Comparative Study between the Quadrature Method of Moments and the Eulerian-Lagrangian to model the Polydispersed Wet-Steam Flows

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Long Abstract

Introduction

One of the biggest challenges in simulating the wet-steam flows in turbines is preserving the details on liquid droplet size distribution. It has been shown that the sizes of water droplets, carried by the steam, greatly influence the flow field, secondary nucleation, efficiency and erosion in the stages downstream the primary nucleation sites [1] [2]. Recently, to represents the polydispersed nature of the wet-steam flows the method of moments (MOM) has received more attention [3] [4] [5]. This method can be performed applying Eulerian frame as well as the Lagrangian one. The MOM is enhanced to admit more complicated droplet growth equation by approximating discrete radii and weights through the n-point Gaussian quadrature. The enhanced approach is named quadrature method of moments (QMOM) which possesses, to a large extent, the merit of the Eulerian-Lagrangian method to retain the polydispersed nature of the flow, while it shows to be promising in modelling full-scale cases as it conveniently lends itself to the Eulerian frame [6]. The application of QMOM in modeling steam condensing flows is still in its infancy and, to the knowledge of the authors, it has not yet been employed for simulating full-scale steam turbines. It is noticed that all the comparative studies between the (Q)MOM and Eulerian-Lagrangian (E-L) method were performed using the Lagrangian frame for both methods [7] [4]. However, the accuracy of the (Q)MOM must be tested using the Eulerian frame, as the main advantage of (Q)MOM over E-L is that it can be cast in the Eulerian frame while preserving the information about the droplets size distribution. This article briefly describes the main constitutes of numerical models of non-equilibrium wet-steam flows. Then, the MOM, QMOM and E-L methods are presented. Moreover, the lack of flexibility of the QMOM over applying higher-order advection schemes for moments fluxes are explained. Eventually, the QMOM is compared with the E-L method, while the QMOM is implemented on the Eulerian frame. It is shown that the accuracy of the QMOM is highly dependent on the grid resolution relative to the E-L method. Therefore, it is concluded that the QMOM is able provide comparable results with that of the E-L, if it is performed on a highly fine grid.

1. Methods

The inviscid one-dimensional flow equations of the vapor and liquid mixture are solved by AUSM (Advection Upstream Splitting Method) flux splitter scheme [8]. Similar to almost all non-equilibrium models, the prediction of the new phase formation is performed in forms of two consecutive stages defined by the nucleation and droplet growth processes. The equations defining the nucleation and growth processes form the wetness source terms in the mixture flow calculations, these equations are integrated in time to update the number and size of water droplets. The evolution of wetness through nucleation and growth/shrink processes are modeled by means of a set of six moments for the QMOM and a large number of droplet groups for the E-L.

2. Results

In this work, two cases are studied using both QMOM and E-L methods, the first case is the well-known nozzle B of Moore experiment [9]. The second case is the same as the first one except for the inlet superheating which is reduced by five degree to enhance the condensation shock and its associated effects. The most important observation is that the QMOM is prone to result in unrealizable moments set when higher-order advection schemes such as the MUSCL are applied, this problem is comprehensively discussed in [10]. By the same token, for the studied cases no solution can be obtained using the third-order MUSCL scheme, as one of the radii for the QMOM takes negative values which physically is not acceptable. This problem is avoided by using fully one-sided second order scheme. However, as a result of lowering the advection scheme order and also the grid-sensitive nature of the methods using the Eulerian frame, it is noticed that the QMOM requires a highly resolved domain to provide grid independent results. The Figure 1 compares the weights using three different grid sizes, it can be seen that the weights are very sensitive to the grid size and the independency of the grid size is not obtained for the grids with less than 1200 elements. Figures 2 compares the droplet size distribution given by the E-L and QMOM, it can be seen that by employing a very fine grid, with 1200 elements, QMOM is able to provide the similar distribution as given by the E-L.

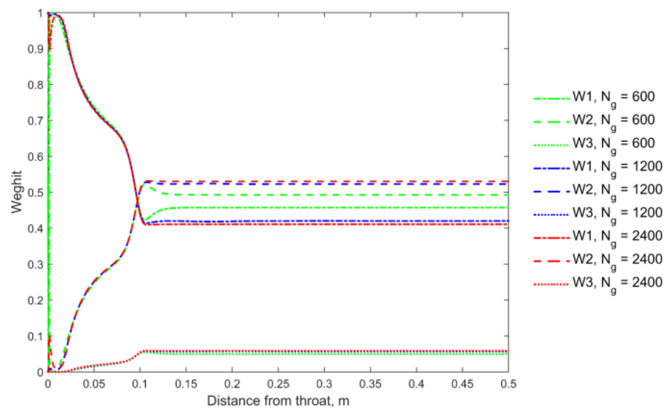

FIGURE 1. Comparison of weights from QMOM using grid sizes of 600, 1200 and 2400 elements for the first studied case, N_g denotes the grid size

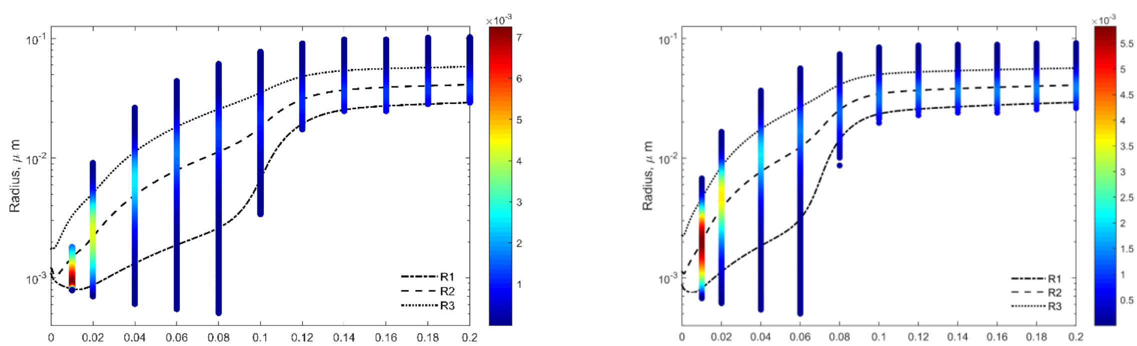

FIGURE 2. Comparison of three radii given by QMOM with the size distributions (solid lines) computed by the Lagrangian, the color bar corresponds to the normalized wetness proportions of droplet groups from the Lagrangian method. Left: the first case with higher superheating at the inlet, right: the second case with lower superheating at the inlet

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