Basic Principles for an Adequate Performance Assessment Standard

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What makes a "GOOD" Standard?

- **It has to deliver the information it was designed for**
- **What information?**
  - A "<u>relative</u>" assessment of performance?
  - Material properties that can be used for an "<u>absolute</u>" assessment of performance?
  - Material properties to be the "<u>input for fire models</u>"?

Example

Energy Conservation

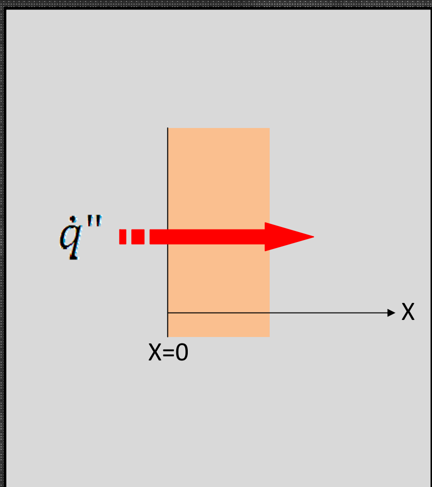
- **How do we assess performance?**
- **Need to quantify heat transfer**
  - Need to define material properties that control heat transfer

Simplifications

- **Transient period is negligible**
- **1-Dimensional**

$$\dot{q}'' = -k\frac{\partial T}{\partial x}$$

$$0 = -k\frac{\partial^2 T}{\partial x^2}$$



How do We Make the Standard?

- We need to find "k"
- We generate the ideal boundary conditions for:

$$\dot{q}'' = -k\frac{\partial T}{\partial x}$$

- Ideal boundary conditions are:

$$T(0)=T_1,\ T(L)=T_2$$

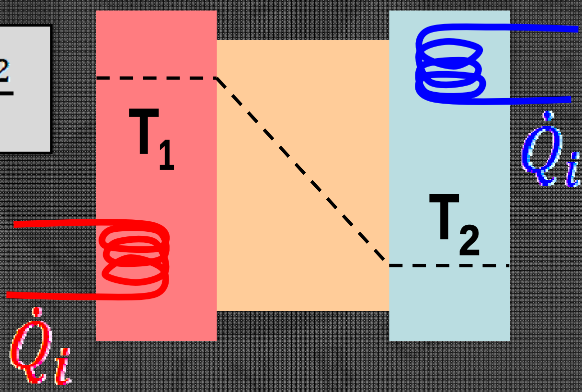
- Have to solve the problem of the contact resistance

Contact Resistance

- Controlled heat sinks at both ends made of a material that has good contact with sample

$$\dot{q}'' = k\frac{T_1 - T_2}{L}$$

$$\dot{q}'' = \frac{\dot{Q}_i}{A}$$



Errors

- **Intrinsic to measurements and procedures**
    - Can be quantified and assessed
- **Intrinsic to the assumptions**
    - Surface condensation and evaporation
        - Not a problem if they are not functions of material properties
    - Transient heat transfer
        - Will require other parameters (ρ,Cp)
    - One-dimensional
        - Only a problem if "k(x,y,z)"

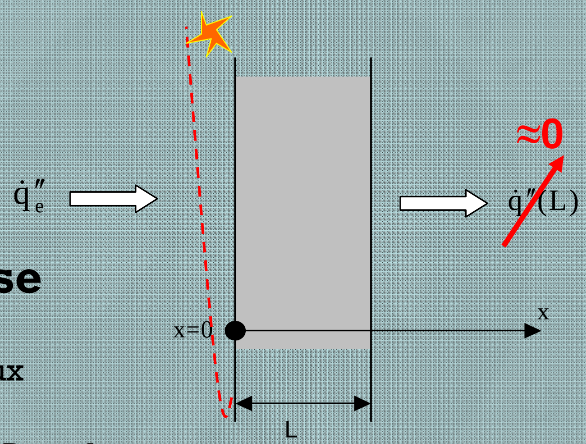
How do we Apply this to Fire?

