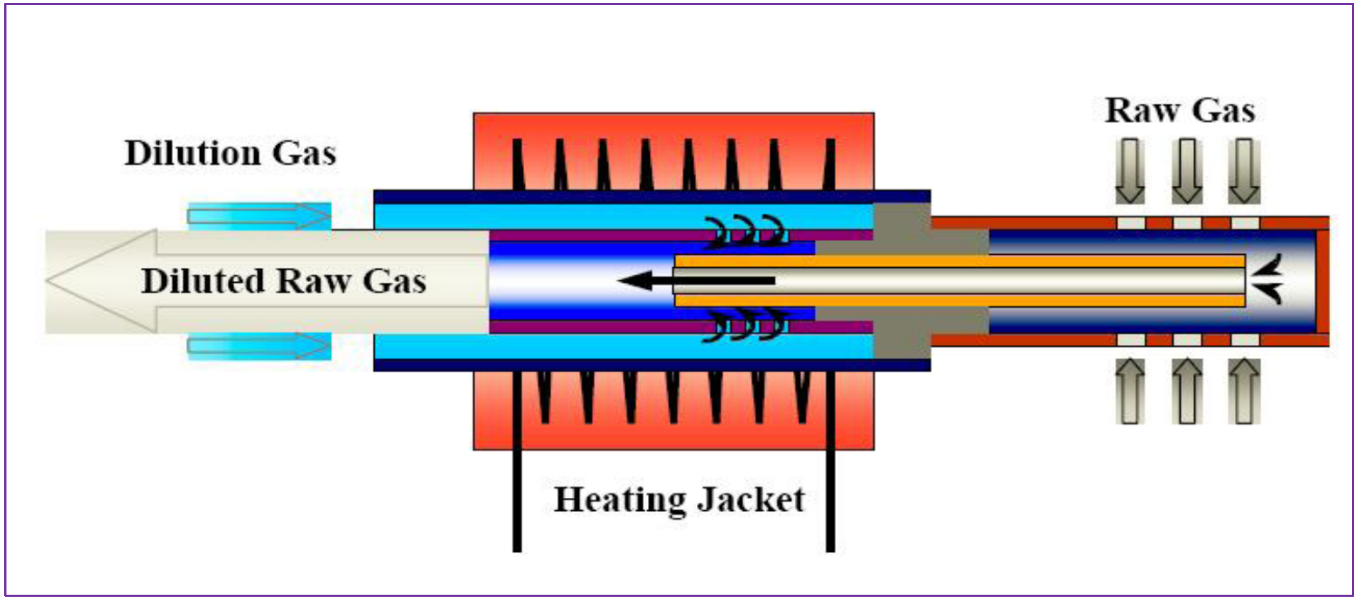
HSDI Diesel Engine Specifications

Number of Cylinders	4
Displacement, cm3	1998.23
Cylinder Bore, mm	86
Stroke, mm	86
Connecting rod length, mm	155
Compression ratio	18.2:1
Injection System	Common Rail
Max Injection Pressure	1600bars
Aspiration	Turbocharged

