

GDR Feux à Nancy, 2023



Simulation numérique d'un feu en milieu confiné mécaniquement ventilé avec aspersion par brouillard d'eau

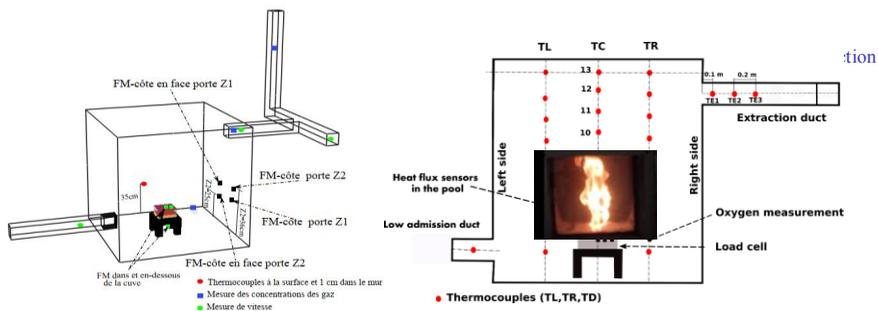
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H. Y. Wang

<https://equipex-gap-prometee.ensma.fr/installations-banc/pericles/>


CONTEXTE

Famme perturbée par l'injection des gouttelettes



DISPOSITIF EXPERIMENTAL

Echelle Réduite : $L = W = H = 1 \text{ m}$ Diamètre du foyer : $D=15 \text{ cm}$ Combustible Liquid : Heptane (98°C)

Taux de renouvellement horaire : 4 – 60

Injecteur du brouillard d'eau

Diamètre de gouttelette : 60 μm

Vitesse de gouttelette : 10 m/s

Débit massique d'eau : 3.5 g/s

MODELISATION NUMERIQUE (PHASE GAZEUSE)

Equations Navier-Stokes

Equation du transport des espèces chimiques

$$\frac{\partial \rho Y_i}{\partial t} + \nabla \cdot (\rho Y_i \mathbf{u}) = \nabla \cdot (\rho D \nabla Y_i) + \dot{\omega}_i'''$$

Equation de l'énergie

$$\frac{\partial \rho h}{\partial t} + \nabla \cdot \rho h \mathbf{u} = \frac{Dp}{Dt} + \dot{q}_c''' + \nabla \cdot \sum_{i=0}^N h_i \rho D_i \nabla Y_i + \nabla \cdot \lambda \nabla T - \nabla \cdot \mathbf{q}_r''' - \mathbf{q}_b'''$$

Equation du transfert radiatif

$$s \cdot \nabla I_\lambda(x, s) = -[\kappa_s(x, \lambda) + \sigma_s(x, \lambda)] I(x, s) + \kappa_s(x, \lambda) I_{b,s}(x, \lambda) + \frac{\sigma_s(x, \lambda)}{4\pi} \int_{4\pi} \Phi(s, s') I_\lambda(x, s') d\Omega'$$

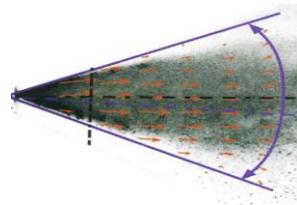
Equation de transport de suie (Nucléation / Grossissement / Oxydation)

$$\frac{\partial \rho M}{\partial t} + \frac{\partial [\rho M (\mathbf{u}_i + \mathbf{u}_i^{th})]}{\partial x_j} - \frac{\partial}{\partial x_j} \left(\frac{\mu}{Sc} \frac{\partial M}{\partial x_j} \right) = \dot{\omega}_{M,inc} + \dot{\omega}_{M,gro} + \dot{\omega}_{M,oxi}$$

MODELISATION NUMERIQUE (PHASE DISPERSÉE)

Trajectoire des gouttelettes

$$\frac{d}{dt} (m_d \mathbf{u}_d) = m_d \mathbf{g} - \frac{1}{2} \rho C_d \pi r_{d,i}^2 (\mathbf{u}_d - \mathbf{u}) |\mathbf{u}_d - \mathbf{u}|$$



Interaction fluide-particule

Force de traînée :
$$\mathbf{F} = \frac{1}{2} \frac{\sum_i \rho C_d \pi r_{d,i}^2 (\mathbf{u}_{d,i} - \mathbf{u}) |\mathbf{u}_{d,i} - \mathbf{u}|}{\delta V}$$

