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Numerical investigations of heat losses to confinement structures from hydrogen-air turbulent flames in ENACCEF facility



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ABSTRACT

In hydrogen safety analysis, structure response due to the pressure and thermal loads from the combustion is of great concern. It is of high significance to understand not only the combustion process itself, but also the heat losses from the combustion products to the solid structures which may have strong impacts on the pressure and temperature decays. In many previous numerical simulations, heat losses from turbulent hydrogen flames to the confinement structures were usually considered to be negligible or less important. However, it has been revealed by many experimental studies that modeling of heat losses from the combustion products is important for accurate predictions. Our objectives are to study the importance of various heat transfer mechanisms and their relative contributions to the total energy losses. Numerical investigations on the mechanisms of heat losses caused by propagating turbulent flames were performed using a semi-implicit pressurebased all-speed CFD code GASFLOW-MPI. Heat losses from turbulent sonic flames to the structures of the ENACCEF facility at IRSN were studied. It appears that the effect of heat losses on the flame propagation properties is not significant. However, the impacts of heat losses on the pressure peak and pressure decay after hydrogen combustions should not be neglected. It indicates from our simulation results that the convective heat transfer and thermal radiative heat transfer are the main contributors of the total energy losses to the structures of ENACCEF. In our cases, the effect of steam condensation heat transfer is relatively small but not negligible. The relative contributions of various heat transfer mechanisms could be different in other experimental facilities with various geometrical configurations, various internal structures, and various optical and thermal characteristics of the burnable gas mixtures. In general, it is suggested to include the heat transfer mechanisms in order to improve the reliability and accuracy of numerical analyses of hydrogen safety issues.

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arradiation constantSiturbulent fiame speedAoutward normal fractional area vectorSisource term of volumeAcell face area for walls or the exposed area for internal structuresSisource term of speciesAconstant coefficient in Zimont modelTgas temperaturebthe velocity of the control surface ST/wtemperature inside the solid structureC-speed of lightUuvelocity vector of the fluidC-1constant coefficientuvelocity vector of the fluidC-2constant coefficientuvelocity vector of the fluidC-3constant coefficientuvelocity vector of the fluidC-4constant coefficientuvelocity vector with the two wall tangential velocityC-7specific heat of the water vapor at constanturdimensionless velocitypressureU'dimensionless velocityurDDakohler numberU'dimensionless velocityD,1molecular diffusivityy'distance to the surfaceD,1molecular diffusivityy'distance to the surfaceD,1urbulent molecular diffusivityy'distance forth efficientD,4mast fraction of hydrogen after combustionradiation energy densityD,4internal energy of the water vaporradiation energy densityD,4internal energy of the water vaporradiation energy densityD,4internal energy of the water vaporradiation energy density <th colspan="2">Nomenclature</th> <th>S_m</th> <th>source term of momentum</th>	Nomenclature		S_m	source term of momentum
