Fire Powder extinguishing analysis using the General Dynamic Equation (GDE)

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Research Motivation

Research Motivation

- Exploring ways to reduce amount of extinguishing aerosol/powder needed to extinguish fire thus:
  - -Reducing fire extinguishing time, reducing damage.
  - -Reducing post fire damage to equipment. ▶
- Developing an analytic tool to analyze the problem

Presentation Out line

- Powder extinguishing analysis- need for an analytic tool
- Extended GDE (General Dynamic Equation)
- Powder extinguishing model of Ozone flame
- Results
- Summary

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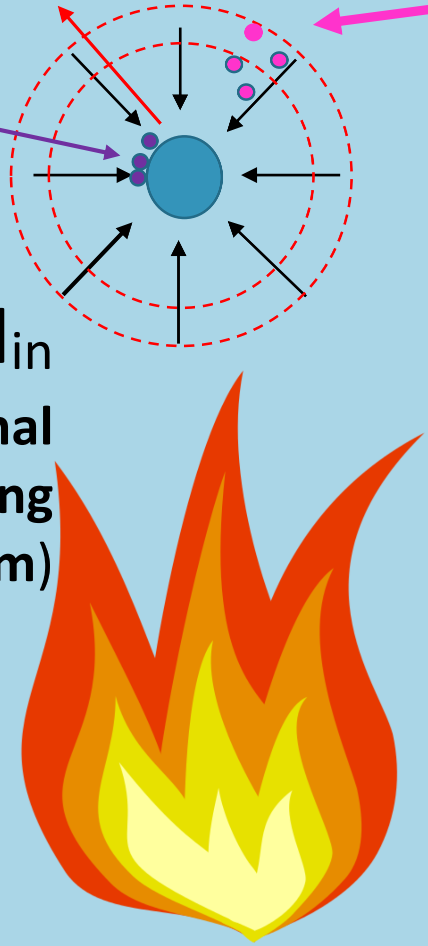
Powder extinguishing analysis- need for an analytic tool

FFR Elimination through chemical or mechanical interaction with powder particle surface (**Heterogenous extinguishing Mechanism –thermal and chemical)**



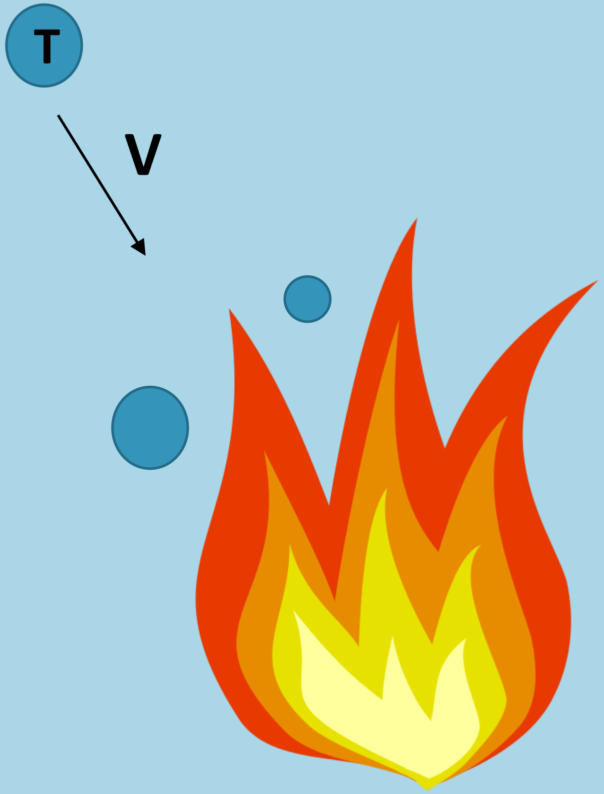
(Thermal extinguishing Mechanism)

FFR-**Flame F**ree **R**adical (O,OH, etc) Elimination through chemical bonding with evap products **(Homogenous extinguishing Mechanism)**

Powder extinguishing analysis- need for an analytic tool

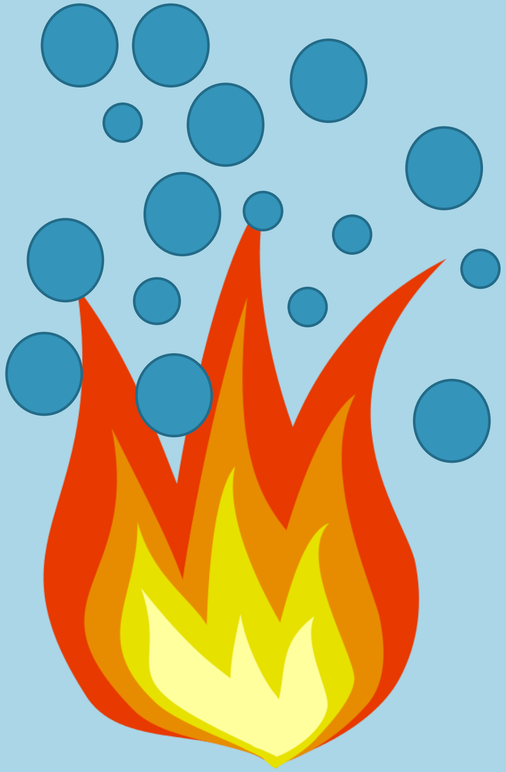
All the extinguishing mechanisms are affected by particle :