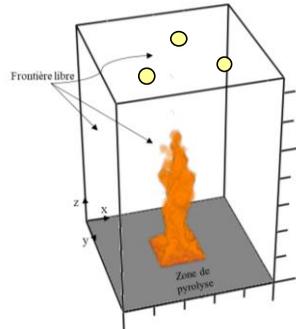
Distribution de taille des gouttelettes

Fonction cumulative volumique

(combinaison des distributions Log-normal et Rosin-Rammler)

$$F(d) = \begin{cases} \frac{1}{\sqrt{2\pi}} \int_0^d \frac{1}{\sigma d'} \exp\left(-\frac{[\ln(d'/d_m)]^2}{2\sigma^2}\right) dd' & (d \leq d_m) \\ 1 - \exp[-0.693(d/d_m)^y] & (d > d_m) \end{cases}$$

FEUX DE NAPPE EN MILIEU OUVERT



Configuration numérique

Domaine de calcul : $L = W = 2 \text{ m}$, $H = 1.5 \text{ m}$

Trois injecteur du brouillard d'eau

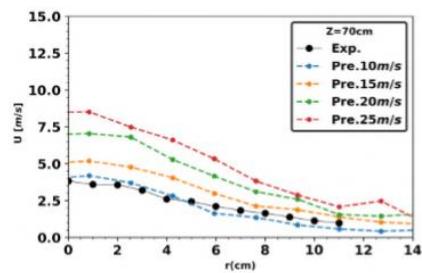
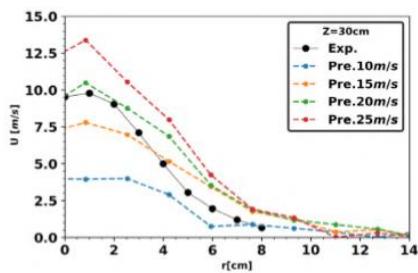
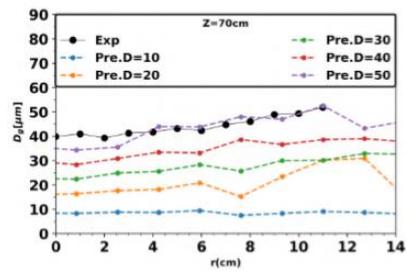
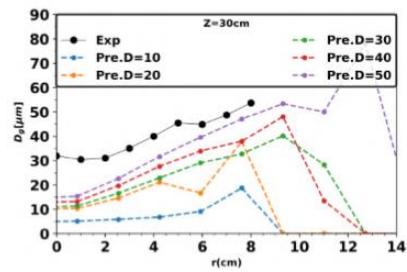
Diamètre du foyer : $D = 30 \text{ cm}$