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$ \begin{array}{cccccc} p_{c} & \text{distance from the first cell center to the wall} \\ p_{c} & \text{distance from the first cell center to the wall} \\ p_{d} & \text{mass transfer coefficient} & Y_{12} & \text{mass fraction of hydrogen before combustion} \\ p_{d} & \text{corrected mass-transfer coefficient} & Y_{12,initial} & \text{mass fraction of hydrogen after combustion} \\ p_{fio} & \text{specific internal energy of the water vapor} & Greek symbols \\ p_{e} & \text{distingtion flux vector} & \dot{a} & \text{thermal influsivity of unburnt mixture} \\ k & \text{thermal conductivity of the solid structure} & a_r & \text{absorption coefficient} \\ l_t & \text{turbulent length scale} & e & \text{dissipation rate of turbulent kinetic energy} \\ p_{m_s} & \text{man beam length} & e_{r,H_0} & \text{grey medium total emissivity} \\ m_k & \text{wall condensation or vaporization rate} & \xi & mean reaction progress variable \\ P_{k} & \text{effective broadening pressure} & \kappa & \text{turbulent kinetic energy} \\ P_{H_0} & \text{water vapor partial pressure} & \lambda & mean free path \\ P_k & \text{turbulent kinetic energy production by viscous} & \mu_{eff} & \text{effective viscosity} \\ \text{forces} & r & \text{molecular viscosity} \\ P_{h_k} & \text{turbulent kinetic energy production by viscous} & p_{h_0} & \text{water vapor density in the gas mixture} \\ P_{a,saturation} & \text{saturation pressure} & \sigma & \text{Stefan-Boltzmann constant} \\ q_i & \text{radiation flux vector} & \sigma_b & \text{constant coefficient} \\ q_{s,cont/m_0} & \text{energy delivered to the structural surfaces by} & \sigma_c & \text{constant coefficient} \\ q_{s,cont/m_0} & \text{energy delivered to the structural surfaces by} & \sigma_c & \text{constant coefficient} \\ q_{s,cont/m_0} & \text{energy delivered to the structural surfaces by} & \sigma_c & \text{constant coefficient} \\ q_{s,cont/m_0} & \text{energy delivered to the structural surfaces by} & \sigma_c & \text{constant coefficient} \\ q_{s,cont/m_0} & \text{energy delivered to the structural surfaces by} & \sigma_c & \text{constant coefficient} \\ q_{s,cont/m_0} & \text{energy delivered to the structural surfaces by} & \sigma_c & \text{constant coefficient} \\ q_{s,cont/m_0} & energy delivered to the structural s$	D _l		y ⁺	dimensionless wall distance
$ \begin{array}{cccc} \mathbf{P}_{H2} & \text{mass fraction of hydrogen} \\ \mathbf{h}_{d} & \text{mass transfer coefficient} \\ \mathbf{h}_{s}^{d} & \text{corrected mass-transfer coefficient} \\ \mathbf{h}_{s}^{d} & \text{corrected mass-transfer coefficient} \\ \mathbf{h}_{s}^{d} & \text{corrected mass-transfer coefficient} \\ \mathbf{h}_{s}^{d} & \text{mass fraction of hydrogen after combustion} \\ \mathbf{h}_{H20}^{d} & \text{specific internal energy of the water vapor} & Greek symbols \\ \mathbf{h}_{s}^{d} & \text{thermal conductivity of the solid structure} \\ \mathbf{k} & \text{thermal conductivity of the solid structure} & \mathbf{a}_{r} & \text{absorption coefficient} \\ \mathbf{k} & \text{thermal conductivity of the solid structure} & \mathbf{a}_{r} & \text{absorption rate of turbulent kinetic energy} \\ \mathbf{L}_{m3} & \text{mean beam length} & \mathbf{e}_{r,H_{2}} & \text{grey medium total emissivity} \\ \mathbf{h}_{s}^{d} & \text{wall condensation or vaporization rate} & \mathbf{e} & \text{dissipation rate of turbulent kinetic energy} \\ \mathbf{h}_{s}^{d} & \text{wall condensation or vaporization rate} & \mathbf{e} & \text{turbulent kinetic energy} \\ \mathbf{h}_{s}^{d} & \text{wall condensation or vaporization pressure} & \mathbf{k} & \text{turbulent kinetic energy} \\ \mathbf{h}_{s}^{d} & \text{wall vapor partial pressure} & \mathbf{k} & \text{turbulent kinetic energy} \\ \mathbf{h}_{s}^{d} & \text{water vapor partial pressure} & \mathbf{h}_{s}^{d} & \text{indermal viscosity} \\ \mathbf{h}_{s}^{d} & \text{turbulent kinetic energy production by viscous} & \mu_{eff} & \text{effective viscosity} \\ \mathbf{h}_{s}^{d} & \text{turbulent kinetic energy production by buoyant} & \mu_{t} & \text{turbulent viscosity} \\ \mathbf{h}_{s}^{d} & \text{turbulent kinetic energy production by buoyant} & \mu_{s} & \text{sutration pressure at the surface