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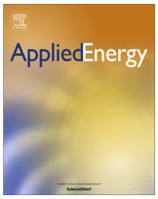

Heat transfer in hcci phenomenological simulation models: A review

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HIGHLIGHTS

- Conventional heat transfer correlations are inadequate for HCCI combustion.
- Single-zone heat transfer is inherently coupled to ignition and combustion.
- The main difficulty is the difference between mean-gas and local max temperature.
- Multi-zone models should use a control volume approach near the cylinder wall.
- Inter-zonal and wall heat transfer should be coupled.

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ABSTRACT

This study presents a review of the heat transfer treatment in HCCI phenomenological simulation models, including single-zone and multi-zone ones. Heat transfer within the combustion chamber is significant when modeling the internal combustion engine in general and the HCCI combustion process in particular. It determines to a great extent the temperature field within the combustion chamber throughout the engine operating cycle, and especially during compression and combustion. In HCCI engines, combustion relies upon the auto-ignition of a premixed charge that is present for most—if not all—of the compression stroke. In this combustion mode the heat transfer process directly affects mean gas and local temperatures, thereby influencing ignition timing, combustion rate and the formation of HC, CO and NO_x emissions. The success of any simulation model in describing or predicting the HCCI combustion process and emissions formation evidently depends partly on its ability to reliably predict the heat transfer phenomena involved.

Despite the importance of the heat transfer process in HCCI simulation, little progress has been made in the past years, compared to the advances that have been achieved experimentally. Moreover, the information regarding phenomenological heat transfer treatment is scattered. The aforementioned provided the motivation for this review that provides initially a critical outlook on the heat transfer correlations that were derived for conventional combustion modes, since these correlations have been—and are still—used frequently in HCCI simulation models. The underlying assumptions of these correlations and the conditions under which they were validated are explicitly stated, in order to appraise their suitability in HCCI phenomenological simulations. Heat transfer treatment in single-zone and multi-zone models is presented subsequently, including HCCI-specific correlations that have been developed in the past years. Issues such as zone configuration, wall heat transfer correlations based on global or local gas properties, and inter-zonal heat transfer are discussed. Moreover, comparative studies that evaluate the relative effectiveness of different correlations are presented. The study concludes with general remarks on phenomenological heat transfer simulation and with suggestions for further research.

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Nomenclature

a, a'	heat transfer constants
A	area (m^2)
b	heat transfer constant
D	cylinder bore (m)
C, c, c_1, c_2	heat transfer constants
C_f	combustion factor
C_u	characteristic velocity coefficient
h	heat transfer coefficient (W/m^2 K), molar specific enthalpy (kJ/kmol)
k	thermal conductivity (W/m K)
L	characteristic length (m)
m	mass (kg)
P, p	pressure (Pa)
$\dot{q}$	heat flux (W/m^2)
$\dot{Q}_g$	gross heat release rate (W)
$\dot{Q}_n$	net heat release rate (W)
$\dot{Q}_w$	wall heat loss rate (W)
Q_i	net heat gained by zone i (kJ)
r	distance (m)
T	(absolute) temperature (K)
t	thickness (m)
u	velocity (m/s)
u_f	flow velocity factor
$\bar{u}_p$	mean piston speed (m/s)
U	internal energy (J)
V	volume (m^3)
y	distance (m)
W	work (J)
z	number of zones

Greek

η_{sc}	scavenging efficiency (–)
θ	angle
κ	von Kármán constant (=0.41)
λ	air-fuel equivalence ratio
μ	dynamic viscosity (kg/(m s))
ν	kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
σ	Stefan–Boltzman constant $5.67 \cdot 10^{-8}$ (W/(m^2 K^4))
ϕ	fuel-air equivalence ratio
ω	angular velocity (rad/s)

Subscripts

bl	boundary layer
cl	coolant
cr	crevice
cyl	cylinder
d	displacement
f	flow
g	gas
i	any zone
j	any location on the combustion chamber wall
l	laminar
mot	motoring
n	normal
out	outflow
r	reference
rad	radiation
t	turbulent
tot	total
w	wall

Superscripts

$*$	characteristic value
$+$	dimensionless value

Dimensionless numbers

Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number

Abbreviations

AF	air-fuel ratio
CA	crank angle
CFD	computational fluid dynamics
CFR	cooperative fuel research
CI	compression-ignition
CR	compression ratio
CV	control volume
DI	direct injection
DICI	direct injection compression-ignition
EGR	exhaust gas recirculation
EVO	exhaust valve opening
HC	(unburned) hydrocarbons
HCCI	homogeneous charge compression ignition
HRR	heat release rate
IMEP	indicated mean effective pressure
IVC	inlet valve closing
MZ	multi-zone
NA	naturally aspirated
NG	natural gas
QLT	qualitative
QNT	quantitative
RG	reformer gas
SC	supercharged
SI	spark-ignition
SZ	single-zone
TDC	top dead center

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