- **Establish the relevant properties**
- **Relevant properties need to be separated from environmental variables – A difficult process**
- **The standard has to be able to assess these properties and establish estimates of error**

The Lateral Ignition Flame Test (LIFT-ASTM-1321)

Ignition Test

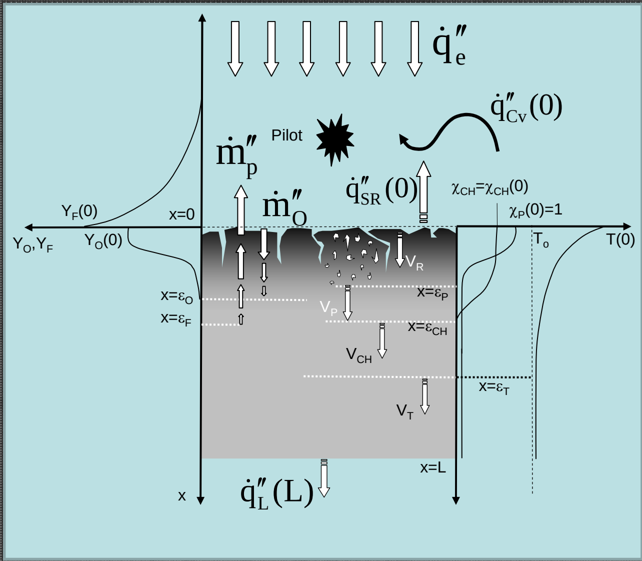
Analysis of the Scenario



- **Simplest case**
  - 1-D
  - Constant heat flux
  - Insulated back
  - Laminar Natural Boundary Layer
  - Strong ignition pilot

Formulation of the Problem

- Simplest case
  - 1-D
  - Constant heat flux



Solid Phase Heat Transfer

$$\frac{\partial}{\partial x}\left(k_S \frac{\partial T}{\partial x}\right) = \frac{\partial(\rho_S C_S T)}{\partial t} + \sum \rho_S \Delta H_i A_i e^{-E_i/RT} + \dot{q}'''_R$$

$t = 0$	$T = T_i$
$x = 0$	$-k_S \left.\frac{\partial T}{\partial x}\right\|_{x=0^+} = \alpha \dot{q}''_e - k_g \left.\frac{\partial T}{\partial x}\right\|_{x=0^-} - \dot{q}''_{S,R}$
$x = L$	$-k_S \left.\frac{\partial T}{\partial x}\right\|_{x=L^-} = \dot{q}''(L)$

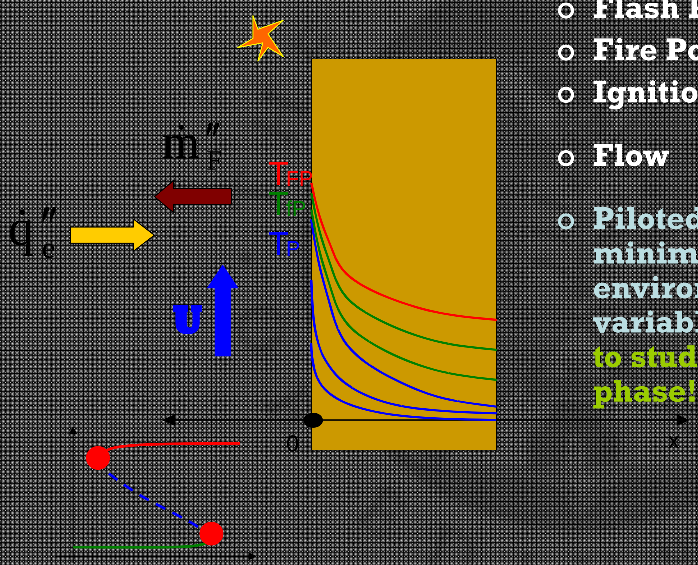
The Objective

$$\dot{m}''_F = \int_0^L \chi(x) Y_F(x) \sum \rho_S A_i e^{-E_i/RT} dx$$

- The Boundary condition for the gas phase

- **$\chi(x)$ is function that defines the fuel permeability**
- **$Y_F(x)$ is the mass fraction of "fuel"**
- **L=thickness of the fuel**

Ignition Criteria



- **Flash Point**
- **Fire Point**
- **Ignition**

- **Flow**

- **Piloted ignition minimizes environmental variables-preferred to study the solid phase!**

The Simplified Scenario

- Laminar boundary layer
- Constant heat flux
- One-dimensional
- Strong Pilot

The Zeroth-Order Solution

$$t_{ig} = t_p + t_m + t_i$$

$$t_{ig} = t_p > t_m > t_i$$

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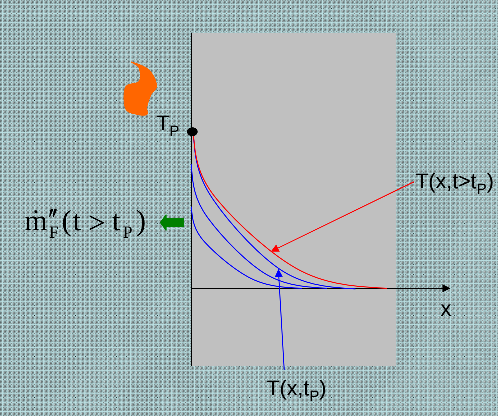
$$t_{ig} \approx t_p$$



