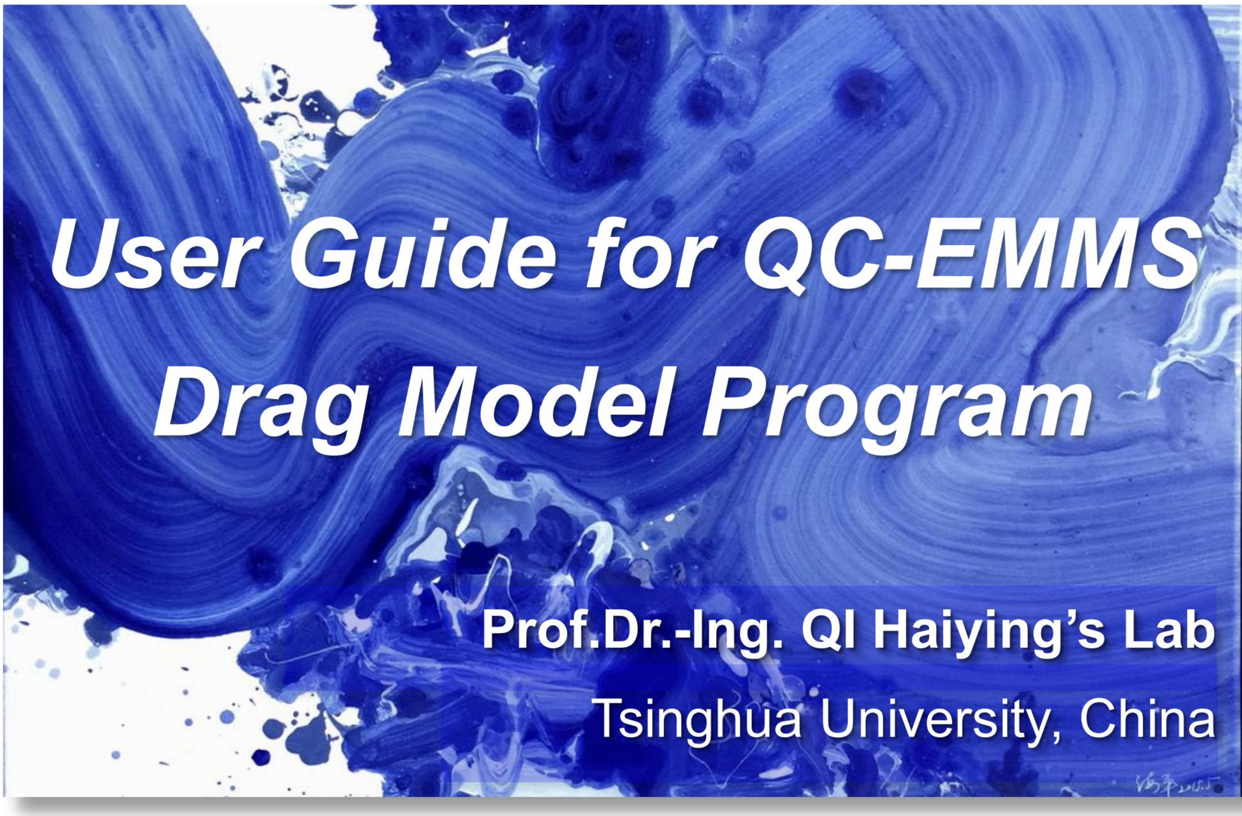
User Guide for QC-EMMS
Drag Model Program
Prof.Dr.-Ing. QI Haiying's Lab
Tsinghua University, China

1. Brief Introduction

QC-EMMS is a gas-solid drag model that considers the remarkable effects of particle clusters during the heterogeneous flow in CFB (Circulating Fluidized Bed). It was developed based on the Energy Minimization in Multi-Scale (EMMS) theory[1]. The QC-EMMS model has shown good accuracy in CFB simulations under a wide range of flow conditions[2-5].

