Nuclear Engineering and Design 286 (2015) 18–26

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

A droplet entrainment model for horizontal segregated flows

Thomas Höhne [a,*], Susann Hänsch [b]

[a] Helmholtz-Zentrum Dresden-Rossendorf (HZDR) – Institute of Fluid Dynamics, P.O. Box 510119, D-01314 Dresden, Germany
[b] Imperial College, Department of Mechanical Engineering, South Kensington Campus, London SW7 2AZ, UK

HIGHLIGHTS

- We further developed the flow morphology detection model AIAD.
- An advanced droplet entrainment model was introduced.
- The new approach is applied against HAWAC experiments.

ARTICLE INFO

Article history:
Received 16 December 2013
Received in revised form 12 January 2015
Accepted 27 January 2015

ABSTRACT

One limitation in simulating horizontal segregated flows is that there is no treatment of droplet formation mechanisms at wavy surfaces. For self-generating waves and slugs, the interfacial momentum exchange and the turbulence parameters have to be modeled correctly. Furthermore, understanding the mechanism of droplet entrainment for heat and mass transfer processes is of great importance in the chemical and nuclear industry.

The development of general computational fluid dynamics models is an essential precondition for the application of CFD codes to the modeling of flow related phenomena. The new formulation for the interfacial drag at the free surface and turbulence parameters within the algebraic interfacial area density model (AIAD) represents one step toward a more physical description of free surface flows including less empiricism. The AIAD approach allows the use of different physical models depending on the local fluid morphology inside a macro-scale multi-fluid framework.

A further step of improving the modeling of free interfaces lies within the consideration of droplet entrainment mechanisms. In this paper a new sub-grid entrainment model is proposed, which assumes that due to liquid turbulence the interface gets rough and wavy leading to the formation of droplets. Therefore, the droplet entrainment model requires the consideration of an additional droplet phase, which is described with an own set of balance equations in the spirit of the particle model. Two local key factors determine the rate of droplet entrainment: the liquid turbulent kinetic energy as well as the outward velocity gradient of the liquid relative to the interface motion. The new droplet entrainment approach is included into CFD simulations for attempting to reproduce existing horizontal two-phase flow data from the HAWAC channel. The computational results are in reasonable agreement with the experimentally observed data.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

For heat and mass transfer processes in two-phase flow systems an understanding of the conditions leading to entrainment of a liquid surface film by a gas flow is of considerable practical importance. The mechanisms of mass, momentum, and energy transfer is significantly altered by the inception of entrainment (Ishii and Grolmes, 1975). A wavy liquid surface can be entrained into a gas flow in different ways. Hydrodynamic and surface forces govern the motion and deformation of the wave crests. One example of droplet formations at the wave crest is shown in Fig. 1 for slug flow condition at the HAWAC channel (Vallée et al., 2008).

Under certain conditions, these forces lead to an extreme deformation of the interface, which results in the breakup of a portion of a wave into several droplets. The forces acting on the wave crests depend on the surrounding flow pattern as well as on the shape of the interface. Ishii and Grolmes (1975) explain the five basic types of entrainment mechanisms, which are shown in Fig. 2. In the first

* Corresponding author. Tel.: +49 3512602425.
E-mail address: T.Hoehne@hzdr.de (T. Höhne).

http://dx.doi.org/10.1016/j.nucengdes.2015.01.013
0029-5493/© 2015 Elsevier B.V. All rights reserved.

Nomenclature

σ	surface tension coefficient of the fluid (N/m)
Φ	interface layer (m)
ν	kinematic viscosity (m^2/s)
$\dot{V}$	volumetric flow rate (m^3/s)
A	interfacial area density (1/m)
a	surface roughness (m)
A_{Ave}	average cross sectional area (m^2)
C	constant (–)
c	critical velocity (m/s)
C_D	drag coefficient (–)
d	local deposition rate (m/s)
d	diameter (m)
D	droplet formation rate per unit volume and time (1/s)
f	blending function (–)
F	force (N)
Fr	Froude number (–)
g	constant of gravity acceleration (m/s^2)
h	height (m)
k	turbulent kinetic energy (m^2/s^2)
L	length scale (m)
$\boldsymbol{n}$	normal vector of the interface (–)
P	production term turbulent kinetic energy (m^2/s^2)
P	pressure (Pa)
Pr	Prandtl number (–)
q	turbulent velocity (m^2/s^2)
Re	Reynolds number (–)
$S_{i,j}$	strain rate (–)
T	temperature (K)
t	time (s)
$\boldsymbol{U}$	slip velocity (m/s)
u, v, w	velocity in x, y, z-direction (m/s)
We	Weber number (–)
α	volume fraction (–)
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
τ	shear stress (Pa)