Taille du maillage : $0.5 - 1 \text{ cm}$

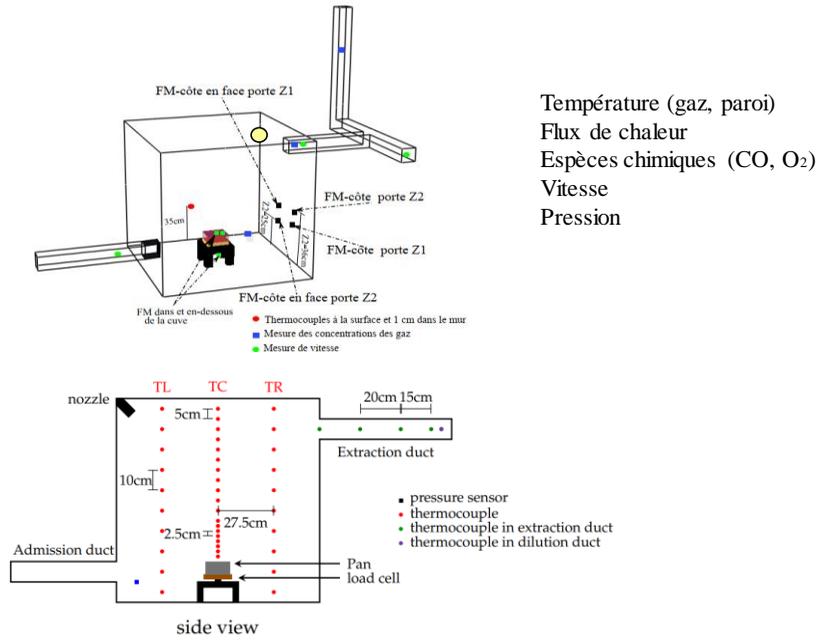
Temps physique : 60 s

Temps CPU: $48 - 72 \text{ h}$

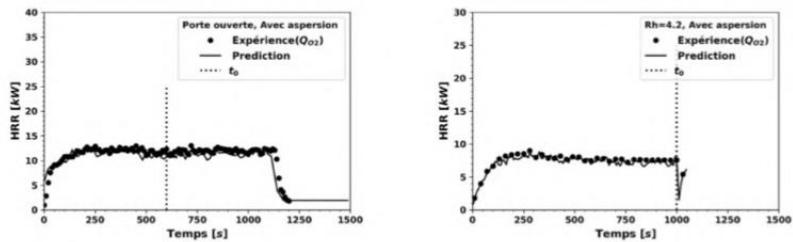
Diametre de Sauter moyen et vitesse d'injection



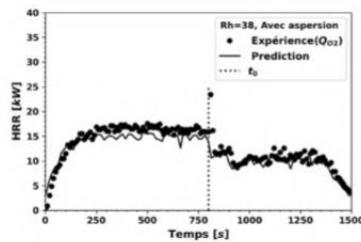
IMPACT DU BROUILLARD D'EAU SUR LE FEU EN MILIEU CONFINÉ



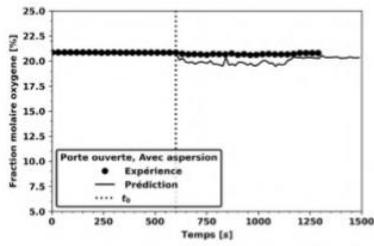
Impact du brouillard d'eau sur l'évolution de la puissance du feu en milieu confiné



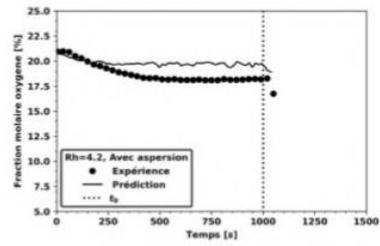
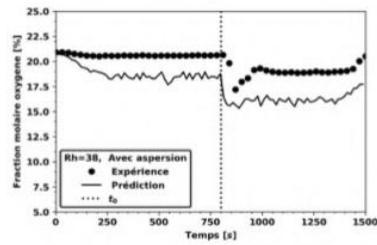
(A) porte ouverte

(B) $Rh = 4,2$ (C) $Rh = 38$

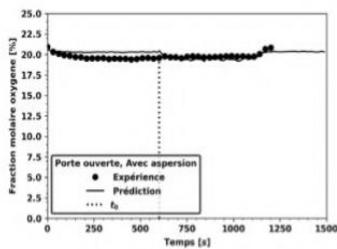
Impact du brouillard d'eau sur la concentration d'oxygène proche du foyer



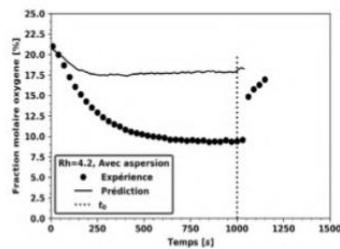
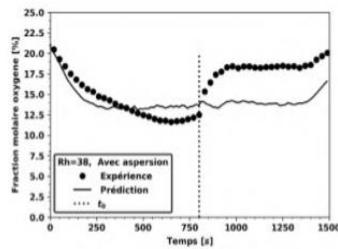
(A) porte ouverte

