A Hybrid EMST-Modified Curl's Model for Turbulent Combustion Modelling

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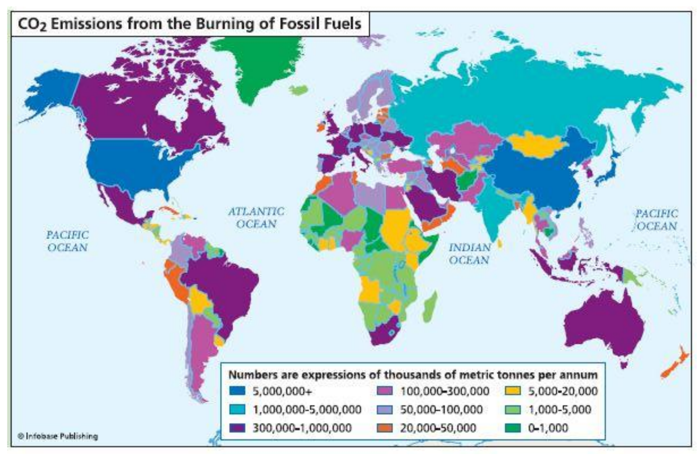
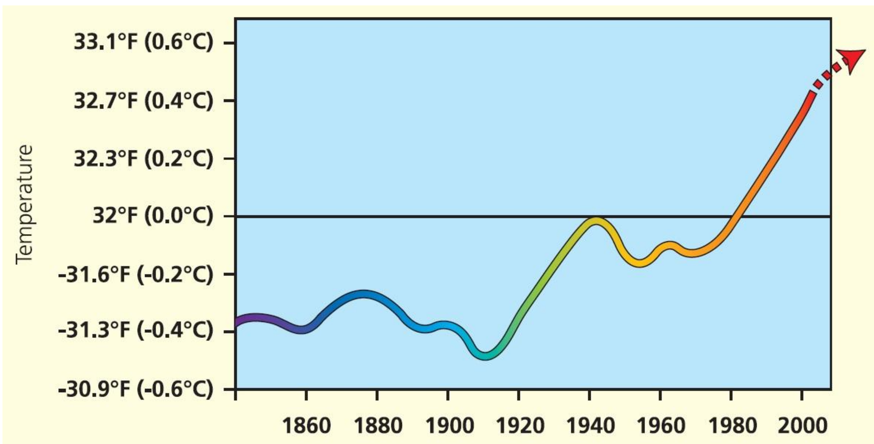
INTRODUCTION

In 2030, it is projected that 18 billion tons of oil equivalent will be used, with 80% to come from fossil fuel [1]. Combustion is still a very important source of energy and efficiency and emissions must be improved.

