The 19th ETH-Conference on Combustion Generated Nanoparticles

Investigation of diesel particle deposition in tubes

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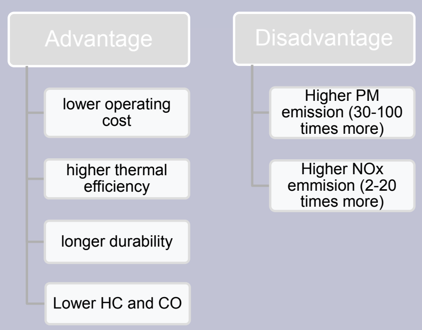
Abstract

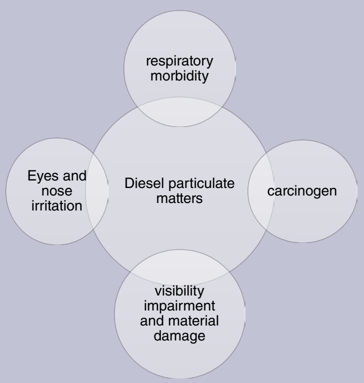
- Plasma treatment reactors have recently been developed for the elimination of diesel particulate matter regarding the reduction of both particle mass and number.
- The role of the plasma itself is obscured by the phenomenon of particle deposition on the surface of the reactor.
- Lagrangian particle tracking provides an effective method for simulating deposition of nano-particles
- The deposition of nano-particles in annular tubes under laminar condition is studied in this study.
- The role of particle diameter, reactor length and flow rates are examined.

Motivation

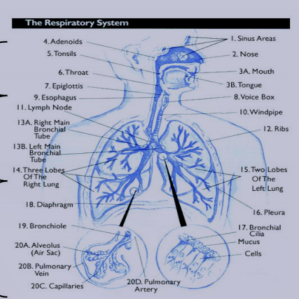
Advantage and disadvantage of diesel engines compared to gasoline engine [1]:



Negative effects of diesel particulate matters [1]:

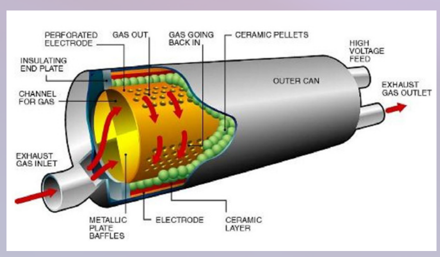


- Nose and Throat Remove Particles > 10 µm
- Trachea and Upper Bronchi remove Particles < 10 µm and > 2.5 µm
- Particles < 2.5 µm and >0.1 µm are deposited in Bronchioles and Alveoli
- Ultrafine particles (<0.1 µm) reach all areas of lung and to some degree diffuse into body tissues

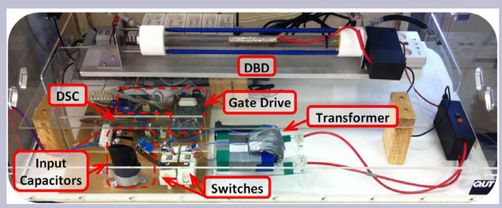


Experimental setup

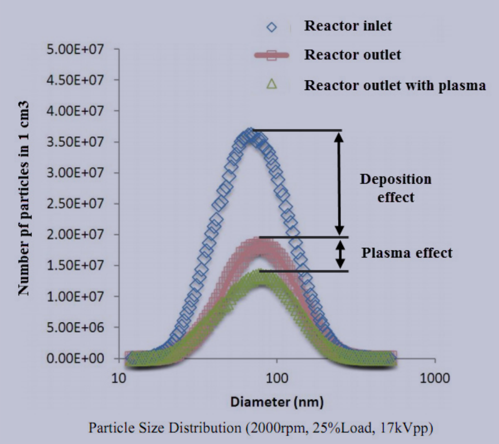
Non thermal plasma as a promising new technology for NOx and PM removal [2]:



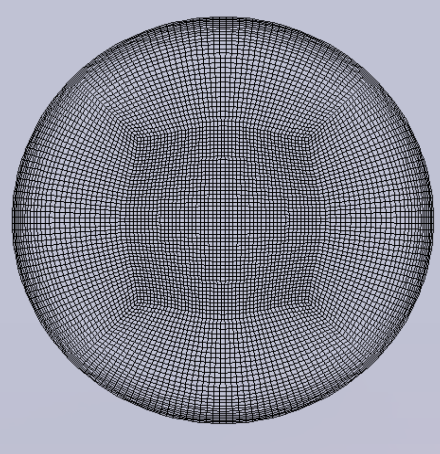
Non thermal plasma for PM mass and number removal [3]:



Deposition effect VS. Plasma effect [3]:



Mesh structure at cross section:



Numerical procedure [4]

1. CFD solution of Navier Stokes Equations for the flow field

$$\rho\frac{DV}{Dt}=F-\nabla P+\mu\nabla^2 V$$

2. Particle equation of motion to model deposition and dispersion of particles

$$\frac{du_i^p}{dt}=\frac{18\mu}{d_p^2\rho_p C_c}(u_i^g-u_i^p)+F_{Brownian}$$

u^p and u^g : Components of the particle and local fluid velocity
µ: Fluid viscosity
ρ_p: Particle density
C_c: Cunningham correction factor to Stokes'drag law

$$F_{Brownian}=\frac{\zeta}{m_d}\sqrt{\frac{1}{\tilde{D}}\frac{2k_BT^2}{\Delta t}}$$