(B) $Rh = 4,2$ (C) $Rh = 38$

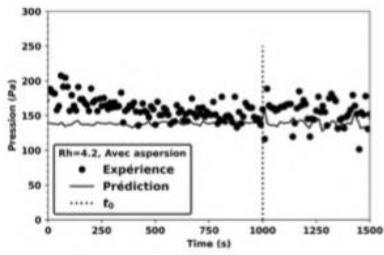
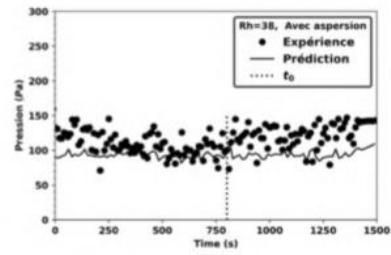
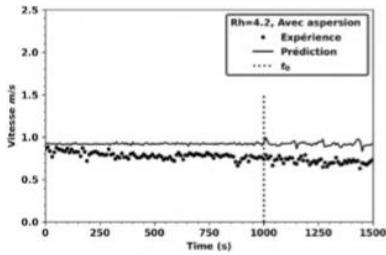
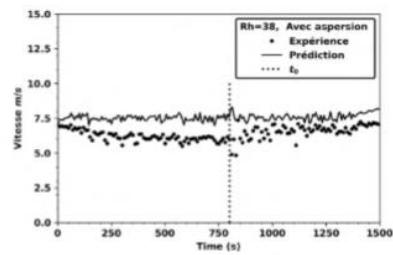
Impact du brouillard d'eau sur la concentration d'oxygène au niveau d'extraction



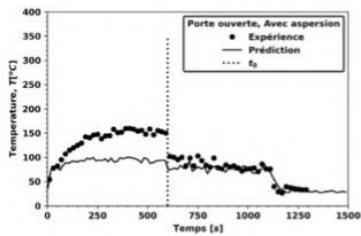
(A) porte ouverte

(B) $Rh = 4,2$ (C) $Rh = 38$

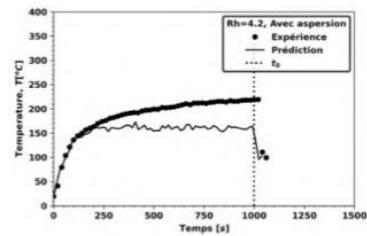
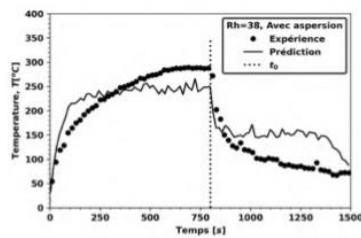
Evolution de la depression (P_0-P) et vitesse d'air à l'entrée de la gaine d'admission

(A) $Rh = 4,2$ (B) $Rh = 38$ (A) $Rh = 4,2$ (B) $Rh = 38$

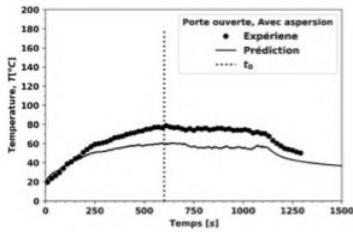
Evolution temporelle de la température au niveau du conduit d'extraction



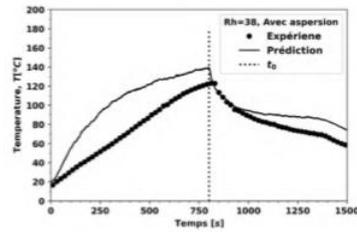
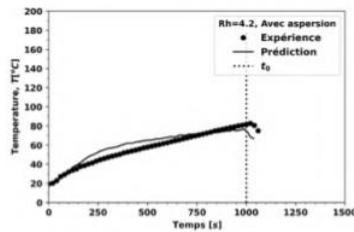
(A) porte ouverte

(B) $Rh = 4,2$ (C) $Rh = 38$

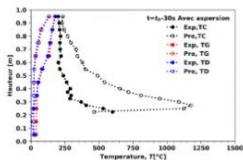
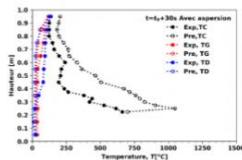
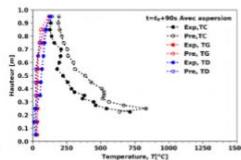
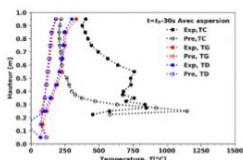
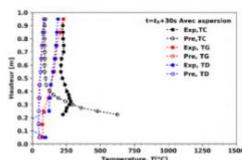
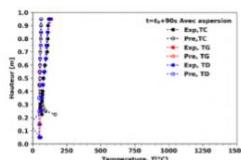
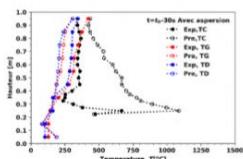
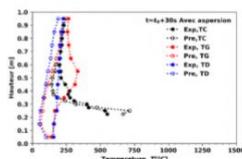
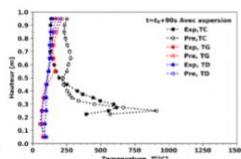
Evolution temporelle de la température au niveau de la paroi du caisson (h=36 cm)