To further extend the model, we uploaded this program to the open-source platform Github. Welcome worldwide scholars to download and use it !

Link: https://github.com/CFACTtsinghua/QC-EMMS

The input parameters are limited to certain ranges in this **trial version**. Welcome to contact us for using the full version and getting more supports!

Contact:

Mr. LIU Yang, yang-liu17@mails.tsinghua.edu.cn

Mr. SONG Yinqiang, syq20@mails.tsinghua.edu.cn

References

[1] J. Li, M. Kwauk, Particle-Fluid Two-Phase Flow, the Energy Minimization Multi-Scale Method, Metallurgical Industry Press, Beijing (1994), ISBN 7-5024-1572-6

[2] C. Chen, Investigation on Mesoscale Structure in Gas-Solid Fluidization and Heterogeneous Drag Model, Springer Press, (2016), ISBN 978-3-662-49371-8

[3] C. Chen, Q. Dai, H. Qi, Improvement of EMMS drag model for heterogeneous gas-solid flows based on cluster modeling, Chem. Eng. Sci. 141 (2016) pp. 8-16.

[4] Q. Dai, C. Chen, H. Qi, A generalized drag law for heterogeneous gas-solid flows in fluidized beds, Powder Technol. 283 (2015) pp. 120-127.

[5] Q. Dai, Meso-scale Analysis and Improvement of Fluidized Heterogeneous Drag Model Based on EMMS Theory, Doctoral thesis, Tsinghua University (2017)

2. Calculation of Drag Correction Factor, H_d

(1) Open " *QC-EMMS Drag Model (Trial Version).exe* ".

(2) 8 parameters with limited ranges need inputting into the program:

- Gas viscosity, μ_g (Pa·s)
- Gas density, ρ_g (kg/m^3)
- Particle density, ρ_p (kg/m^3)
- Particle diameter, d_p (μm)
- Minimal fluidization solid volume fraction, $\varepsilon_{s,mf}$ (-)
- Superficial gas velocity, U_g (m/s)
- Solid mass circulation rate, Gs (kg/m^{2}s)
- Bed-averaged solid volume fraction, $\varepsilon_{s,bed}$ (-)

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*******************************************************************
*                       QC-EMMS Drag Model                        *
*                      Trial Version Program                      *
*      Professor QI Haiying's Lab, Tsinghua University, China     *
*******************************************************************


Input parameters are limited to certain ranges in this trial version.
Welcome to contact us for using full version!
Please refer to User Guide for contact information.