temperature} \\ \mathbf{p}_{s,saturation} & \text{saturation pressure} at the surface temperature \\ \mathbf{p}_{s,saturation} & \text{saturation pressure} & \mathbf{r}^{b} & \text{constant coefficient} \\ \mathbf{q}_{s,cond/vap} & \text{energy delivered to the structural surfaces by} & \sigma_{b} & \text{constant coefficient} \\ \mathbf{q}_{s,cond/vap} & \text{energy delivered to the structural surfaces by} & \sigma_{c} & \text{constant coefficient} \\ \mathbf{q}_{s,cond/vap} & \text{energy delivered to the structural surfaces by} & \sigma_{c} & constant coe$	D_t	turbulent molecular diffusivity	y _c	distance from the first cell center to the wall
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$ \begin{array}{cccc} & {\rm J}_{z}{\bf A} & {\rm mass diffusion flux vector} & \dot{a} & {\rm thermal diffusivity of unburnt mixture} \\ & {\rm thermal conductivity of the solid structure} & {\rm a} & {\rm absorption coefficient} \\ & {\rm turbulent length scale} & {\rm e} & {\rm dissipation rate of turbulent kinetic energy} \\ & {\rm mass} & {\rm mean beam length} & {\rm e}_{r,H_2O} & {\rm grey medium total emissivity} \\ & {\rm mean beam length} & {\rm e}_{r,H_2O} & {\rm grey medium total emissivity} \\ & {\rm fs} & {\rm wall condensation or vaporization rate} & {\rm fs} & {\rm mean reaction progress variable} \\ & {\rm Ph}_{i,O} & {\rm steam mole fraction} & {\rm Θ_m} & {\rm mass transfer correct coefficient} \\ & {\rm P_e} & {\rm effective broadening pressure} & {\rm κ} & {\rm turbulent kinetic energy} \\ & {\rm Mist conductive vapor partial pressure} & {\rm μ_i} & {\rm mean free path} \\ & {\rm P_k} & {\rm turbulent kinetic energy production by viscous} & {\rm μ_{if}} & {\rm molecular viscosity} \\ & {\rm $freess} & {\rm μ_{if}} & {\rm molecular viscosity} \\ & {\rm $freess} & {\rm μ_{if}} & {\rm molecular viscosity} \\ & {\rm $freess} & {\rm μ_{if}} & {\rm molecular viscosity} \\ & {\rm P_{rk}} & {\rm turbulent kinetic energy production by buoyant} & {\rm μ_{t}} & {\rm turbulent prandtl number} \\ & {\rm $\rho_{s,saturation}$} & {\rm $saturation pressure} & {\rm $the surface temperature} \\ & {\rm $\rho_{s,saturation}$} & {\rm $saturation pressure} & {\rm $the surface temperature} \\ & {\rm $q_{s,condvorp}$} & {\rm $energy delivered to the structural surfaces by} & {\rm σ_{b}} & {\rm $constant coefficient} \\ & {\rm $q_{s,condvorp}$} & {\rm $energy delivered to the structural surfaces by} \\ & {\rm $steam phase change} & {\rm δ_{s}} & {\rm $wall shear stress} \\ & {\rm $fex $ ratio} & {\rm σ_{s}} & {\rm $constant coefficient} \\ & {\rm $q_{s,condvorp}$} & {\rm $energy delivered to the structural surfaces by} \\ & {\rm $steam phase change} & {\rm δ_{s}} & {\rm $wall shear stress} \\ & {\rm $fex $ ratio} & {\rm $constant coefficient} \\ & {\rm $s_{s,condvorp}$} & {\rm $energy delivered to the structural surfaces by} \\ & {\rm s_{s}} & {\rm $shear stress} \\ & {\rm $fex $ ra$	hs	heat transfer coefficient		
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$ \begin{array}{ccc} l_{t} & \mbox{turbulent length scale} & e & \mbox{dissipation rate of turbulent kinetic energy} \\ l_{ms} & \mbox{mean heam length} & e_{r,H_2O} & \mbox{grey medium total emissivity} \\ mbox{mean reaction progress variable} & \mbox{mean reaction reaction variable} & \mbox{mean reaction reaction variable} & \mbox{mean reaction reaction variable} & \mbox{mean reaction reaction} & \mbox{mean reaction} & mea$	k	thermal conductivity of the solid structure	α _r	absorption coefficient
$\begin{array}{l c c c } Import Im$	lt	turbulent length scale	ε	dissipation rate of turbulent kinetic energy
$\begin{array}{llllllllllllllllllllllllllllllllllll$	L _{ms}	mean beam length	ϵ_{r,H_2O}	grey medium total emissivity
$\begin{array}{llllllllllllllllllllllllllllllllllll$	ḿs	wall condensation or vaporization rate	ξ	mean reaction progress variable
$\begin{array}{llllllllllllllllllllllllllllllllllll$	n_{H_2O}	steam mole fraction	Θ_m	mass transfer correct coefficient