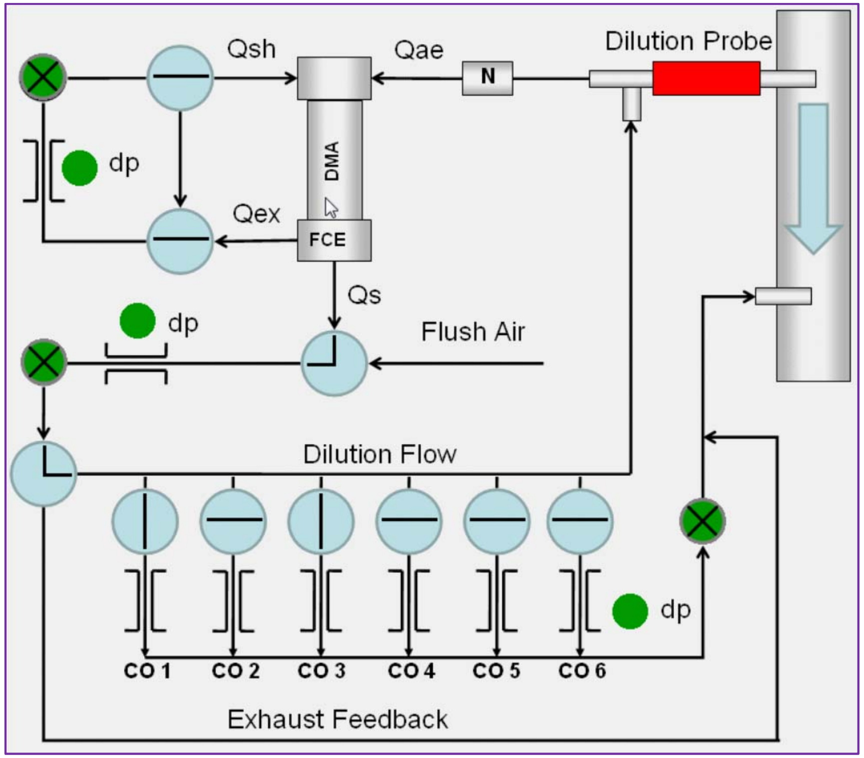
PREVIEW OF THE NATURE OF SAMPLES

- **Baseline through engine sweeps:**
  - various injection timings
  - Various loads and speeds to review smoke numbers
  - with and without EGR.
- **Engine operating condition fixed at two loads:**
  - 2.5 Bar BMEP (Low load) laden with more volatile fractions
  - 5.0 Bar BMEP (High load) with more dry soot based on insight from smoke number