- position
- diameter
- temperature
- velocity



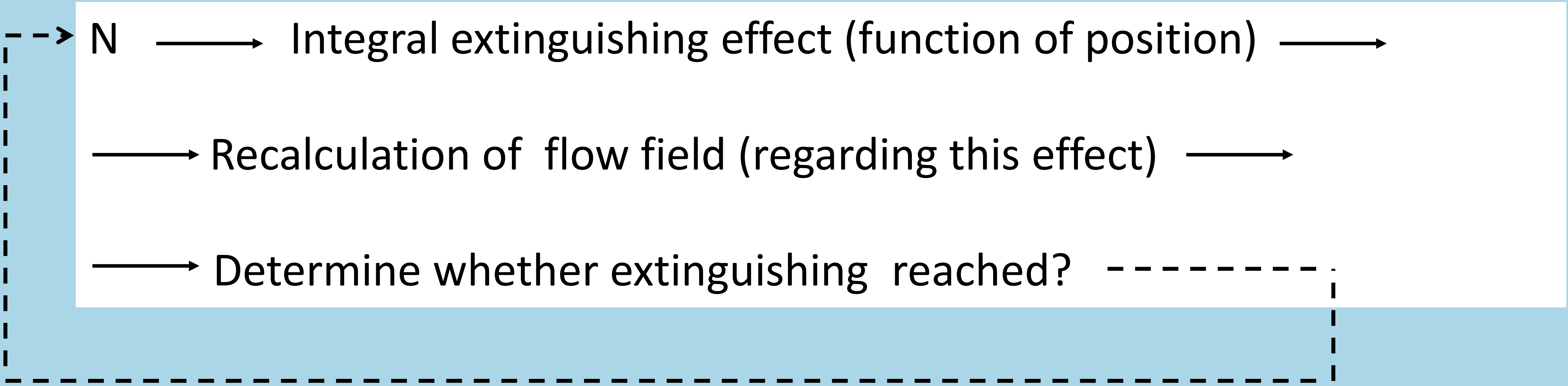
Powder extinguishing analysis- need for an analytic tool

The Integral effect of extinguishing is also function of particles cloud number\concentration



Powder extinguishing analysis- need for an analytic tool

- Conclusion: We need an analytic tool that will give us extinguishing powder particle number distribution as function of : **N (position, velocity, diameter, temp, time)**



N → Integral extinguishing effect (function of position) →

→ Recalculation of flow field (regarding this effect) →

→ Determine whether extinguishing reached?

GDE

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Extended GDE

(a) n –**normalized number density** as a function of position ,velocity, mass and temperature of the particles:
$n\ (x_p,\ y_p,\ z_p,\ u_p,\ v_p,\ w_p,\ m_P\ ,T_p\ ,t)$.

The definition of n is so, that in order to calculate Np- number of particles within infinitesimal "volume":

$$Np=n*dx_p*dy_p*dz_p*du_p*dv_p*dw_p*dm_p*dT_p$$

Extended GDE

(b) Introducing time derivatives for each variable :

$$I_{x_p} = \frac{dx_p}{dt} \triangleq u_p \qquad I_{y_p} = \frac{dy_p}{dt} \triangleq v_p \qquad I_{Z_p} = \frac{dZ_p}{dt} \triangleq w_p$$

$$\frac{du_p}{dt} = I_{u_p}(x_p, y_p, z_p, u_p, v_p, w_p, m_p, T_p, t) \qquad \frac{dv_p}{dt} = I_{v_p}(x_p, y_p, z_p, u_p, v_p, w_p, m_p, T_p, t)$$

$$\frac{dw_p}{dt} = I_{w_p}(x_p, y_p, z_p, u_p, v_p, w_p, m_p, T_p, t)$$

$$\frac{dm_p}{dt} = I_{m_p}(x_p, y_p, z_p, u_p, v_p, w_p, m_p, T_p, t)$$

$$\frac{dT_p}{dt} = I_{T_p}(x_p, y_p, z_p, u_p, v_p, w_p, m_p, T_p, t)$$

Extended GDE

Extended GDE formulation (Eulerian approach):

$$\frac{\partial n}{\partial t} = -\frac{\partial\left(nI_{xp}\right)}{\partial x_p} - \frac{\partial\left(nI_{yp}\right)}{\partial y_p} - \frac{\partial\left(nI_{zp}\right)}{\partial z_p} - \frac{\partial\left(nI_{up}\right)}{\partial u_p} - \frac{\partial\left(nI_{vp}\right)}{\partial v_p} - \frac{\partial\left(nI_{wp}\right)}{\partial w_p} - \frac{\partial\left(nI_{mp}\right)}{\partial m_p} - \frac{\partial\left(nI_{Tp}\right)}{\partial T_p} + P$$