$\begin{array}{cccc} P_{H_2O} & \mbox{water vapor partial pressure} & \lambda & \mbox{mean free path} \\ P_k & \mbox{turbulent kinetic energy production by viscous} & \mu_{eff} & \mbox{effective viscosity} \\ p_{kb} & \mbox{stresses} & \mu_l & \mbox{molecular viscosity} \\ forces & \mu_t & \mbox{turbulent viscosity} \\ p_{kc} & \mbox{turbulent kinetic energy production by buoyant} & \mu_t & \mbox{turbulent viscosity} \\ forces & \mu & \mbox{molecular viscosity} \\ p_{s,saturation} & \mbox{sturation pressure at the surface temperature} \\ p_{s,saturation} & \mbox{saturation pressure at the surface temperature} \\ p_{sat} & \mbox{saturation pressure} & \mbox{sturation pressure} \\ saturation pressure & \mbox{sturation pressure} & \mbox{sturation saturation pressure} \\ q_A & \mbox{internal energy flux vector} & \sigma_b & \mbox{constant coefficient} \\ q_{s,cond/vap} & \mbox{energy delivered to the structural surfaces by} & \mbox{ore to the structural surfaces by} & \mbox{steam phase change} & \mbox{ore term of convective heat transfer} \\ q_{s,cond/vap} & \mbox{et ratio} & \mbox{sures} & \mbox{mean free path} \\ R & \mbox{flex ratio} & \mbox{surese} & \mbox{ore term of convective heat transfer} \\ P_{s,laturation} & \mbox{surese} & \mbox{mean free path} \\ P_{s,laturation} & \mbox{surese} $	Pe	effective broadening pressure	κ	turbulent kinetic energy
P_k turbulent kinetic energy production by viscous μ_{eff} effective viscosity $stresses$ μ_l molecular viscosity P_{kb} turbulent kinetic energy production by buoyant μ_t turbulent viscosity P_{kb} turbulent kinetic energy production by buoyant μ_t turbulent viscosity Pr_t turbulent Prandtl number ρ_{H_2O} water vapor density in the gas mixture $p_{s,saturation}$ saturation pressure at the surface temperature $\rho_{s,saturation}$ the saturation water vapor density at the p_{sat} saturation pressure σ Stefan-Boltzmann constant q_i radiation flux vector σ_b constant coefficient $q_{s,cond/vap}$ energy delivered to the structural surfaces by steam phase change $\hat{\sigma}_s$ vall shear stress R flex ratio $\hat{\sigma}_s$ vall shear stress R flex ratio $\hat{\sigma}_t$ turbulent integral time scale R_{ewall} wall Reynolds number φ_{eff} effective thermal conductivity $S_{L,conv}$ source term of convective heat transfer φ_l thermal conductivity S_L iurbulent Schmidt number φ_t turbulent thermal conductivity S_L laminar flame speed φ_T rate factor for corrected heat-transfer coefficient.	P_{H_2O}	water vapor partial pressure	λ	mean free path
$\begin{array}{ c c c } & \mbox{stresses} & μ_l molecular viscosity \\ & multiple transfer of the structural surface of the structural surface subset of the structural subset of the structural subset of the structural subset of the str$	P_k	turbulent kinetic energy production by viscous	μ_{eff}	effective viscosity
P_{kb} turbulent kinetic energy production by buoyant forces μ_t turbulent viscosity P_{T_t} turbulent Prandtl number ρ_{H_2O} water vapor density in the gas mixture $p_{s,saturation}$ saturation pressure at the surface temperature p_{sat} ρ_{H_2O} water vapor density in the gas mixture p_{sat} saturation pressure σ Stefan-Boltzmann constant q_i radiation flux vector σ_b constant coefficient $q_{s,conv}$ energy delivered to the structural surfaces by steam phase change σ_c constant coefficient R_{ewall} flex ratioourset transfer ϕ_{eff} effective thermal conductivity $S_{L,conv}$ source term of convective heat transfer ϕ_l turbulent integral time scale R_{ewall} source term of internal energy ϕ_{eff} effective thermal conductivity S_L laminar flame speed ϕ_r rate factor for corrected heat-transfer coefficient.		stresses	μ_l	molecular viscosity
