UNIVERSITI PUTRA MALAYSIA

SIMULATION OF LIQUID-LIQUID DISPERSED FLOW IN HORIZONTAL PIPE USING COMPUTATIONAL FLUID DYNAMICS

RASHMI G WALVEKAR

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

February 2007

MOHD KHALID MASTERS OF SCIENCE 2006

A COMPARATIVE STUDIES ON POLYPROPYLENE-CELLULOSE AND POLYPROPYLENE- OIL PALM EMPTY FRUITBUNCH BIOCOMPOSITES

MOHD KHALID

MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA

July 2006

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DEDICATED TO MY FAMILY

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment
of the requirement for the degree of Master of Science

SIMULATION OF LIQUID-LIQUID DISPERSED FLOW IN HORIZONTAL PIPE USING COMPUTATIONAL FLUID DYNAMICS

By

RASHMI G WALVEKAR

February 2007

Chairman : Siti Aslina Hussain, PhD

Faculty : Engineering

Liquid-liquid dispersed flows are commonly encountered in many of the industrial applications such as polymerization, emulsification, batch and continuous stirred reactors and pipeline flows such as in petroleum industries. Liquid-liquid two phase flows are very complex due to the existence of several flow patterns and mechanisms. Numerical approaches offer the flexibility to construct computational models which can adapt large variety of physical conditions without constructing large scale prototypes.

The present work focuses on predicting the phase hold-up across a pipe cross-section and *ambivalence range* for phase inversion phenomena at different mixture velocity and range of input water fraction. The Computational Fluid Dynamics (CFD) computations were carried using FLUENT 6.2.16 while the geometry was created in pre-processor, GAMBIT 2.2.3. Dispersed phase dynamics and the turbulent continuous phase are modeled using an Eulerian-Eulerian approach and standard $k-\varepsilon$ turbulence model. To check the reliability of the CFD code, the predicted results were validated with experimental results of previous work at different mixture velocities and phase fractions.

CFD predicted the flow phenomenon such as phase transition from water-in-oil dispersion to oil-in-water dispersion and flow development along the length of the pipe. CFD code also predicted the phase hold-up distributions at pipe cross section. The pressure gradient trends similar to those observed in previous experimental results were obtained using CFD code. The phase inversion point obtained was within the ambivalence range suggested in literature. The numerical CFD simulations also confirmed that interphase drag, lift and turbulent dispersion forces has significant influence on spatial phase distribution. CFD simulations so obtained were subsequently compared with experimental results from previous researchers and correlation featuring range of mixture velocities and phase inputs. The predicted hold-up profiles were in good agreement with the previous experimental results for high mixture velocities and were in reasonable agreement with those of lower mixture velocity. Overall good qualitative agreement was achieved between physical model and simulated results.

Abstrak tesis ini dikemukakan kepada Senat Universiti Putra Malaysia sebagai
memenuhi keperluan untuk ijazah Master Sains

SIMULASI ALIRAN SERAKAN BENDALIR DIDALAM PAIP MENDATAR MENGGUNAKAN PENGIRAN DINAMIK BENDALIR

Oleh

RASHMI G WALVEKAR

Februari 2007

Pengerusi : Siti Aslina Hussain, PhD

Fakulti : Kejuruteraan

Kebanyakan aliran tersebar pelbagai cecair boleh ditemui dalam pelbagai aplikasi industri seperti pempolimeran, pengemulsifikasian, reaktor teraduk aliran kelompok dan aliran terus serta aliran dalam paip yang biasanya ditemui dalam industri petroleum. Sistem aliran cecair dua fasa adalah sangat rumit disebabkan kewujudan pelbagai corak aliran dan mekanisme. Pendekatan secara numerikal menawarkan fleksibiliti untuk membina model pengiraan yang berpadanan dengan pelbagai keadaan fizikal tanpa keperluan untuk membina prototaip yang sebenar.

Kajian ini tertumpu kepada pengramalan isi tertahan fasa yang berlaku pada keratan rentas paip dan julat ambivalens untuk fenomena penyonsangan fasa pada halaju bancuhan serta julat masukan pecahan air yang berlainan. Komputasi CFD dilakukan menggunakan FLUENT 6.2.16 manakala geometri dihasilkan menggunakan GAMBIT 2.2.3. Dinamik fasa sebaran dan fasa pengeloraan berterusan diselesaikan menggunakan model Eulirian-Eulerian dan model pengeloraan piawaian, $k-\varepsilon$.

Untuk menentusahkan kebolehpercayaan kod CFD, keputusan pengramalan telahpun dibandingkan dengan keputusan eksperimen daripada kerja-kerja terdahulu.

CFD meramalkan fenomena pengaliran seperti peralihan fasa dari penyebaran air-dalam-minyak kepada minyak-dalam air dan perkembangan aliran sepanjang paip. Kod CFD juga meramalkan pengagihan isi tertahan fasa pada keratan rentas paip dan memberikan trend kecerunan tekanan yang serupa dengan yang diperhatikan dalam kerja-kerja eksperimen terdahulu. Titik penyongsangan fasa yang diramalkan juga didapati berada dalam julat ambivalens yang dicadangkan oleh bahan rujukan. Simulasi numerikal CFD juga menentusahkan seretan antara fasa, apungan dan daya penyebaran pergolakan mempengaruhi ruangan taburan fasa. Simulasi CFD juga dibandingkan dengan keputusan eksperimen daripada penyelidik-penyelidik terdahulu dan korelasi pada halaju adukan dan input fasa yang berlainan. Pengramalan ke atas profil isi tertahan adalah berserasi dengan keputusan eksperimen yang dijalankan pada halaju adukan tinggi dan agak berserasi dengan yang dijalankan pada halaju adukan rendah. Secara keseluruhan, keserasian kualitatif yang tinggi wujud antara model fizikal dan keputusan simulasi.