  - TGA/DSC analysis in another experiment deduced proportions of Volatile Fractions and Soot in samples from the two different engine loads.

THE MIXING TUBE DILUTER



LAY OUT OF THE ELECTRICAL MOBILITYSPECTROMETER SHOWING THE DILUTION SUB-SYSTEM



EMS Dilution Ratios

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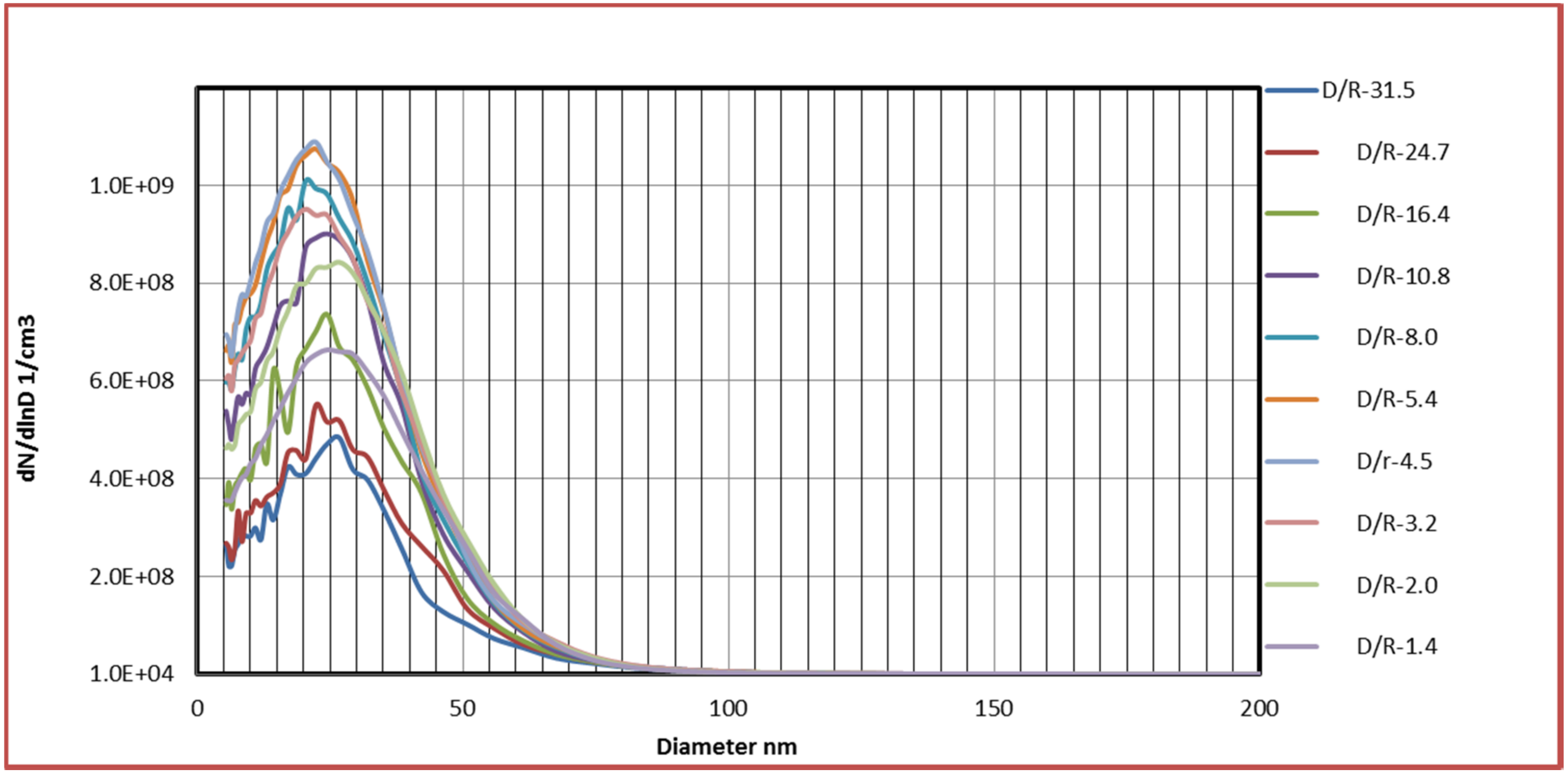
2.57	2.0	49.42	1.27	Co6
2.57	1.4	71.15	1.83	Co1+Co3+Co4+Co4+Co6
2.57	1.0	100.00	2.57	