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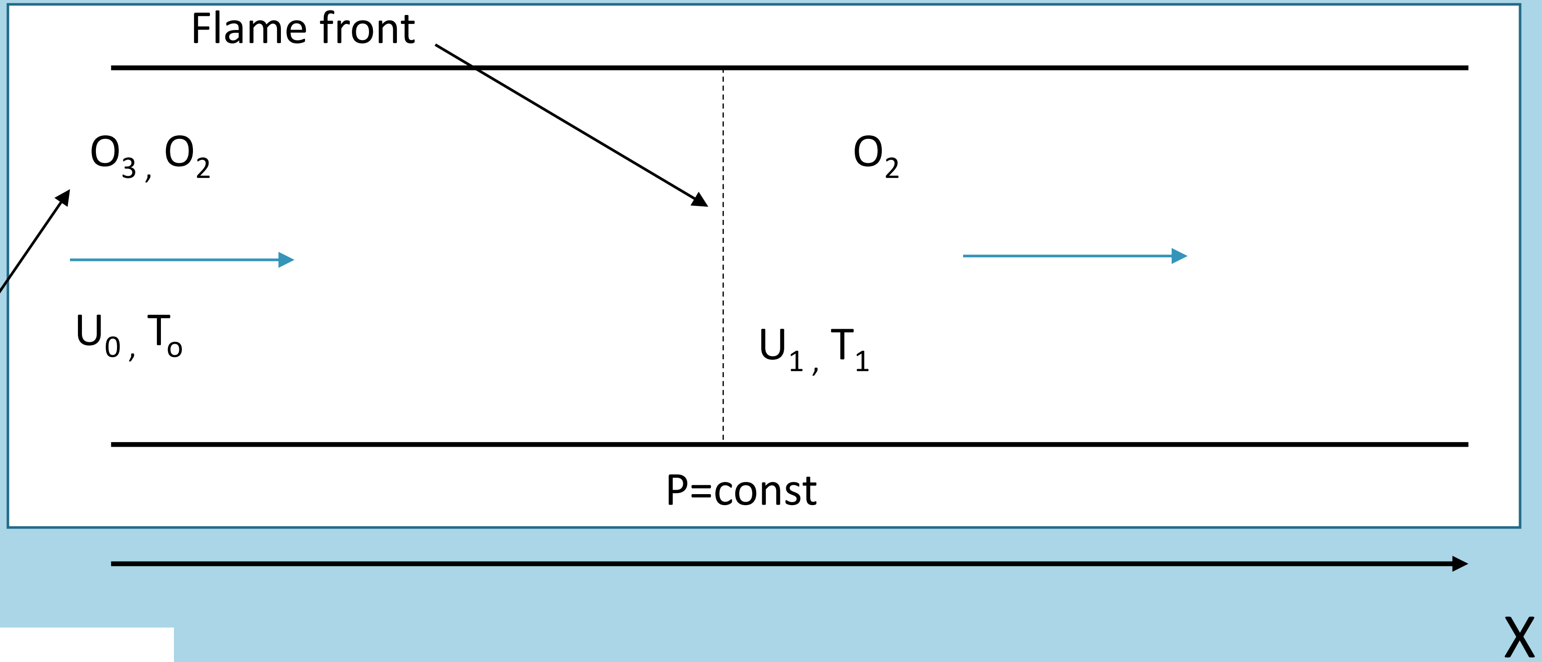
Powder extinguishing model (1)