Diffusion coefficient

$$\tilde{D}=\frac{k_BTC_c}{3\pi\mu d_p}$$

d_p: Particle diameter (m)

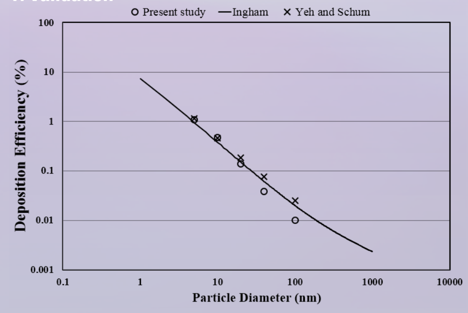
Boundary condition

Flow
Paraobolic velocity profile at the inlet
Outflow at the outlet
No slip condition at the wall

Particle
Injection of 70000 particles at 1cm from the inlet and 0.1 mm away from the wall
Escape condition at the outlet
Trap condition at the wall

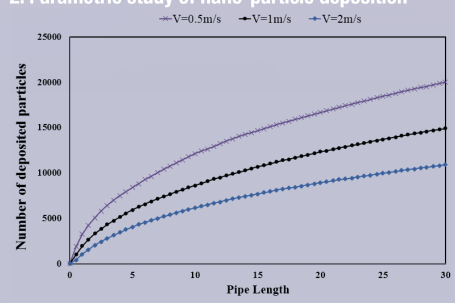
Results

1. Validation

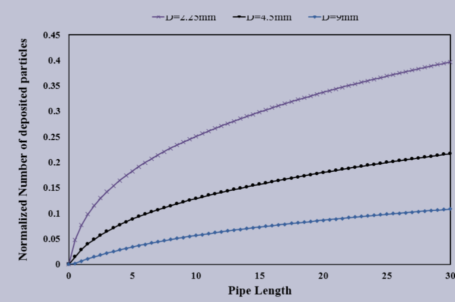


The variation of nano particle deposition efficiency as a function pf particle diameter at the inlet velocity of 1m/s.

2. Parametric study of nano-particle deposition



Effect of inlet velocity on the deposition of 5nm particles through the pipe length



Effect of pipe diameter on the deposition of 5nm particles through the pipe length

Ingham equation [5]

$$DE=1-\left(0.819e^{-14.63\Delta}+0.0976e^{-89.22\Delta}+0.0325e^{-228\Delta}+0.0509e^{-125.9\Delta^{2/3}}\right)$$

Δ is the dimensionless diffusion parameter

$$\Delta=\frac{\tilde{D}L_{pipe}}{4U_{in}R^2}$$

L_{pipe}: Pipe length
R: Pipe radius
U_{in}: Inlet velocity of the pipe

Emission standards over time for diesel cars in Japan, EU, and the USA [6]:

Country	Standard	Date	CO	HC	HC +NOx	NOx	PM	PN
			g/km					#/km
Japan	Emission Standards for Diesel Passenger Cars							
	Vehicle weight							
	< 1250 kg	2002	0.63	0.12		0.28	**0.052**	
		2005	0.63	0.024		0.14	**0.013**	
		2009	0.63	0.024		0.08	**0.005**	
	> 1250 kg	2002	0.63	0.12		0.3	**0.056**	
		2005	0.63	0.024		0.15	**0.014**	
		2009	0.63	0.024		0.08	**0.005**	
EU	Emission Standards for Diesel Passenger Cars							
	Euro 4	2005.01	0.5		0.3	0.25	**0.025**	
	Euro 5a	2009.09	0.5		0.23	0.18	**0.005**	
	Euro 5b	2011.09	0.5		0.23	0.18	**0.005**	**6E+11**
	Euro 6	2014.09	0.5		0.17	0.08	**0.005**	**6E+11**
US California	LEV II Emission Standards for Passenger Cars and LDVs < 8500 lbs; 50,000 miles/5 years							
			CO	HCHO	NMOG	NOx	PM	
			g/mile					
	LEV	2004-2010	3.4	0.015	0.075	0.05		
	ULEV		1.7	0.008	0.04	0.05		
	SULEV							

Note: PN - Particle Number, NMOG - non-methane organic gases, HCHO – formaldehyde, LEV-Low Emission Vehicles, ULEV-Ultra Low Emission Vehicles, SULEV-Super Ultra Low Emission Vehicles

Emissions Requirements for Diesel Heavy Duty Vehicles in Australia [7]:

Country	Standard	Date	CO	HC	HC +NOx	NOx	PM	PN
AU			g/kWh					
	ADR80/02 (Stationary Cycle)	2007-2008	1.5	0.46	-	3.5	**0.02**	-
	ADR80/02 (Transient Cycle)		4.0	0.55	-	3.5	**0.03**	-
	ADR80/02 (Stationary Cycle)	2010-2011	1.5	0.46	-	2.0	**0.02**	-
	ADR80/02 (Transient Cycle)		4.0	0.55	-	2.0	**0.03**	-

Conclusion

- The advantage of lagrangian particle tracking method due to considering particle inertia than the Eulerian method
- Increasing particle deposition efficiency by decreasing inlet velocity and pi pe diameter
- Decreasing the ratio of number of deposited particles by increasing the length of the pipe
- For nano particles with the diameter more than 40nm, the calculated DE is less than Eulerian method due to statistical error or the inertia effect.

References

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