Parameter input:
Gas viscosity, μg (1.75e-5 ~ 1.85e-5 Pa·s)
1.8e-5
Gas density, ρg (1.2 ~ 1.3 kg/m3)
1.2
Particle density, ρp (2400 ~ 2600 kg/m3)
2500
Particle diameter, dp (280 ~ 320 μm)
300
Minimal fluidization solid volume fraction, εs,mf (0.5 ~ 0.6)
0.5
Superficial gas velocity, Ug (7 ~ 8 m/s)
7.5
Solid mass circulation rate, Gs (130 ~ 170 kg/m2s)
150
Bed-averaged solid volume fraction, εs,bed (0.07 ~ 0.08)
0.07
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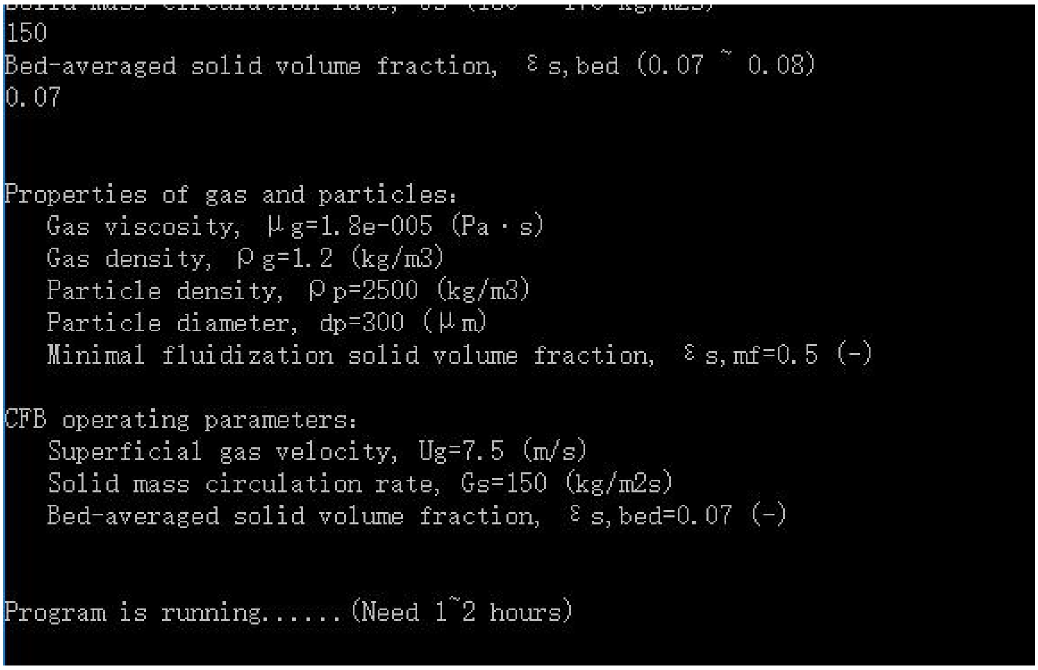
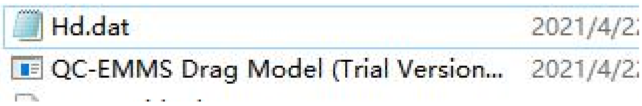
Press "Enter" button to input the next parameter. If some parameters are out of range, please try again.

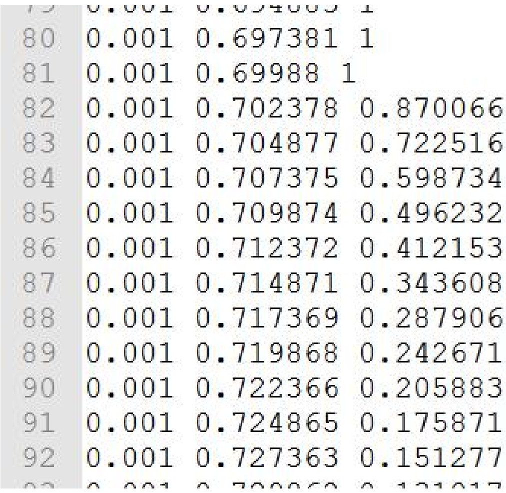
(3) After inputting parameters, it takes 1-2 hours to complete the calculation.



A “*Hd.dat”* data file containing 3 columns and 201201 rows can be created in the same folder with the program:

- First data column: Superficial gas-solid slip velocity, U_{slip} (m/s)
- Second: Local gas volume fraction, ε_g (-)
- Third: Drag correction factor, H_d (-)





The drag correction factor, H_d, is the ratio of the drag function, β, calculated by QC-EMMS model to the β from Wen-Yu model:

$$H_d = \frac{\beta_{QC-EMMS}}{\beta_{WY}} \tag{1}$$

$$\beta_{WY} = \frac{3}{4} C_{D0} \frac{\varepsilon_s \varepsilon_g \rho_g \left| \vec{u}_g - \vec{u}_s \right|}{d_p} \varepsilon_g^{-2.65}, \quad C_{D0} = \begin{cases} \frac{24\left(1+0.15\,\mathrm{Re}^{0.687}\right)}{\mathrm{Re}}, & \mathrm{Re} < 1000 \\ 0.44, & \mathrm{Re} \ge 1000 \end{cases} \tag{2}$$

3. Coupling of QC-EMMS with CFD Platform

Here we provide the coupling method of QC-EMMS model with Fluent®.