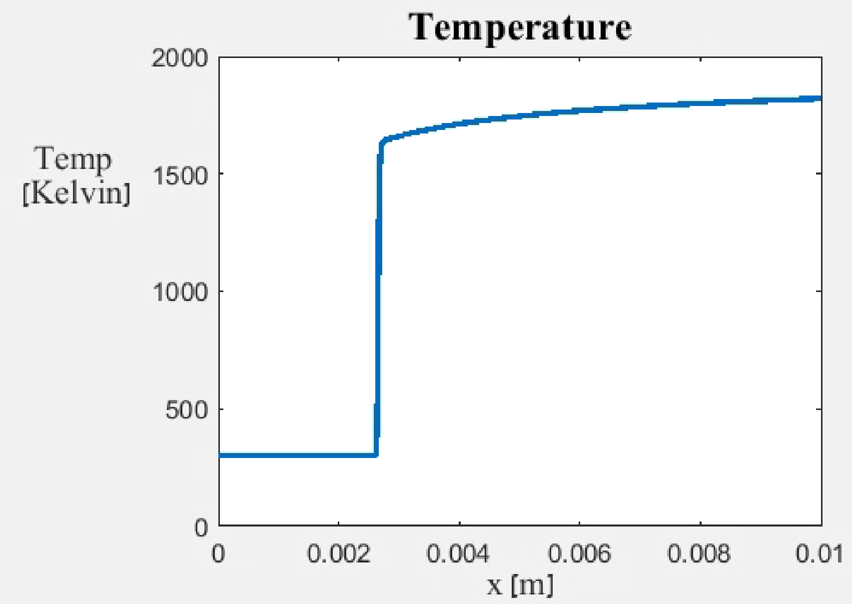


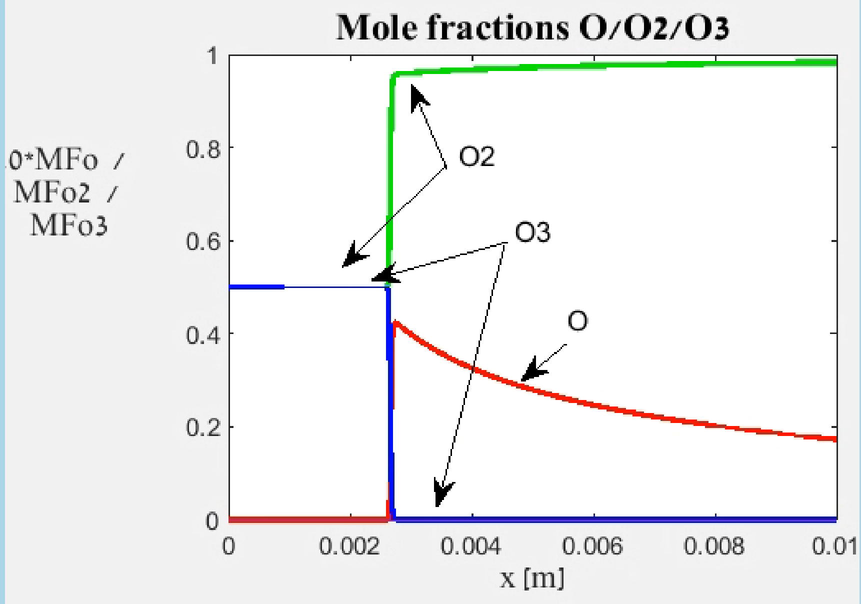
IOMF=
Initial Ozone Mole Fraction

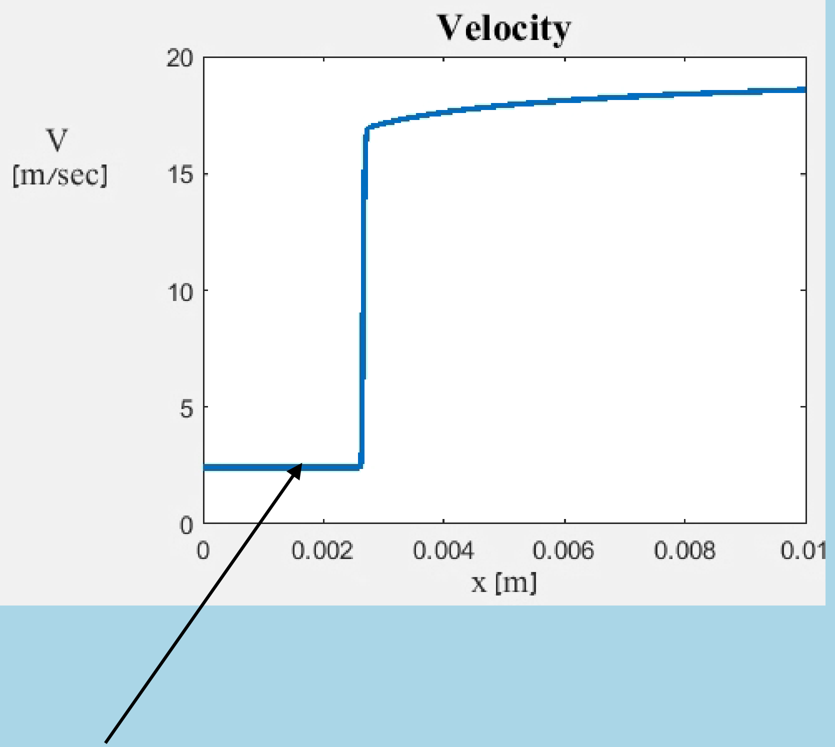
$$= \frac{M_{F\,O_3}}{M_{F\,O_3}+M_{F\,O_2}}$$

$O_3+M \rightleftarrows O+O_2+M$		(R1)
$O+O_3 \rightleftarrows O_2 + O_2$		(R2)
$O+O+M \rightleftarrows O_2 + M$		(R3)

Powder extinguishing model (2)
Ozone Flame with IOMF=0.5







Burning Velocity= 2.4[m/sec]

Powder extinguishing model (3)

Main model modifications to Extinguishing model:

- Definition of theoretical extinguishing powder - thermo physical properties same as potassium (K)

- Constant rate Inhibition reaction:

$$O+O+K \longrightarrow O_2+K \quad (\underline{\text{with no energy addition} \setminus \text{ removal}})$$

- Inhibition Reaction is triggered only by :
  1) Evaporated potassium (Homogenous extinguishing mechanism)
  2) Total Solid powder surface area per volume (Heterogenous mechanism, chemical & thermal)

- Potassium (vapor or particle) act as a "Third body" , and only with regard to the inhibition reaction.

Powder extinguishing model (4)

- Main model modification to Extinguishing model (continue):
  - Extinguishing conditions are reached when we compute 10% of the uninhibited burning velocity (0.2[m/sec]).

Powder extinguishing model, Governing Equations (5)

- **Steady State Continuity:**

$$\varepsilon\rho u(x) = (\varepsilon\rho u)_0 + \int_0^x \dot{W}_{Kevap}(x)dx$$

Powder extinguishing model, Governing Equations (2)

- **Species equations for i=O, O_2, K:**

$$\varepsilon\rho\frac{\partial(Y_i)}{\partial t}=-\varepsilon\rho u\frac{\partial(Y_i)}{\partial x}-\frac{\partial(\varepsilon\rho Y_i V_i)}{\partial x}-Y_i\dot{W}_{Kevap}+\dot{W}_{i_{production}}$$

Powder extinguishing model, Governing Equations (3)

- **Energy Equation:**

$$\varepsilon\rho\sum_i Y_i C_{p_i}\frac{\partial T}{\partial t} = \frac{\partial\left(\lambda\varepsilon\frac{\partial T}{\partial x}\right)}{\partial x} - \varepsilon\rho u\sum_i Y_i C_{p_i}\frac{\partial T}{\partial X} - \sum_i \varepsilon\rho Y_i V_i C_{p_i}\frac{\partial T}{\partial X} - \sum_i h_i \dot{W}_{K_{evap}\backslash i_{che}} + A1 - A2$$

Homogenous & Heterogenous inhibition

Particle Thermal inhibition

Energy given to the flow by the evaporating particles

Powder extinguishing model, Governing Equations (4)

- **General Dynamic Equation (GDE)**

$$\frac{\partial n}{\partial t} = -\frac{\partial\left(\mathbf{n}I_{x_p}\right)}{\partial x_p} - \frac{\partial\left(\mathbf{n}I_{u_p}\right)}{\partial u_p} - \frac{\partial\left(\mathbf{n}I_{d_p}\right)}{\partial d_p} - \frac{\partial\left(\mathbf{n}I_{T_p}\right)}{\partial T_p}$$

Powder extinguishing model, Governing Equations (4)

$$I_{x_p} = \frac{dx_p}{dt} \triangleq u_p$$

Powder extinguishing model, Governing Equations (4)

$$I_{u_p} = \frac{3\rho\left(u - \ u_p\right)^2 C_D(Re)}{4\rho_{K_l} d_p} \frac{(u(x) - u_p)}{\left|u(x) - u_p\right|}$$

Powder extinguishing model, Governing Equations (4)

$$I_{d_p} \triangleq \frac{d(d_p)}{dt} = -\frac{2\dot{w}_k}{\rho_{K_l}\pi {d_p}^2}$$

$\dot{w}_k$- *Evaporation rate for single particle taken from* ***Abramzon Sirignano*** *evaporation model*

Powder extinguishing model, Governing Equations (4)