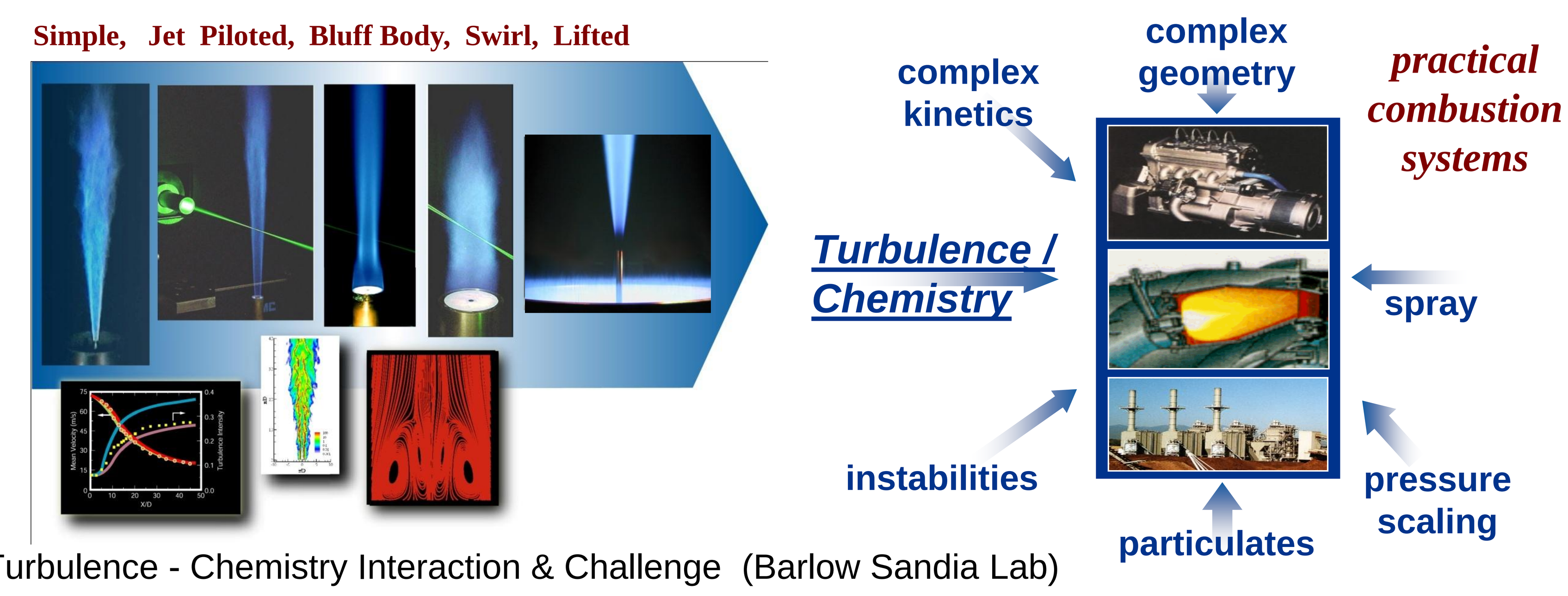


World CO_2 emission,1990 ~ 2025 (Source EIA)



Increase of earth temperature (1980-2030) [1]

Non-premixed jet flames are use for furnaces, gas turbines and flares.

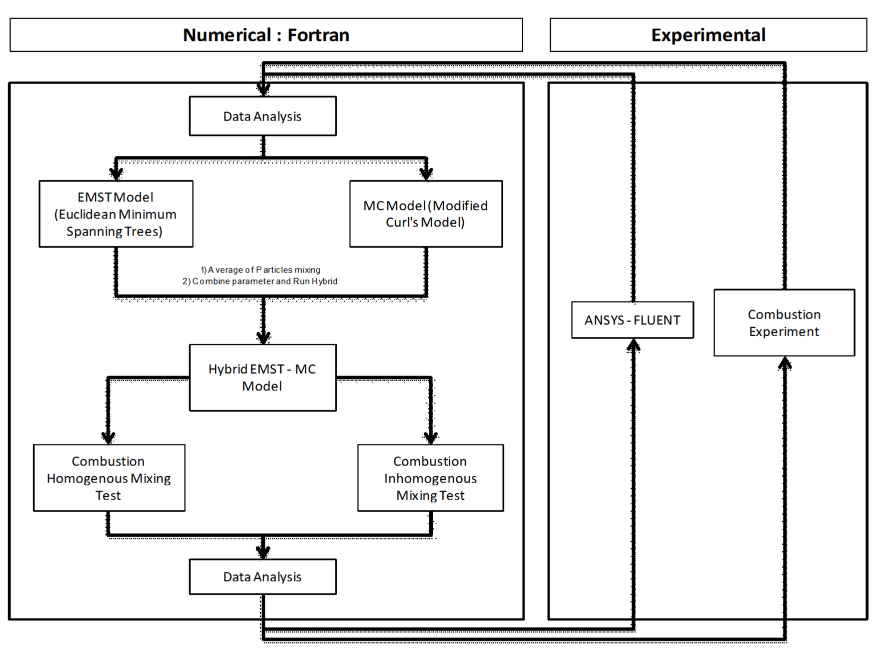


Turbulence - Chemistry Interaction & Challenge (Barlow Sandia Lab)