Analytical Framework

- $t_{ig} \approx t_p$ and $T_{ig} \approx t_p$

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

$$\begin{cases} x=0 & -k\dfrac{\partial T}{\partial x} = \dot{q}''_S(0,t) \\ t=0 \\ x \to \infty & T = T_\infty \end{cases}$$

- Scaling all variables

$$\bar{T} = \frac{T - T_\infty}{T_{ig} - T_\infty} \qquad \bar{x} = \frac{x}{x_c} \qquad \bar{t} = \frac{t}{t_c} \qquad \bar{\dot{q}}'' = \frac{\dot{q}''}{\dot{q}''_c}$$

$$x_c = k / h_T \qquad t_c = k\rho C / h_T^{\,2} \qquad \dot{q}''_c = h_T (T_{ig} - T_\infty) / a$$

- Leads to the following solution

$$\bar{T}_S = \bar{\dot{q}}''_e \left[1 - e^{\bar{t}} \operatorname{erfc}(\sqrt{\bar{t}}\,) \right]$$

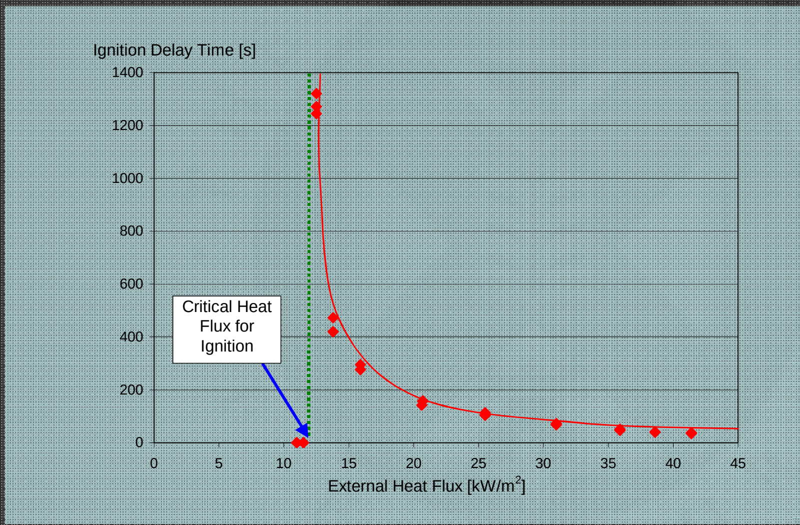
Taylor Series Expansions

- High Heat Flux $\qquad \bar{t}_{ig} \to 0 \qquad \bar{t}_{ig} = \dfrac{\pi}{4}\dfrac{1}{(\bar{\dot{q}}''_e)^2}$

- Low Heat Flux $\qquad \bar{t}_{ig} \to \infty \qquad \bar{t}_{ig} = \dfrac{1}{\pi}\left(\dfrac{1}{1 - 1/\bar{\dot{q}}''_e}\right)^2$

- Critical Heat Flux for Ignition $\qquad \dot{q}''_c = h_T (T_{ig} - T_\infty) / a$

Ignition Delay Time



Results

- The experimental data is fitted to the theoretical predictions and all characteristic values are extracted
- The total heat transfer coefficient is evaluated (h_T)
- Material properties are evaluated ($k\rho C$, T_{ig})

<u>Assumptions</u>

- Semi-Infinite Solid
- Linearized Total Heat Transfer Coefficient: $h_T = h_C + h_{s,r}$
- Solid remains inert until ignition

Parameters

- $k\rho C$
- T_{ig}

ASTM-E-1321

- **This information is the backbone of the standard**
  - Is this an adequate interpretation for the "relative" assessment of the material?
  - Is this an adequate interpretation to extract "properties" for fire modelling?
- **Does the analysis have to be so simple?**
- **Do we need to make all the assumptions?**
- **What is the error introduced in the assumptions?**

Assumptions

- The assumptions need to be revisited in detail
  - Semi-Infinite Solid
  - Linearized Heat Transfer Coefficient ($h_T=h_C+h_{S,r}$)
  - Solid remains inert until ignition

Numerous Studies

Is this a Good Standard?

- $k\rho C$, T_{ig} have been shown to depend on the environmental conditions

...But they are the properties governing ignition

...But the standard operates under relevant environmental conditions

- A good Relative standard
- Not good to deliver Properties for Modelling

Summary

- A good standard delivers the relevant "**parameters**"

  ...does not compound parameters that have independent influence on the process

- A good standard is based on a method that **minimizes** error

  ...does not have to mimic reality

Thank you