I_{T_p} calculated from first thermodynamics law for the particle (lumped):

$$m_p \frac{d(h_{fK}(T_p))}{dt} = \dot{Q}_l - \dot{w}_{kevap} h_{fg_K}$$

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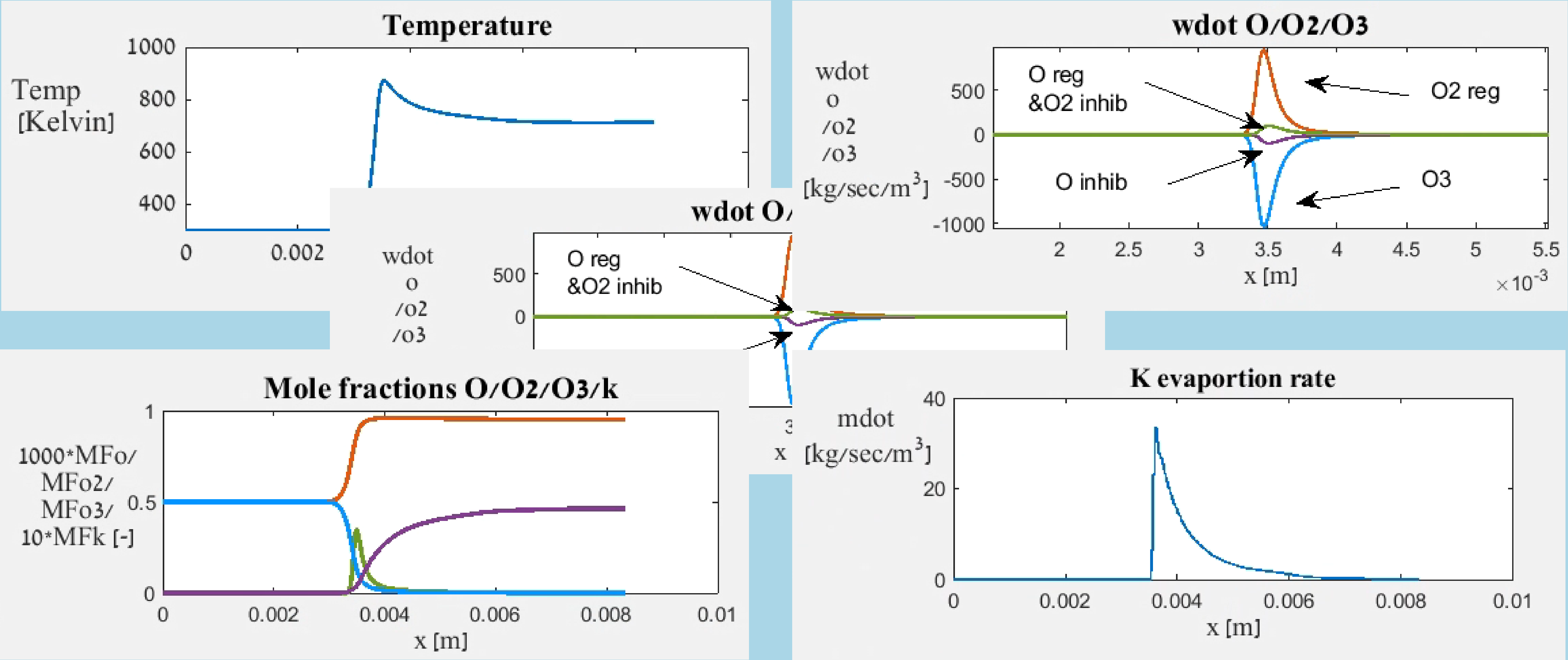
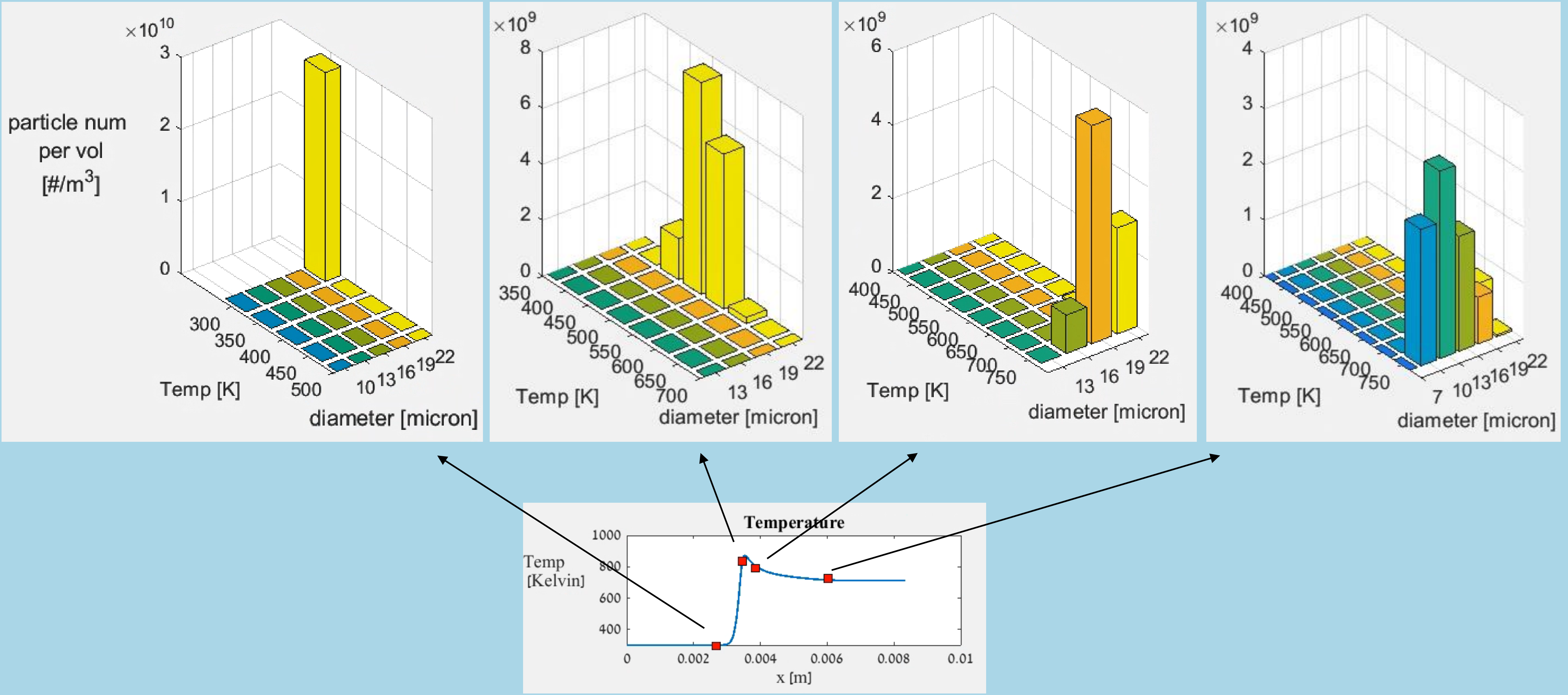
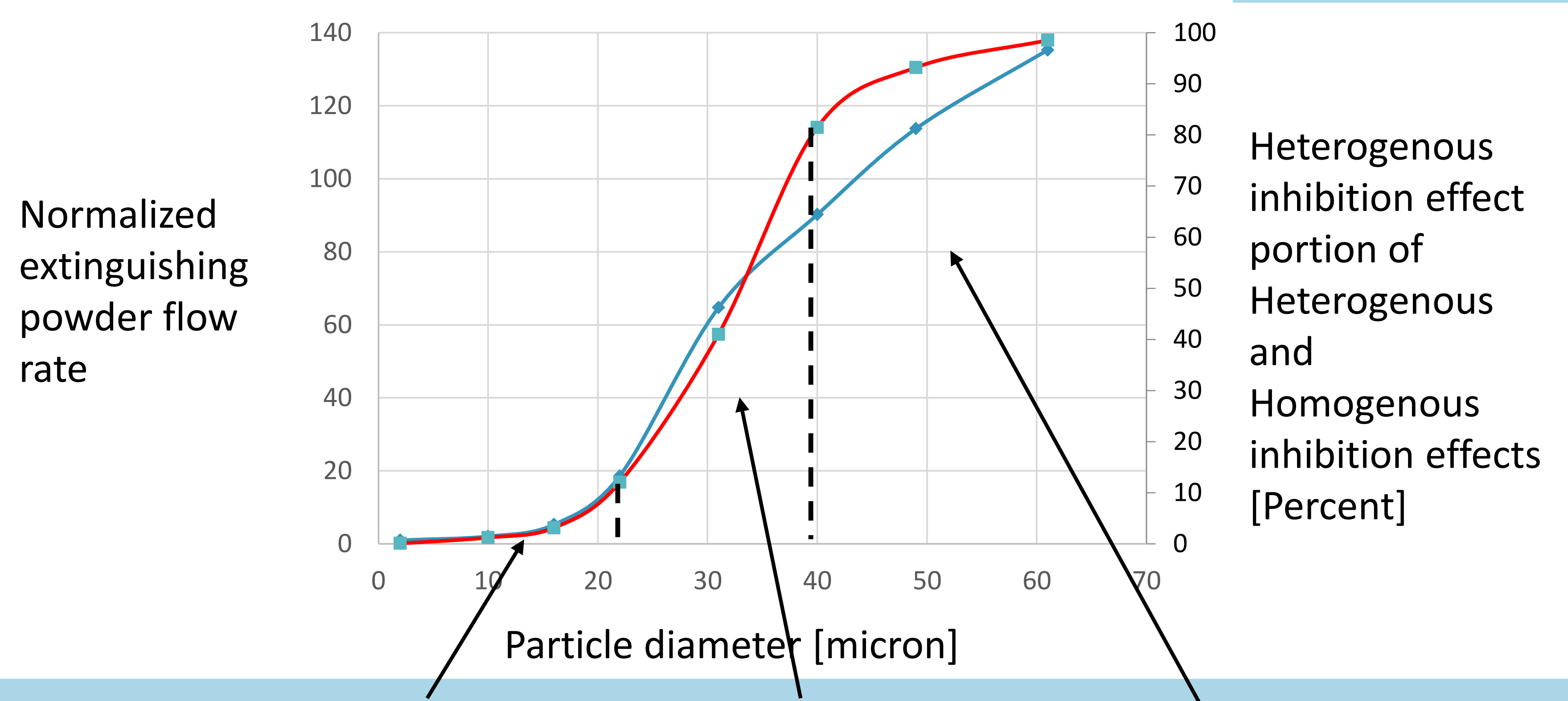
Typical results-22 micron powder particle