TEST MATRIX FOR BOTH LOAD CONDITIONS

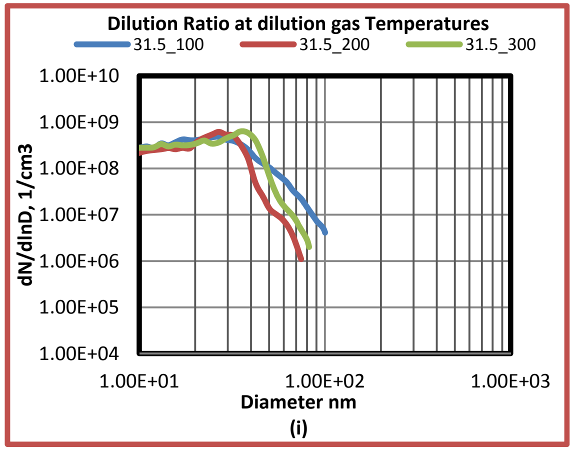
Temps [degC]	Closed – Loop Dilution Ratios									
	31.5	24.7	16.4	10.8	8.0	5.4	4.5	3.2	2.0	1.4
100										
200										
300										

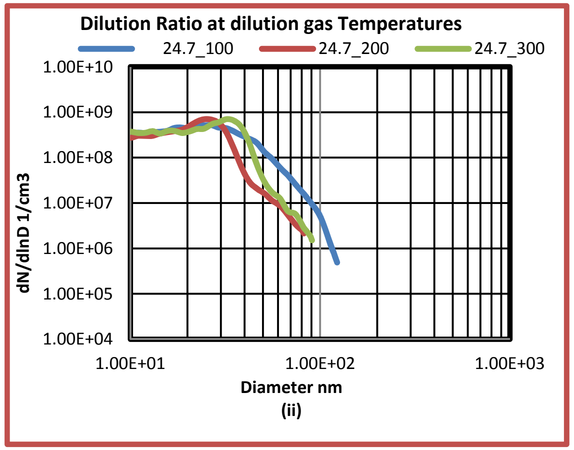
RESULTS AND CONCLUSIONS

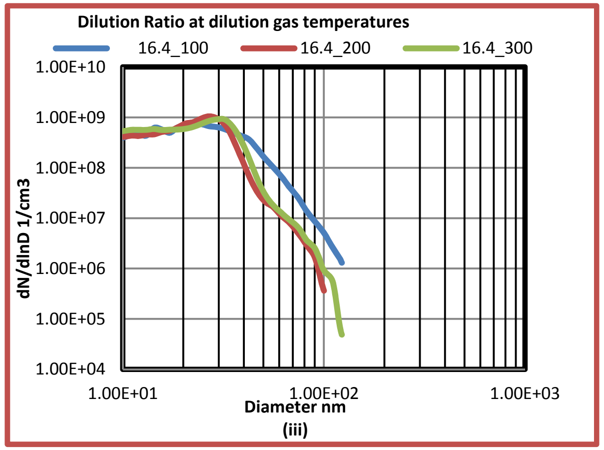
TYPICAL PARTICLE NUMBER CONCENTRATION FOR VARIOUS DILUTION RATIOS AT 100degC ON LOW OPERATION

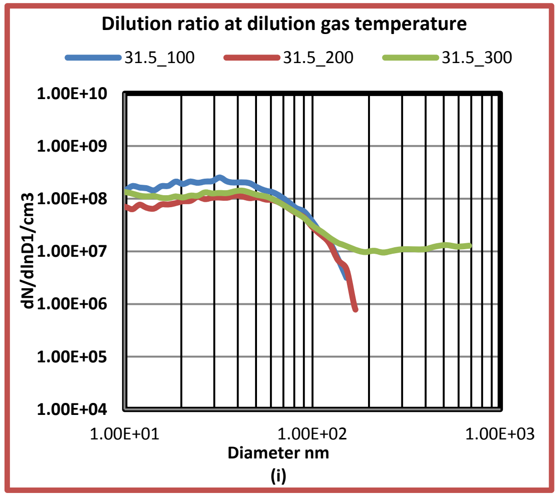


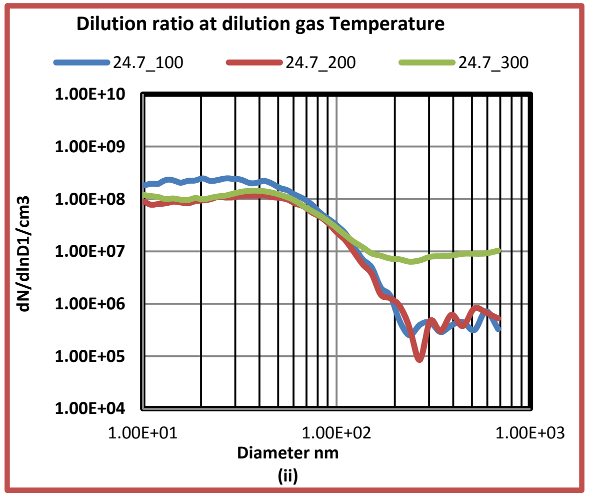
RESULTS – COMPARING INFLUENCE OF DILUTION CONDITION ON PARTICLE NUMBER DISTRIBUTION FOR LOW AND HIGH LOAD ENGINE OPERATION