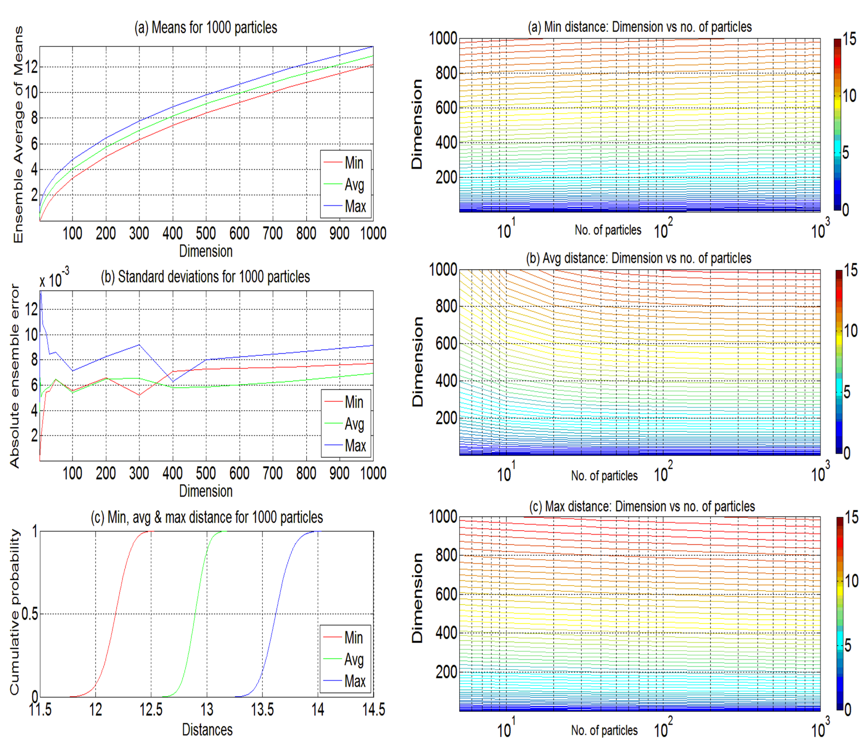
Numerous turbulent combustion models have been devised for the diffusion process. Some scalar micro-mixing models for the probability density function [PDF] models [2] are: Curl's Model [3], Modified Curl's [4], Euclidean Minimal Spanning Tree (EMST) [5] and Stochastic Multiple Mapping Conditioning (MMC) [6]. These models are use particle interaction to model the micro-mixing process. The selection process for the particles to be mixed is a major difference between these models.

METHODOLOGY

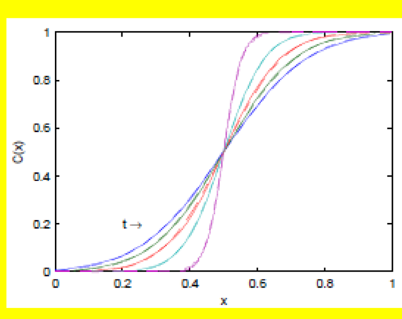
Computational modelling using Fortran and combustion experiment by bluff-body burner configuration.



Current mixing models are either non-local or over-local producing an imperfect combustion modelling process. A new hybrid models and Stochastic Particle Diffusion Length (SPDL) [7] model are being developed based on a study on practical localness using random inter-particle distance [8].



Statistical analysis for 1000 particles and Inter-particles distances for min, average and max distance. [8]



Gaussian cumulative distribution functions (cdf) with same mean and variance as ensemble. This plot demonstrates the validation of SPDL model [7]

The simulation of 1000 particles with 1000 realisations was carried out for 1000 dimensions. The statistical analysis found that the inter-particles distances are normally distributed. The distance is low for low numbers of dimensions and the maximum possible inter-particle distance is proportional to the square root of the number of dimensions

Governing Equations

Probability Density Function (PDF) [2]

$$\frac{\partial(\rho P)}{\partial t}+\frac{\partial(\rho u_i P)}{\partial x_i}+(pg-\frac{\partial p'}{\partial u_i})\frac{\partial P}{\partial \mu_i}+\sum_{k=1}^{n}\frac{\partial}{\partial \psi_k}(w_k P)=-\frac{\partial}{\partial \mu_i}\left\{\left\langle -\frac{\partial \tau_{ji}}{\partial x_i}+\frac{\partial p'}{\partial x_j}\middle| u,\psi\right\rangle P\right\}-\sum_{k=1}^{n}\frac{\partial}{\partial \psi_k}\left\{\left\langle \frac{\partial}{\partial x_i}(\rho D\frac{\partial \psi_k}{\partial x_i}\middle| u,\psi\right\rangle P\right\}$$

Modified Curl's Model[4]

Mixing without localness behaviour

$$\phi_i^{MC}(t+\delta t)=\phi_i^{MC}(t)+\frac{1}{2}\beta\left(\phi_j^{MC}(t)+\phi_i^{MC}(t)\right)$$

$$\phi_j^{MC}(t+\delta t)=\phi_j^{MC}(t)+\frac{1}{2}\beta\left(\phi_j^{MC}(t)+\phi_i^{MC}(t)\right)$$

EMST Model [5]

Mixing over localness behaviour

$$\phi_i^{EMST}(t+\delta t)=\phi_i^{EMST}(t)+dP_b\delta t\left(\phi_j^{EMST}(t)+\phi_i^{EMST}(t)\right)$$

$$\phi_j^{EMST}(t+\delta t)=\phi_j^{EMST}(t)+dP_b\delta t\left(\phi_i^{EMST}(t)+\phi_j^{EMST}(t)\right)$$