Typical results-22 micron powder particle
Temp& diameter distribution Vs position



Powder extinguishing rate VS Powder diameter (1)

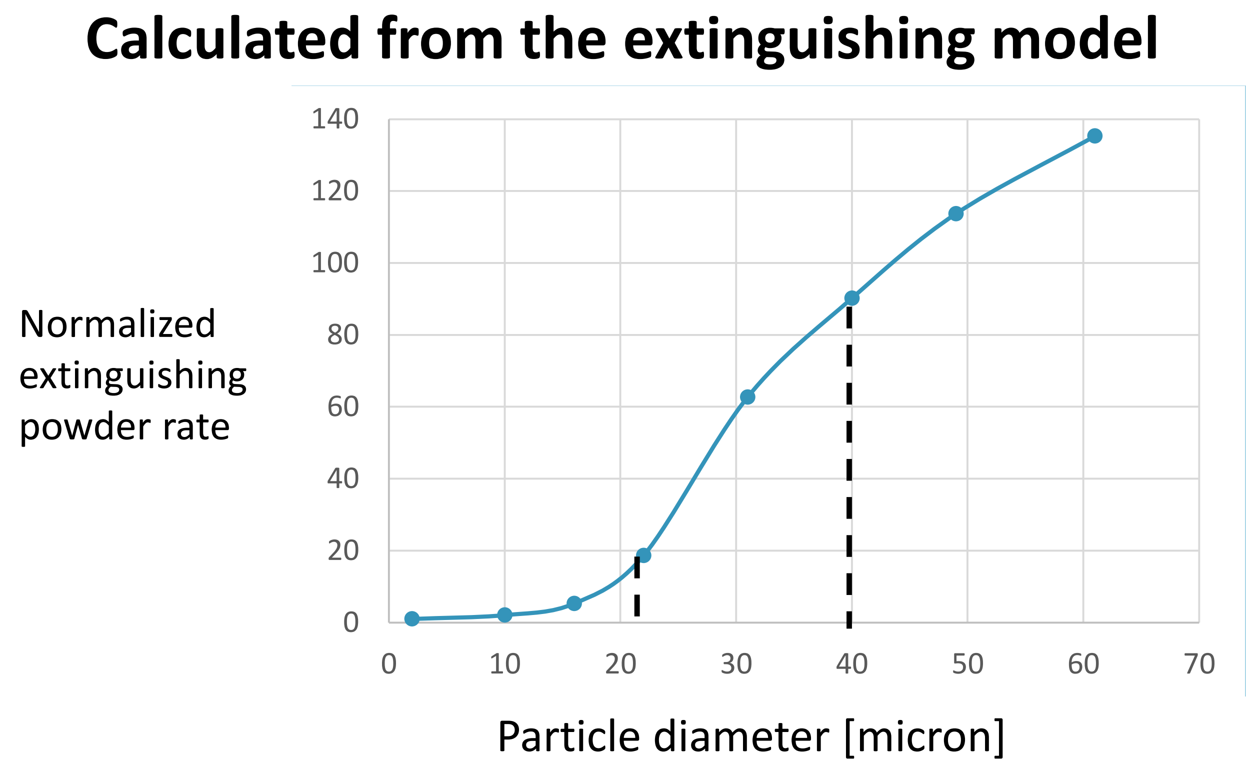


Zone 1 –Governed by Homogenous mechanism

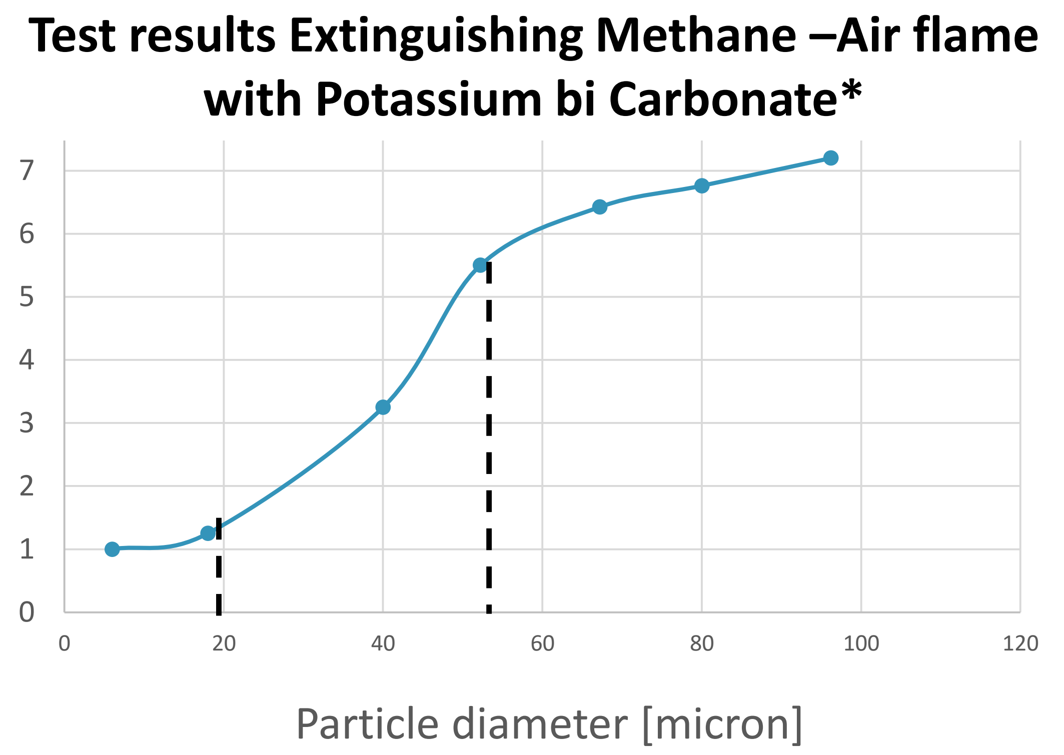
Zone 2 –Transition between Homogenous mechanism to Heterogenous mechanism

Zone 3 –Governed by Heterogenous mechanism

Powder extinguishing rate VS Powder diameter (2)