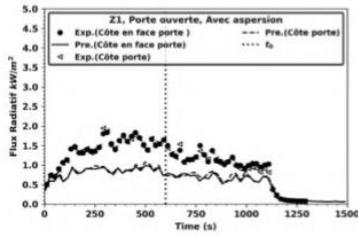
(A) porte ouverte

(B) $Rh = 4, 2$ (C) $Rh = 38$

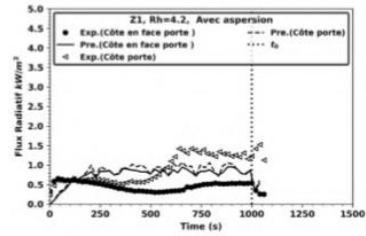
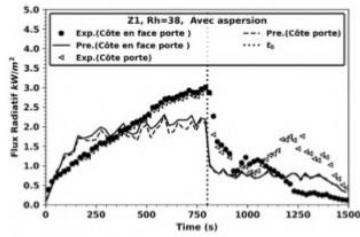
Profils de la température sur l'arbre central TC, TG, TD sans et avec brouillard d'eau

(A) $t=t_0-30s$, porte ouverte(B) $t=t_0+30s$, porte ouverte(C) $t=t_0+90s$, porte ouverte(D) $t=t_0-30s$, $Rh = 4, 2$ (E) $t=t_0+30s$, $Rh = 4, 2$ (F) $t=t_0+90s$, $Rh = 4, 2$ (G) $t=t_0-30s$, $Rh = 38$ (H) $t=t_0+30s$, $Rh = 38$ (I) $t=t_0+90s$, $Rh = 38$

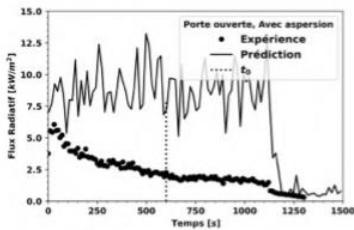
Evolution temporelle du flux radiatif reçu au niveau de la paroi du caisson (h=36 cm)



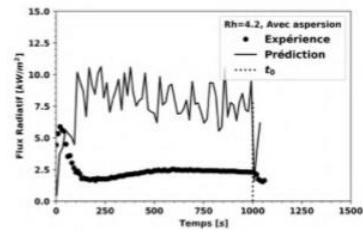
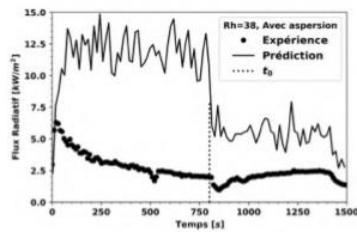
(A) porte ouverte

(B) $Rh = 4,2$ (C) $Rh = 38$

Impact du brouillard d'eau sur le flux radiatif à la surface du combustible liquide



(A) porte ouverte

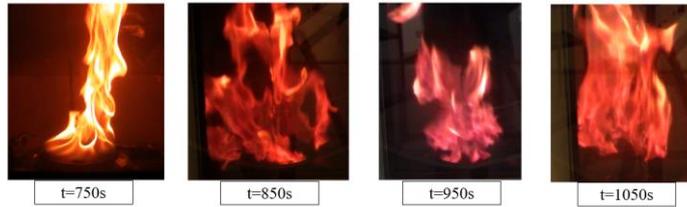
(B) $Rh=4,2$ (C) $Rh=38$

Conclusions et perspectives

RH<28, Flamme perturbée par l'injection des gouttelettes avec une extinction de flamme



RH>38, Flamme avec une expansion et un aplatissement de la flamme tourbillonnaire



Modèle de combustion (améliorations avec une cinétique chimique complexe)

Modèle de suie (transfert radiatif, flux de chaleur)