forces ν molecular kinetic viscosity Pr_t turbulent Prandtl number ρ_{H_2O} water vapor density in the gas mixture $p_{s,saturation}$ saturation pressure at the surface temperature $\rho_{s,saturation}$ the saturation water vapor density at the p_{sat} saturation pressure $\sigma_{s,saturation}$ Structural surface conditions q^A internal energy flux vector σ_{b} Stefan-Boltzmann constant q_i radiation flux vector σ_b constant coefficient $q_{s,conv}$ energy delivered to the structural surfaces by convection σ_e constant coefficient $q_{s,cond/vap}$ energy delivered to the structural surfaces by steam phase change δ_c chemical time scale R flex ratio σ_e constant coefficient R_{ewall} wall Reynolds number ϕ_{eff} effective thermal conductivity $S_{L,conv}$ source term of convective heat transfer ϕ_l thermal conductivity S_L source term of internal energy ϕ_T rate factor for corrected heat-transfer coefficient S_L laminar flame speed ϕ_T rate factor for corrected heat-transfer coefficient	P_{kb}	turbulent kinetic energy production by buoyant	μ_{t}	turbulent viscosity
Pr_t turbulent Prandtl number ρ_{H_2O} water vapor density in the gas mixture $p_{s,saturation}$ saturation pressure at the surface temperature $\rho_{s,saturation}$ the saturation water vapor density at the p_{sat} saturation pressure $\sigma_{s,saturation}$ the saturation water vapor density at the q_rA internal energy flux vector σ Stefan-Boltzmann constant q_i radiation flux vector σ_b constant coefficient $q_{s,conv}$ energy delivered to the structural surfaces by convection σ_e constant coefficient $q_{s,cond/vap}$ energy delivered to the structural surfaces by steam phase change δ_c chemical time scale R flex ratio σ_t turbulent integral time scale Re_{wall} wall Reynolds number φ_{eff} effective thermal conductivity $S_{I,conv}$ source term of convective heat transfer φ_l turbulent thermal conductivity S_I source term of internal energy ϕ_T rate factor for corrected heat-transfer coefficient. S_L laminar flame speed ϕ_T rate factor for corrected heat-transfer coefficient.		forces	ν	molecular kinetic viscosity
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$\begin{array}{llllllllllllllllllllllllllllllllllll$	p _{s,saturati}	ion saturation pressure at the surface temperature	$ ho_{ m s,saturatio}$	<i>m</i> the saturation water vapor density at the
$ \begin{array}{cccc} \mathbf{q} \cdot \mathbf{A} & \mbox{internal energy flux vector} & \sigma & \mbox{Stefan-Boltzmann constant} \\ \mathbf{q}_i & \mbox{radiation flux vector} & \sigma_b & \mbox{constant coefficient} \\ \mathbf{q}_{s,conv} & \mbox{energy delivered to the structural surfaces by} & \sigma_k & \mbox{constant coefficient} \\ \mbox{convection} & \sigma_e & \mbox{constant coefficient} \\ \mathbf{q}_{s,cond/vap} & \mbox{energy delivered to the structural surfaces by} & \hat{\sigma}_e & \mbox{constant coefficient} \\ \mathbf{q}_{s,cond/vap} & \mbox{energy delivered to the structural surfaces by} & \hat{\sigma}_e & \mbox{constant coefficient} \\ \mathbf{q}_{s,cond/vap} & \mbox{energy delivered to the structural surfaces by} & \hat{\sigma}_c & \mbox{chemical time scale} \\ \mbox{steam phase change} & \hat{\sigma}_s & \mbox{wall shear stress} \\ \mathbf{R} & \mbox{flex ratio} & \mbox{flex ratio} & \hat{\sigma}_t & \mbox{turbulent integral time scale} \\ \mbox{Rewall} & \mbox{wall Reynolds number} & \mbox{φ_{eff} & effective thermal conductivity} \\ \mbox{Sl}_{conv} & \mbox{source term of convective heat transfer} & \mbox{φ_l & \mbox{turbulent thermal conductivity} \\ \mbox{Sl}_t & \mbox{source term of internal energy} & \mbox{φ_t & \mbox{turbulent thermal conductivity} \\ \mbox{Sl}_L & \mbox{luminar flame speed} & \mbox{φ_T & \mbox{rate factor for corrected heat-transfer coefficient} \\ \end{tabular}$	$p_{\rm sat}$	saturation pressure		structural surface conditions