Calculated from the extinguishing model

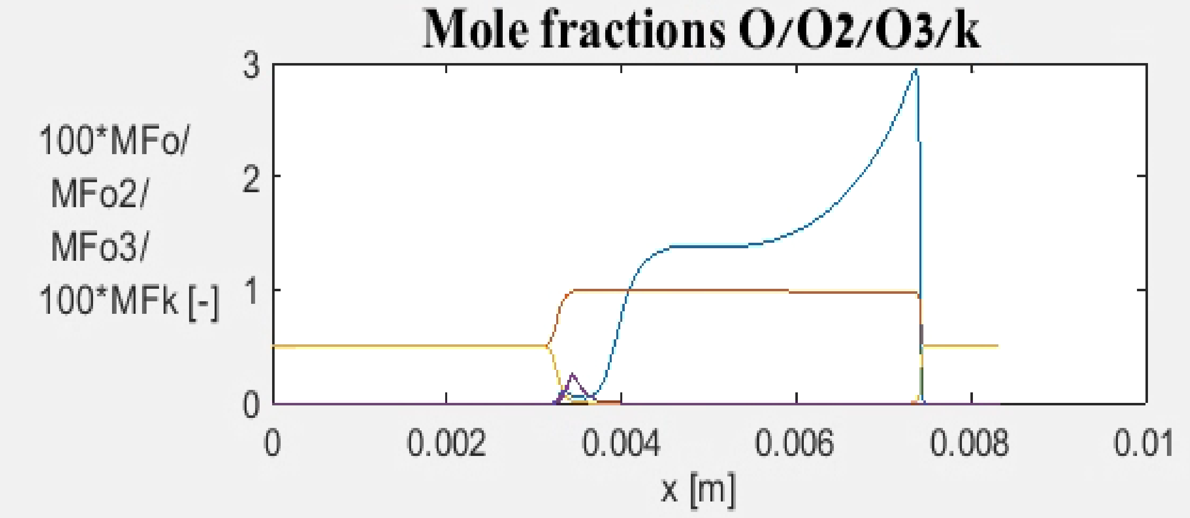


Test results Extinguishing Methane –Air flame with Potassium bi Carbonate*

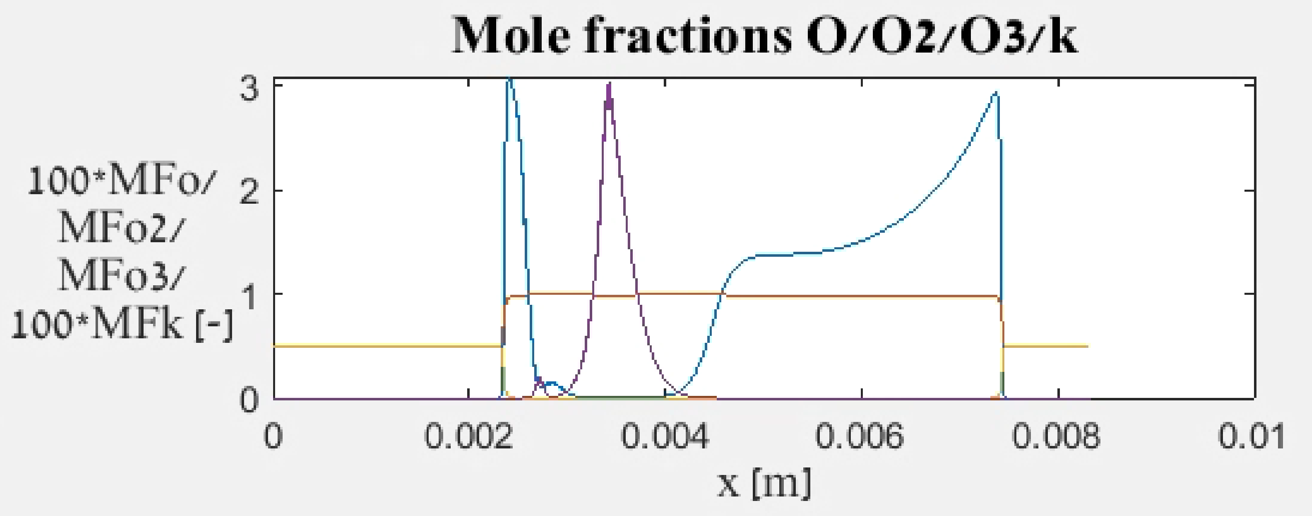
* Taken from G.Fischer, J.T. Leonard (October 1995)

Powder extinguishing rate VS Powder diameter (3)

Zone 2 – Heterogenous Mechanism importance



Heterogenous & Homogenous inhibit mechanisms



Heterogenous mechanism disabled

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Summary (1)

- Introducing **extended GDE** to allow us to calculate concentration of extinguishing powder reaching the flame.

- The analysis of extinguishing flow rate Vs particle diameter exhibits 3 zones –each with different inhibition mechanism. These results are coherent with extinguishing test results from literature.

Summary (2)

- Low diameter powder (aerosol) has definite extinguishing advantage regarding the powder mass needed to extinguish the fire

- In the next step we will change the particle injection velocity relative to the flow and try to understand its effect on the extinguishing powder concentration.

THANK YOU.

Powder Extinguishing -General

- Common extinguishing powders are composed of salts:

  Ammonium nitrate(NH_4NO_3), **Potassium chloride** (KCl), **Ammonium sulfate** ($(NH_4)_2SO_4$) and other materials.

- Particle diameter varies between 10-90[µm] (SPEA Superfine Powder Extinguishing Agent -10 [µm]).

Powder Extinguishing Mechanism

Powder Fire Suppression

Homogeneous Mechanism

Direct Inhibition of Powder evaporation products with the FFR, without participation of third body \wall.

In most cases the reaction occurs near the particle surface.

Heterogeneous Mechanism

Chemical absorption of FFR to Particle surface. Another attacking FFR recombines with the first one due to particle's surface energy dissipation.

The product is desorbed from particle.

Product doesn't propagate completion of oxidation.

THERMAL MECHANISM

- Heat taken from the flame reaction while powder particles are being decomposed \evaporated.
- Mechanical interference of "powder cloud" to FFR which bump into the particles, lose energy and recombine, thus –oxidation cannot propagate ("Flame Arrestor") .

Powder Extinguishing Post fire damage

BASIC GDE

$$\frac{\partial \boldsymbol{n}}{\partial \boldsymbol{t}} = -\frac{\partial(\boldsymbol{n}\boldsymbol{I}_{\boldsymbol{m}_{\boldsymbol{p}}})}{\partial \boldsymbol{m}_{\boldsymbol{p}}} + \boldsymbol{P}$$