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I certify that the Examination Committee met on 16.02.2007 to conduct the final examination of Rashmi G Walvaker on her Master of Science in Environmental Engineering thesis entitled “Simulation of Liquid-Liquid Dispersed Flows in Horizontal Pipe Using CFD” in accordance with Universiti Pertanian Malaysia (Higher degree) Act 1980 and Universiti Pertanian Malaysia (Higher degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

RASHMI G WALVEKAR

Date:

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A	Flow area	[m^2]
C_{DM}	Drag coefficient in the presence of adjacent drops	[-]
C_{D0}	Drag coefficient	[-]
C_L	Lift coefficient	[-]
$C_{1\varepsilon}, C_{2\varepsilon}, C_{\mu}, C_{v}$	Model constants	[-]
D	Pipe diameter	[m]
D'	Diffusivity	[m^2/s]
D_t	Disersed phase turbulent viscosity	[kg/ms]
D	Drop diameter	[mm]
d_e	Equivalent drop diameter	[mm]
d_{32}	Sauter mean drop diameter	[mm]
d_{10}	Linear mean drop diameter	[mm]
d_j	Drop diameter of size j	[mm]
d_i	Drop diameter of sampling size interval i	[mm]
$d_{\max}$	Maximum drop diameter	[mm]
F	Force	[N/m]
F_D	Drag force	[N/m]
F_L	Lift force	[N/m]
F_{vm}	Virtual mass force	[N/m]
F	Friction factor	[-]
G	Acceleration due to gravity (= 9.81)	[m/s^2]

G_k	Generation of turbulent kinetic energy	$[N/m^2s]$
H	Dimensionless height ratio	[-]
I	Turbulence intensity	[-]
K	Turbulent kinetic energy	$[m^2/s^2]$
k_c	Turbulent kinetic energy of continuous phase	$[m^2/s^2]$
k'	Consistency factor	[-]
k_{pq}	Interphase exchange coefficient	[-]
K_L	Mass transfer coefficient	$[kg/m^2s]$
L	Pipe length	$[m]$
L_t	Length scale of turbulent eddies	$[m]$
L	Turbulent length scale	$[m]$
$\dot{m}$	Mass flow rate	$[kg/s]$
N	Number of drops in distribution	[-]
n'	Power law index	[-]
n_i	Number of drops in interval *i*	[-]
P	Pressure	$[N/m^2]$
R	Pipe roughness	[-]
Re	Reynolds number	[-]
Re_c	Reynolds number of continuous phase	[-]
Re_y	Near wall Reynolds number	[-]
Re_{flow}	Flow Reynolds number	[-]
Re_{DH}	Reynolds number using hydraulic diameter	[-]
S	Slip ratio	[-]

$S_\varphi, S_k, S_\varepsilon$	Source terms	$[kg/m^2s]$
T	Time	[*sec*]
U_{sc}	Continuous phase superficial velocity	[*m/s*]
U	Velocity	[*m/s*]
U_c	Continuous phase velocity	[*m/s*]
U_*	Velocity	[*m/s*]
U'_f	Turbulent velocity fluctuation	[*m/s*]
U_x	Velocity in x direction	[*m/s*]
U_y	Velocity in y direction	[*m/s*]
U_z	Velocity in z direction	[*m/s*]
U_{mix}	Mixture velocity	[*m/s*]
U_s	Superficial velocity	[*m/s*]
V_s	Slip velocity	[*m/s*]
V	Velocity of phases	[*m/s*]
v_{dr}	Drift velocity	[*m/s*]
y_w	Distance from pipe wall	[*m*]
X	Martinelli and Lockhart parameter	[-]
Y^+	Wall function	[-]

Greek Symbols

α	Volume fraction/ Hold-up	[-]
α_c	Continuous phase volume fraction	[-]

α_d	Dispersed phase volume fraction	[-]
ε_M	Mean rate of energy dissipation per unit mass in pipe flow	[m^2/s^3]
ε_l	Local rate of energy dissipation per unit mass in pipe flow	[m^2/s^3]
τ_t	Characteristic time of energetic eddies in turbulent flow	[s]
θ	Angle between mean dispersed phase velocity and mean relative velocity	[deg]
τ_F	Characteristic particle relaxation time	[s]
μ	Viscosity	[kg/ms]
μ_t	Turbulent viscosity	[kg/ms]
μ_g	Viscosity of gas phase	[kg/ms]
μ_l	Viscosity of liquid phase	[kg/ms]
μ_c	Viscosity of continuous phase	[kg/ms]
ρ	Density	[kg/m^3]
ρ_c	Density of continuous phase	[kg/m^3]
ρ_g	Density of gas phase	[kg/m^3]
ρ_l	Density of liquid phase	[kg/m^3]
ρ_d	Density of dispersed phase	[kg/m^3]
σ_{pr}	Dispersion Prandtl number	[-]
$\sigma_k, \sigma_\varepsilon$	Model constants	[-]
λ	Coefficient of resistance	[-]