$ \begin{array}{ccc} q_{i} & \mbox{radiation flux vector} & \sigma_{b} & \mbox{constant coefficient} \\ q_{s,conv} & \mbox{energy delivered to the structural surfaces by} & \sigma_{k} & \mbox{constant coefficient} \\ convection & \sigma_{e} & \mbox{constant coefficient} \\ q_{s,cond/vap} & \mbox{energy delivered to the structural surfaces by} & \hat{\sigma}_{c} & \mbox{chemical time scale} \\ q_{s,cond/vap} & \mbox{energy delivered to the structural surfaces by} & \hat{\sigma}_{c} & \mbox{chemical time scale} \\ steam phase change & \hat{\sigma}_{s} & \mbox{wall shear stress} \\ R & \mbox{flex ratio} & \mbox{flex ratio} & \hat{\sigma}_{t} & \mbox{turbulent integral time scale} \\ Re_{wall} & \mbox{wall Reynolds number} & \mbox{g}_{eff} & \mbox{effective thermal conductivity} \\ S_{I,conv} & \mbox{source term of convective heat transfer} & \mbox{g}_{l} & \mbox{turbulent thermal conductivity} \\ S_{C} & \mbox{turbulent Schmidt number} & \mbox{g}_{t} & \mbox{turbulent thermal conductivity} \\ S_{I} & \mbox{source term of internal energy} & \mbox{g}_{T} & \mbox{rate factor for corrected heat-transfer coefficient} \\ S_{L} & \mbox{luminar flame speed} & \mbox{source term of internal energy} & \mbox{g}_{T} & source $	q∙A	internal energy flux vector	σ	Stefan–Boltzmann constant
$\begin{array}{llllllllllllllllllllllllllllllllllll$	q_i	radiation flux vector	σ_{b}	constant coefficient
$ \begin{array}{c} \mbox{convection} & \mbox{convection} & \mbox{seam} & \mbox{convection} & \mbox{seam} & \mbox{seam} & \mbox{phase} & \mbox{change} & \mbox{seam} & \mbox{phase} & \mbox{change} & \mbox{seam} & \mbox{phase} & \mbox{change} & \mbox{seam} & sea$	q _{s,conv}	energy delivered to the structural surfaces by	σ_k	constant coefficient
$\begin{array}{ll} q_{s,cond/vap} & \text{energy delivered to the structural surfaces by} & \hat{o}_c & \text{chemical time scale} \\ & \text{steam phase change} & \hat{o}_s & \text{wall shear stress} \\ \hline R & \text{flex ratio} & \hat{o}_t & \text{turbulent integral time scale} \\ \hline Re_{wall} & \text{wall Reynolds number} & \varphi_{eff} & \text{effective thermal conductivity} \\ \hline S_{I,conv} & \text{source term of convective heat transfer} & \varphi_l & \text{thermal conductivity} \\ \hline Sc_t & \text{turbulent Schmidt number} & \varphi_t & \text{turbulent thermal conductivity} \\ \hline S_I & \text{source term of internal energy} & \varphi_T & \text{rate factor for corrected heat-transfer coefficient.} \\ \hline S_L & \text{laminar flame speed} \end{array}$		convection	σ_{ϵ}	constant coefficient
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$ \begin{array}{ll} S_{I,conv} & \text{source term of convective heat transfer} & \varphi_l & \text{thermal conductivity} \\ Sc_t & \text{turbulent Schmidt number} & \varphi_t & \text{turbulent thermal conductivity} \\ S_I & \text{source term of internal energy} & \phi_T & \text{rate factor for corrected heat-transfer coefficient.} \\ S_L & \text{laminar flame speed} & \end{array} $	Re _{wall}	wall Reynolds number	φ_{eff}	effective thermal conductivity
Sc_tturbulent Schmidt number φ_t turbulent thermal conductivityS_Isource term of internal energy ϕ_T rate factor for corrected heat-transfer coefficient.S_Llaminar flame speed	S _{I,conv}	source term of convective heat transfer	φ_l	thermal conductivity
S_I source term of internal energy ϕ_T rate factor for corrected heat-transfer coefficient. S_L laminar flame speed	Sct	turbulent Schmidt number	φ_{t}	turbulent thermal conductivity
S _L laminar flame speed	SI	source term of internal energy	ϕ_{T}	rate factor for corrected heat-transfer coefficient.
	SL	laminar flame speed		

Introduction

Hydrogen safety analysis has become one of the important tasks for nuclear safety engineers especially after the energetic hydrogen explosions occurred at the nuclear power plants at Fukushima Daiichi in 2011. Complex physical phenomena are involved in the nuclear reactor containment during the severe accident, such as flashing of water, turbulent flow, convection heat transfer, radiation heat transfer, steam condensation and evaporation, heat conduction in solid structure, hydrogen deflagration and detonation, Download English Version:

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