User manual for varRhoTurbVOF 2

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This user manual mainly introduces how to use some new functionalities added to varRhoTurbVOF [1].

1 Variable-density effect in turbulence modeling

A boolean variable, `varRho`, is defined with its default value set to true, meaning that the variable-density effect will be considered in turbulence models. Users can set it to false in `turbulenceProperties` such that the density field is set to unity during the turbulence modeling. For either approach, users need to make sure that the divergence schemes are set up properly in the `fvSchemes` file.

2 Turbulence damping modeling

The turbulence damping model is implemented as a `fvOptions` that works for both ω- and ϵ-based turbulence models. For the former, the following term is added to the ω equation [2, 3]

$$S_\omega = \mathrm{sign}(B)\frac{36B^2}{\beta\tilde{\rho}\Delta y^3}\left(\delta\frac{A_h\mu_h^2}{\rho_h} + \frac{A_l\mu_l^2}{\rho_l}\right), \tag{1}$$

where subscripts h and l denote the heavy phase and the light phase, respectively; $A_h = 2\alpha_h|\nabla\alpha_h|$ and $A_l = 2\alpha_l|\nabla\alpha_l|$ are interfacial area densities for the heavy phase and light phase, respectively; $\beta = 0.075$ is a coefficient in the turbulence model.

For ϵ-based turbulence models the following term is added to the ϵ equation [3, 4]

$$S_\epsilon = \mathrm{sign}(B)\frac{36B^2C_2C_\mu^2 k}{\beta^2\tilde{\rho}\Delta y^3}\left(\delta\frac{A_h\mu_h^2}{\rho_h} + \frac{A_l\mu_l^2}{\rho_l}\right), \tag{2}$$

where k is the turbulent kinetic energy; $C_2 = 1.92$ and $C_\mu = 0.09$ are coefficients in the turbulence model.

The turbulence damping model can operate in different modes based on the following parameters. We note that values of β, C_2 and C_μ can also be changed by the user. However, this is not recommended.

2.1 B

The damping factor B controls the magnitude of the source term. It should be noted that the value of B depends on both mesh sizes and flow conditions. Therefore, users are strongly advised to conduct a sensitivity study on it.

2.2 Δy

Δy is calculated in two ways based on the input parameter `lengthScale`

$$\Delta y = \begin{cases} \sqrt[3]{V}, & \text{if } \texttt{lengthScale} \text{ is set to ``cubeRoot''}, \\ \frac{V}{\frac{1}{2}\sum\limits_i |\boldsymbol{S}_i \cdot \boldsymbol{n}|}, & \text{if } \texttt{lengthScale} \text{ is set to ``FA''}, \end{cases} \tag{3}$$

where V is the volume of each discretized cell; $\boldsymbol{n}$ is the interface normal vector at the cell; $\boldsymbol{S}_i$ is the surface area vector of any face that surrounds the cell.

2.3 $\tilde{\rho}$

$\tilde{\rho}$ is introduced to allow the model to work no matter the variable-density effect is considered or not

$$\tilde{\rho} = \begin{cases} 1, & \text{if variable-density effect is considered}, \\ \rho, & \text{if variable-density effect is not considered}. \end{cases} \tag{4}$$

Instead of using a user input like `varRho`, the above switch condition is evaluated internally by checking the dimension of the solved equation.

2.4 δ

δ is calculated as follows based on a user input `dampingTreatment`

$$\delta = \begin{cases} 1, & \text{if } \texttt{dampingTreatment} \text{ is set to ``symmetric''}, \\ 0, & \text{if } \texttt{dampingTreatment} \text{ is set to ``heavyZero''}, \\ -\frac{\rho_h}{\rho_l}\frac{\mu_l^2}{\mu_h^2}, & \text{if } \texttt{dampingTreatment} \text{ is set to ``heavyNegative''}. \end{cases} \tag{5}$$

2.5 sign(B)

This is an experimental feature that will only be activated if `dampingTreatment` is set to "symmetric". In this cases, supplying a negative B will artificially increase the turbulence level.

2.6 Source term treatment

By default, S_ω and S_ϵ are added to the corresponding equations explicitly. Users can choose to add them implicitly by setting `explicitSourceTreatment` to false, if this enhances the stability.

3 Tutorial

A tutorial for this new version is provided in `tutorials/turbulenceDamping` folder. The tutorial is based on Run-250 in [5]. Simulations with model parameters given in Table 1 are run to demonstrate how to use the newly added functionalities. The `lengthScale` parameter is set to "FA" for all $B > 0$ cases.

A comparison for the calculated turbulent kinetic energy is given in Fig 1. It is clearly seen that, when the variable-density is neglected (case-1 and case-5), k profiles are totally mispreidicted. By considering the variable-density effect (case-2 and case-6), the abrupt change in k is qualitatively captured. Using the turbulence damping model with appropriate parameters, much better agreements with the experiment are obtained for the remaining cases.

Table 1: Case setups.

case	turbulence model	varRho	B	dampingTreatment
1	k-ω SST	false	0	-
2	k-ω SST	true	0	-
3	k-ω SST	false	135	heavyNegative
4	k-ω SST	true	120	heavyNegative
5	standard k-ϵ	false	0	-
6	standard k-ϵ	true	0	-
7	standard k-ϵ	false	75	heavyZero
8	standard k-ϵ	true	60	heavyZero

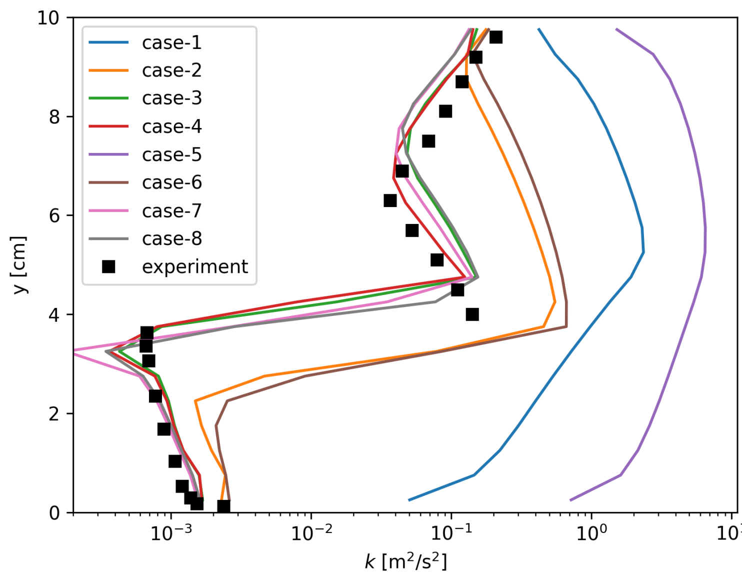

Figure 1: Coupling scheme for coupled simulations.

References

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[4] E.M.A. Frederix, A Mathur, D Dovizio, B.J. Geurts, and E.M.J. Komen. Reynolds-averaged modeling of turbulence damping near a large-scale interface in two-phase flow. *Nuclear Engineering and Design*, 333:122–130, 2018.

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