Nozzle and Jet Studies

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Outlines

• Mercury Flow in Target Delivery Pipe (Without Weld)
• Mercury Flow in Target Delivery Pipe (With Weld)
• Jet Flow Using CLSVOF in FLUENT
  — Coupled Level Set Volume of Fluid (CLSVOF)
  — ANSYS FLUENT
• Computational Fluid Dynamics (CFD) code used for simulation, visualization and prediction of fluid flow, heat and mass transfer as well as reactions
• User Defined Function (UDF) gives user rights to define his own functions in C language.
Hg Flow in Target Delivery Pipe Without Weld (1)

Fig. 1 Target supply pipe of the MERIT experiment

Fig. 2 Configurations of pipes investigated

Most interested Weld located
Hg Flow in Target Delivery Pipe Without Weld (2)

- **Theoretical analysis (laminar flow)**
  - Assessment of the extra terms

- **Numerical simulations (turbulent flow)**
  - Evaluation of turbulent models: Realizable k-ε (RKE)
  - Numerical solutions for the studied eight geometries
    - Axial velocity distribution
      \[ U^* = \frac{U}{U_b}, \text{ where } U_b \equiv \frac{\int ud\Omega}{|\Omega|} \]
    - Momentum thickness distribution at the exit (instability mode)
      \[ \theta_r = \int_0^a \frac{U}{U_{\text{max}}} (1 - \frac{U}{U_{\text{max}}}) dr \]
    - Turbulence intensity distribution at the exit (fluctuation)
      \[ I \equiv \frac{u'}{U_b} = \frac{\sqrt{2k/3}}{U_b} \]
Hg Flow in Target Delivery Pipe Without Weld (3)

The straight pipe with a convergent nozzle has the lowest intensity level at the exit plane.

Fig. 3 Turbulence level at the exit ($\varphi_{\text{with}} / \varphi_{\text{without}}$: Pipe of half bend angle $\varphi$ with/without a nozzle) (a) horizontal distribution, (b) vertical distribution

The straight pipe with a convergent nozzle has the lowest intensity level at the exit plane.

Fig. 4 Coordinates ($r, \theta, z$) defined for curved pipe

Convex(CV)  Concave(CC)
Hg Flow in Target Delivery Pipe With Weld (1)

Location of interests: welded-joint between items 2 and 3; item 2: Ti-6Al-4V; item 3: Ti Grade 2.
Hg Flow in Target Delivery Pipe With Weld (2)

- To understand the effect of bead geometry on the turbulence level of the flow at pipe exit.
  - Flat surface
  - Whole azimuthal weld with semi-circle cross section
    - Major radius = 0.884”
    - Minor radius = 1/16”
  - Partial azimuthal weld with semi-circle cross section
    - only has 30° of azimuth from −15° to +15° relative to “up”

Fig. 7 The semi-circle topology of the Weld
Hg Flow in Target Delivery Pipe With Weld (3)

Fig. 8 Three meshes for the 90°/90° pipe
Hg Flow in Target Delivery Pipe
With Weld (4)

Next: Run FLUENT in the Feynman Cluster At Princeton University

Fig. 9 Comparison among three meshes (a) U* (b) Turbulence Intensity (TI)

Fig. 10 Comparison for pipes with/without a weld for mesh 1 (a) U* (b) Turbulence Intensity (TI)
Jet Flow Using CLSVOF in FLUENT (1)

![Image of liquid jet development](image)

**Volume of Fluid (VOF)**

Volumetric phase fraction $F$
- Phase 1: $F=1$
- Phase 2: $F=0$
- Interface: $0<F<1$

**Level Set (LS)**

Level-Set function $\Phi$
- Phase 1: $\Phi>0$
- Phase 2: $\Phi<0$
- Interface: $\Phi=0$

**Fig. 11 (a) Development of the liquid jet (time step is 2.5 \(\mu\)m) (Menard, 2007)**

<table>
<thead>
<tr>
<th>Jet characteristics</th>
<th></th>
<th>Turbulent intensity</th>
<th>Turbulent length scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter, $D$ ((\mu)m)</td>
<td>Velocity (m s(^{-1}))</td>
<td>$u/U_{\text{liq}} = 0.05$</td>
<td>$0.1D$</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase</td>
<td>Density (kg m(^{-3}))</td>
<td>Viscosity (kg m(^{-1})s(^{-1}))</td>
<td>Surface tension (N m(^{-1}))</td>
</tr>
<tr>
<td>Liquid</td>
<td>696</td>
<td>$1.2 \times 10^{-3}$</td>
<td>0.06</td>
</tr>
<tr>
<td>Gas</td>
<td>25</td>
<td>$1 \times 10^{-5}$</td>
<td></td>
</tr>
</tbody>
</table>
Jet Flow Using CLSVOF in FLUENT (2)

Fig. 11 (b) Liquid jet surface and break-up near the jet nozzle

Fig. 11 (c) Liquid parcels
Jet Flow Using CLSVOF in FLUENT (4)

Initialization ➔ Start time loop ➔ Advection of $\phi$

Calculate $\kappa, \bar{n}$ from $\phi$

Get $u, P$, surface tension from N-S

Advection of $F$ and $\phi$

Couple LS and VOF $H(\phi) = F$

Reinitialisation of $\phi$

Time loop complete?

End

Nichita (2010)

$\kappa = \nabla \cdot \frac{\nabla \phi}{|\nabla \phi|}, \bar{n} = \frac{\nabla \phi}{|\nabla \phi|}$

$\rho(U_t + U \cdot \nabla U) = -\nabla P + \nabla \cdot (2\mu D) - \gamma \kappa \nabla H + G$

$\phi_t + U \cdot \nabla \phi = 0 \quad F_t + U \cdot \nabla F = 0$

$F_{ij} = \frac{1}{|\Omega_{ij}|} \int_{\Omega_{ij}} (H\phi)d\Omega_{ij}$

$\phi_t + \omega \cdot \nabla \phi = S(\phi^0)$, where $\omega = S(\phi^0) \frac{\nabla \phi}{|\nabla \phi|}$

$\rho = \rho_g (1 - H) + \rho_l H, \mu = \mu_g (1 - H) + \mu_l H$

$H(\phi) = \begin{cases} 0 & \text{if } \phi < -\varepsilon \\ \frac{(\phi + \varepsilon)/(2\varepsilon) + \sin(\pi \phi / \varepsilon)/(2\pi)} & \text{if } |\phi| < \varepsilon \\ 1 & \text{if } \phi > \varepsilon \end{cases}$

B. A. Nichita, 2010, An improved CFD tool to simulate adiabatic and diabatic two-phase flows
Jet Flow Using CLSVOF in FLUENT (5)

Finite Volume Discretization of Level Set Equation

\[ \phi_t + \nabla \cdot (U\phi - D_T \nabla \cdot \phi) = 0 \]

where \( D_T = 0.129 \bar{k}^2 / \varepsilon \)

- **Temporal Term** \( \phi_t \)
  3\textsuperscript{rd} order TVD R-K (total variation diminishing Runger-Kutta)

- **Convective Term** \( \nabla \cdot (U\phi) \)
  3\textsuperscript{rd} order ENO (Essentially Non-Oscillatory)

- **Diffusive Term** \( \nabla \cdot (D_T \nabla \cdot \phi) \)
  2\textsuperscript{nd} Central Difference