Hybrid Model

$$\phi_i^{Hybrid}(t+\delta t)=(1-C_H)\phi_i^{MC}(t+\delta t)+(C_H)\phi_i^{EMST}(t+\delta t)$$

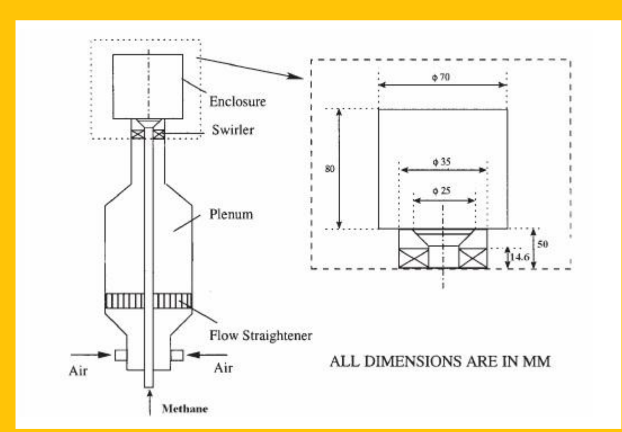
mixing factor, $C_H=\frac{\langle(\Delta l)^{MC}\rangle-\langle(\Delta l)\rangle}{\langle(\Delta l)^{MC}\rangle-\langle(\Delta l)^{EMST}\rangle}$

where:

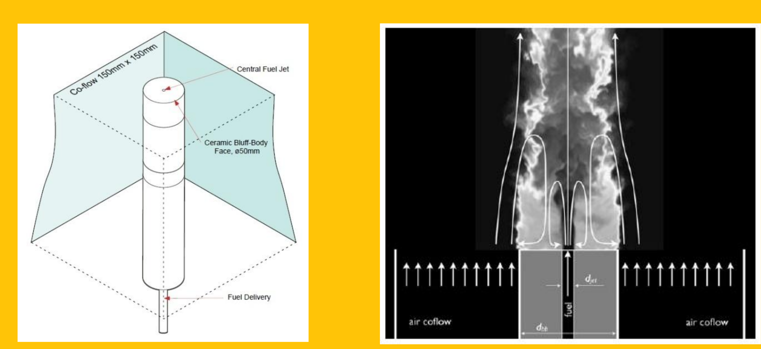
$$\langle(\Delta l)^2\rangle=2\langle N\rangle(\Delta t)$$

EXPERIMENTAL SETUP

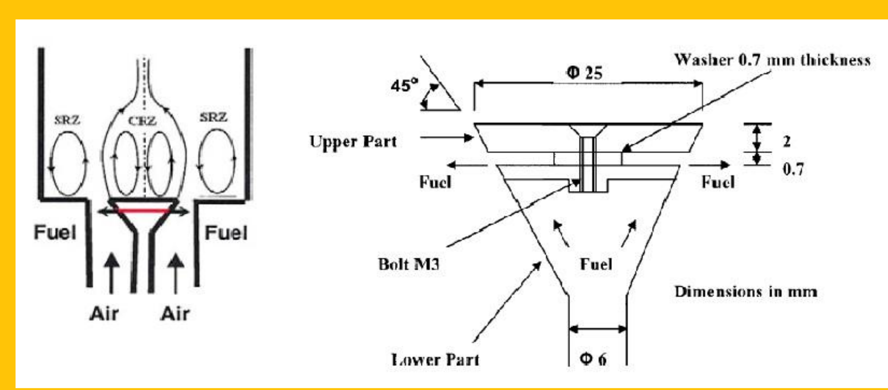
Bluff-body burner will be designed and setup for the experimental work. Part of the validation will be done through computational fluid dynamic (CFD) modelling (ANSYS Fluent)



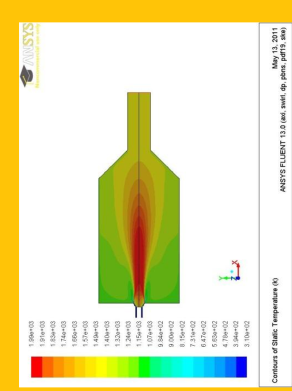
Bluff-body burner [9]



Bluff-body burner and flame configuration [10]



Bluff-body burner [9]



CFD modelling

BB flame[10]

CONCLUSION

New stochastic micro-mixing models for turbulent combustion modelling are under development through an understanding of the behaviour of the inter-particle distances. It may be possible to describe the shortcomings of models that neglect the diffusion length scale and devise new models that incorporate the diffusion length scale for potentially improved accuracy.

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