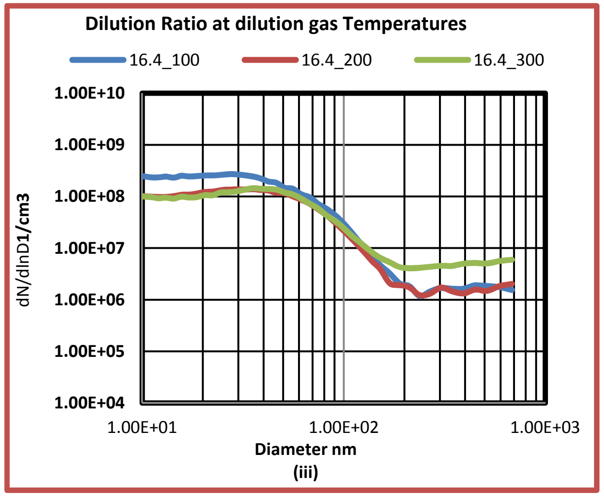




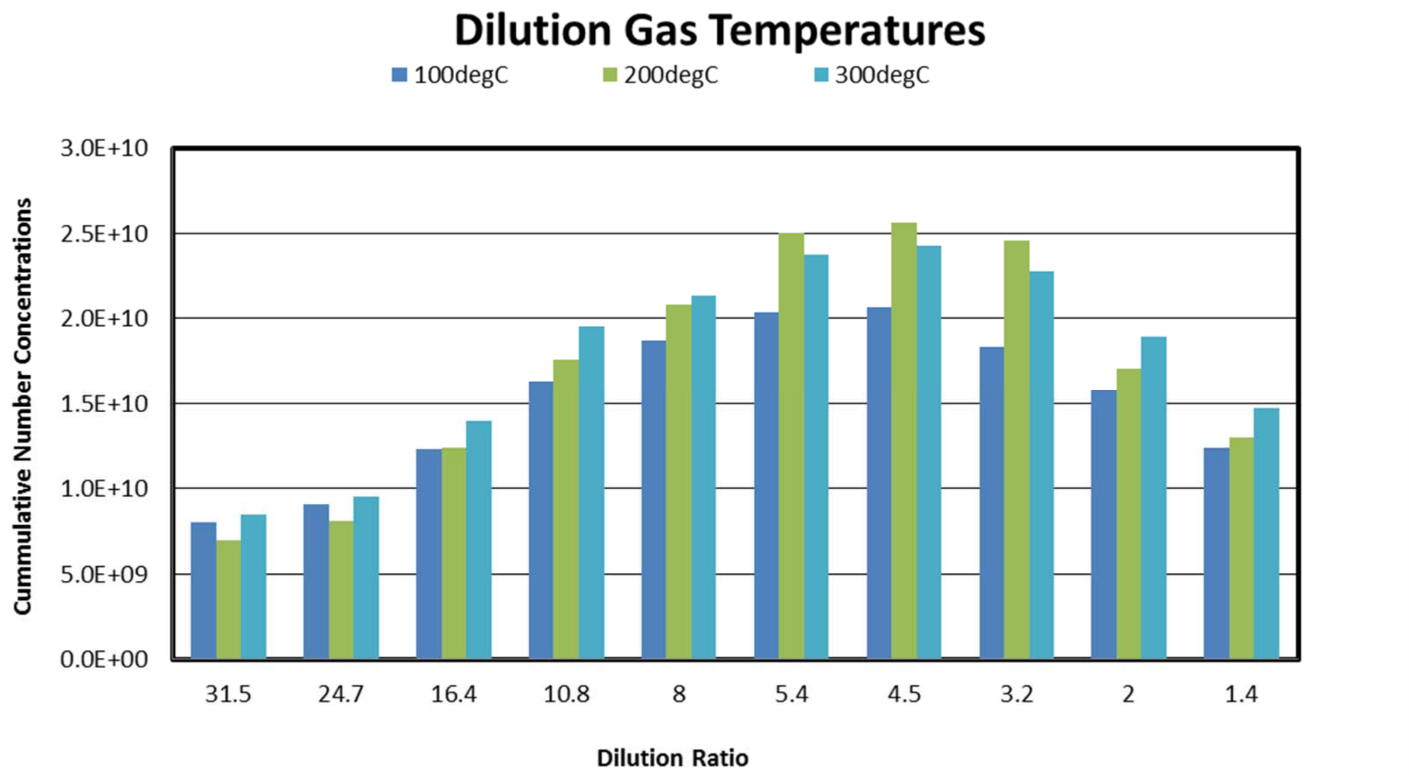