Subscript

B	bubble
D	drop
c	channel
FS	free surface
G	gas
i	phase index
L	liquid
l	lower boundary
s	superficial
SWT	sub-grid wave turbulence
t	turbulent
u	upper boundary
W	wall

type the tops of large amplitude roll waves are sheared off from the wave crests by the turbulent gas flow (Hewitt and Hall-Taylor, 1970). The drag force acting on the wave tops deforms the interface against the retaining force of the liquid surface tension. The second type of entrainment is caused by undercutting the liquid film by a gas flow (Hewitt and Hall-Taylor, 1970). The third type is related to the bursting of gas bubbles. It was shown by Newitt et al. (1954) that drops can be generated by a bubble rising to the surface of a liquid. The fourth type of entrainment is caused by the impingement of liquid drops or mass to the film interface. Advancing roll-wave fronts may produce small size droplets by this mechanism. A universal droplet entrainment model should cover all of these cases.

Fig. 1. Droplet formation at the wave crest (slug flow condition at HAWAC channel).

2. Algebraic interfacial area density model

The AIAD model was developed in close cooperation by ANSYS and HZDR and is described in Yegorov and Menter (2004), Höhne and Vallée (2010), Höhne et al. (2011) and Höhne (2013).

The basic idea of the AIAD model is:

- The interfacial area density (IAD) allows the detection of the morphological form and the corresponding switch of each correlation from one object pair to another.
- It provides a law for the interfacial area density and the drag coefficient for a full range of phase volume fractions from no liquid to no gas.
- The model improves the physical modeling in the asymptotic limits of bubbly and droplet flows.
- The interfacial area density in the intermediate range is set to the interfacial area density for free surface.

The approach used in the AIAD model is to define blending functions depending on the volume fraction that enable switching

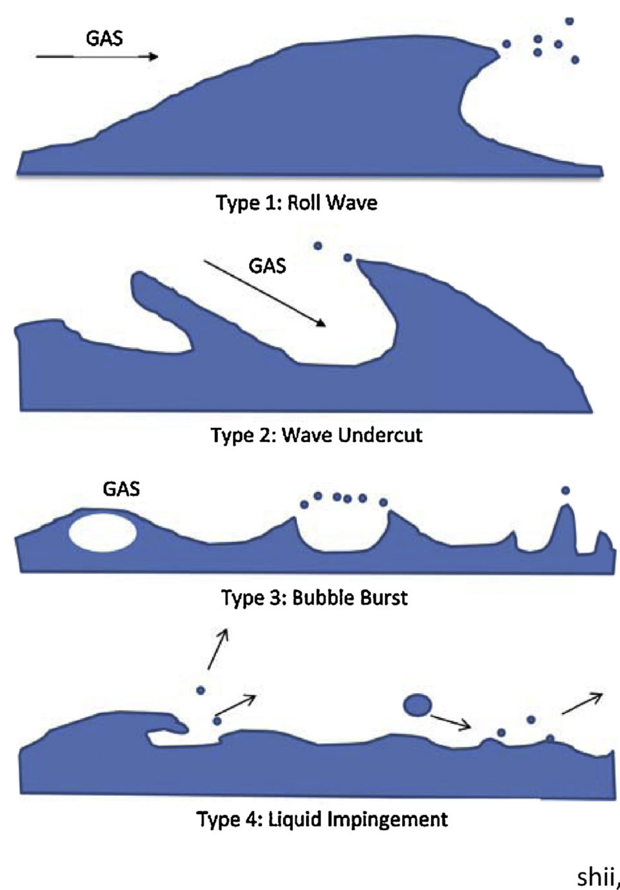

Fig. 2. Different droplet entrainment mechanisms (Ishii and Grolmes, 1975).

Download English Version:

https://daneshyari.com/en/article/6761270

Download Persian Version:

https://daneshyari.com/article/6761270

Daneshyari.com