(1) Put "*Hd.dat*" and the User Defined Function code "*drag_qc_emms.c*" into the same folder with the Fluent® case.

(2) Compile and load the "*drag_qc_emms.c*"：Define→User-Defined→Functions→Compiled→Add "*drag_qc_emms.c*"→Build→Load

(3) Drag modification: Phase Interaction→Drag→Wen-Yu→Select "Drag Modification"→Set "Drag Factor" to user-defined→qc_emms_drag

(4) Set a User Defined Memory: Define→User-Defined→Memory→Set "Number of User-Defined Memory Locations" to 1.

4. Simulation Example

Here we give a CFB riser simulation example for testing the trial version program. The simulation was preformed using the Eulerian-Eulerian approach and the QC-EMMS drag model [2,4]. The detailed simulation conditions can be found in Refs. [2] and [4].

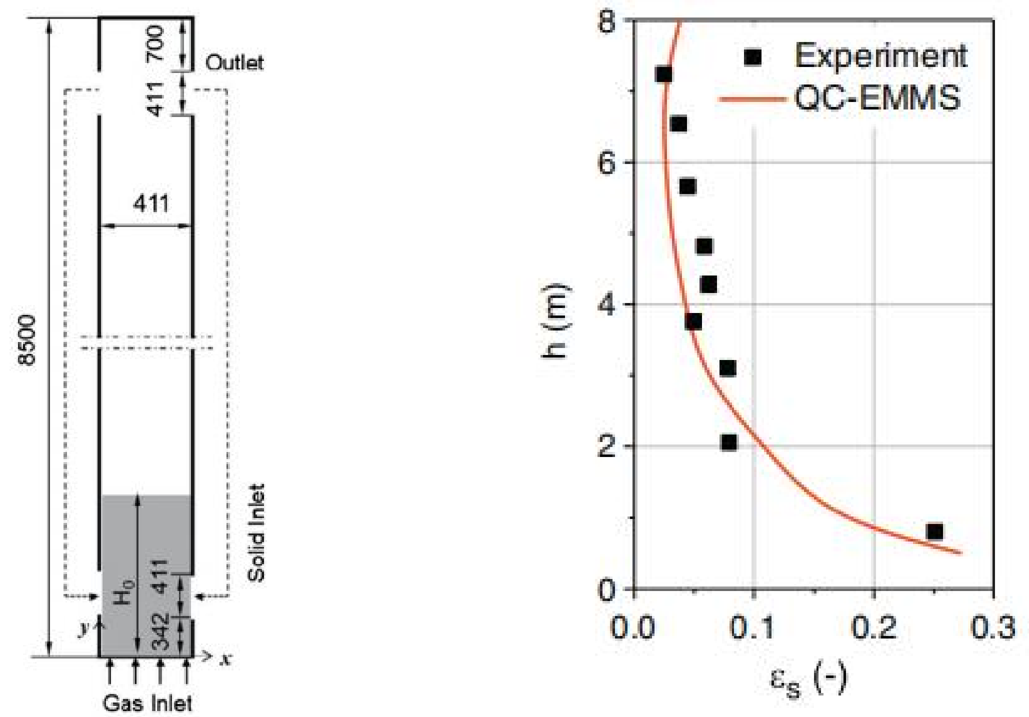


Fig. 1. CFB riser geometry and simulated axial distribution of cross-sectional averaged solid volume fraction [2,4]

Table 1. Simulation conditions [2,4]

Gas			Particle				
Density ρ_g	Viscosity μ_g	Superficial velocity U_g	Density ρ_p	Diameter d_p	Bed-averaged solid volume fraction $\varepsilon_{s,bed}$	Circulation rate Gs	Minimal fluidization solid volume fraction $\varepsilon_{s,mf}$
(kg/m^3)	(Pa·s)	(m/s)	(kg/m^3)	(μm)	(-)	(kg/m^{2}s)	(-)
1.225	1.789×10^{-5}	7.6	2500	300	0.0762	151.6	0.5