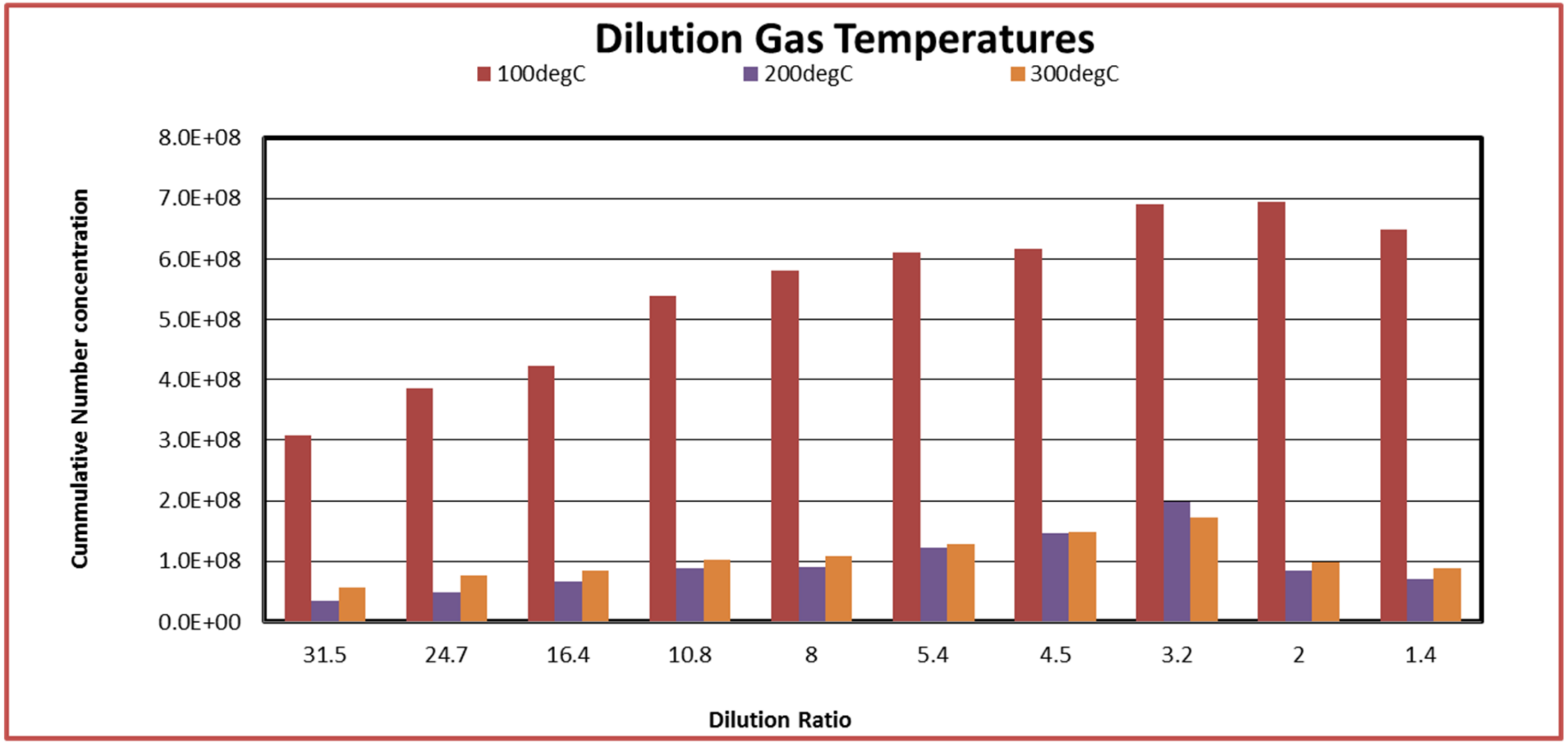




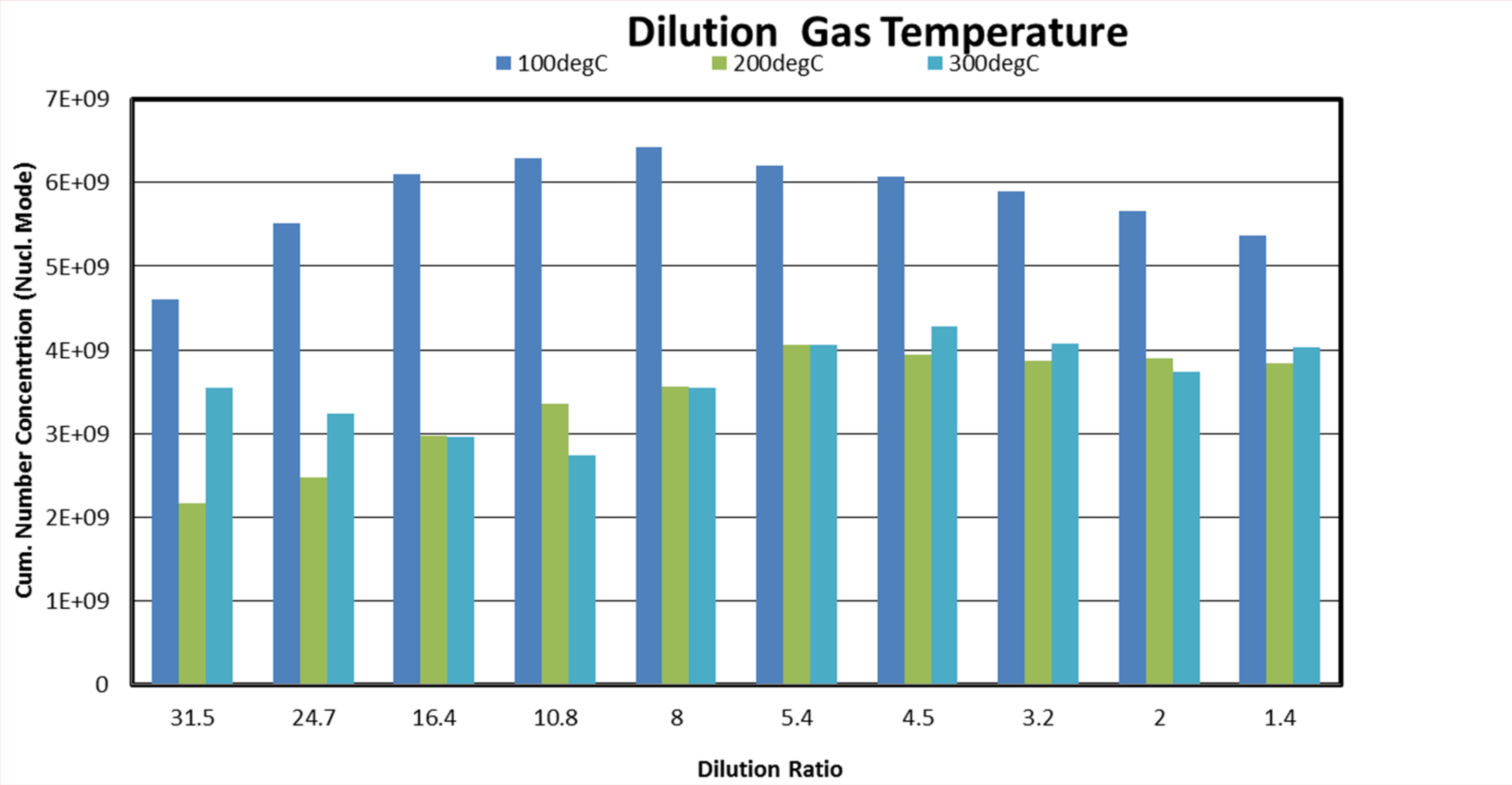
EFFECT OF DILUTION CONDITION – CUMULATIVE NUMBER CONCENTRATION ON LOW LOAD (NUCLEATION MODE)



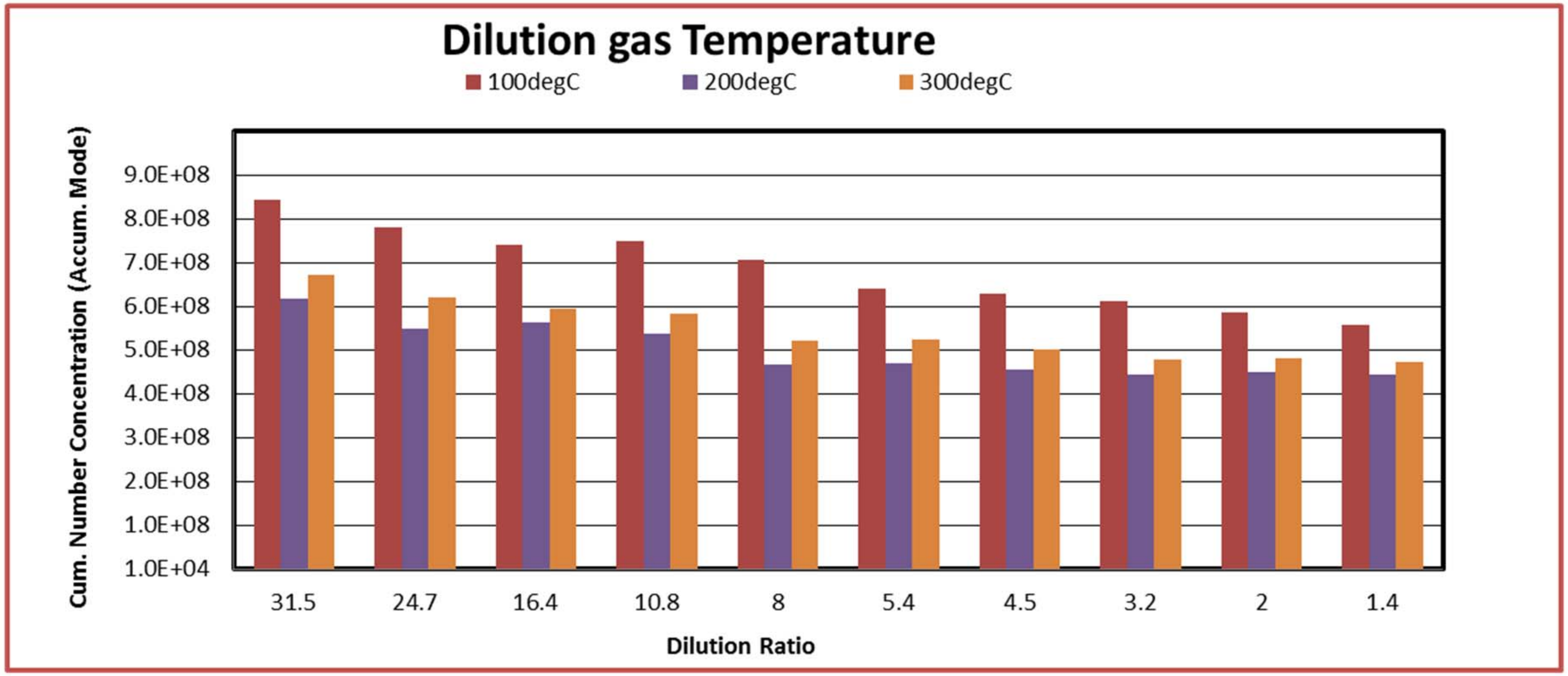
EFFECT OF DILUTION CONDITION – CUMULATIVE NUMBER CONCENTRATION ON LOW LOAD(ACCUMULATION MODE)



EFFECT OF DILUTION CONDITION – CUMULATIVE NUMBER CONCENTRATION ON HIGH LOAD(NUCLEATION MODE)



EFFECT OF DILUTION CONDITION – CUMULATIVE NUMBER CONCENTRATION ON HIGH LOAD(NUCLEATION MODE)



SUMMARY AND CONCLUSIONS

Findings:

- Dilution affects particle number size distributions in different ways
- The nucleation mode particle concentrations are higher in low load than high load
- The accumulation mode particles are more in high load than low load
- Dilution at low temperature leads to high condensation of volatile fractions and cause particles to also transform into accumulation mode
- These effects are rooted in the transformation dynamics of species expressed by saturation ratio, of which dilution ratio and temperature are key parameters
- Implicitly, Hot dilution suppresses condensation of volatile particles

Conclusion:

The result of this study is that one must consider the conditions of measurement when interpreting results. This would mean that it is difficult to compare exhaust measurements taken by different groups unless the exact parameters for mixing and cooling in the measurement system are known.

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