Simulation of the Turbulent Flow in HEV Static Mixers: Mixing of Ethanol with Gasoline

Eissa, A.
Department of Chemical Engineering, Cairo University, Giza, Egypt, 13566, 1

Introduction

Mixing is a typical unit operation that occurs almost in all chemical industries. Static – alternatively termed motionless – mixers are being widely used due to their low power consumption, low capital investment, minimal maintenance costs and versatility. The traditional helical mixing element is mainly used for in-line blending under laminar and transitional flow conditions. The High Efficiency Vortex (HEV) mixers are used for turbulent blending of gases or miscible liquids. Few studies have explored how mixing proceeds in static mixers under turbulent conditions [1]. HEV mixers have been in use in the process industries for several years now [2], yet their mixing efficiency, as compared with empty pipes, has not been carefully assessed [1]. Computational fluid dynamics offers an essential tool for understanding static mixer performance since experiments cannot provide the detailed point-to-point measurements. The flow pattern and mixing characteristics of HEV static mixers are analyzed through simulations for turbulent flow conditions using Comsol Multiphysics. The chosen system is ethanol-gasoline system in which ethanol is added to gasoline in a ratio of 1:9.
The studied case in this paper is a typical mixing of two immiscible liquid under turbulent conditions using k-ε turbulent model and convection and diffusion model. These models have been widely used in computational fluid mechanics [1]

Use of COMSOL Multiphysics

A 3D modeling space dimension was used in Chemical Engineering Modes using k-ε and convection and diffusion models. The 3D representation of the HEV mixer is shown in Figure 1. We have used 1/8 th of a cylinder (pipe) that represents the problem instead of whole pipe to minimize processing time. The dimensions of the system are as follows:

- Pipe diameter: 10 cm
- Pipe length: 42.5 cm
- Tab dimensions: (as shown in **Figure 1**)
- Tab angles: 90, 110 and 135 degrees. (see **Figure 2**)

These dimensions –except for the tab angles- are depicted from previous study [HYPERLINK \l "Bak94" 3]. Physical properties are given in Table (1). The boundary conditions are as follows:

- ***For k-ε model:***
  - o Entrance (z = 0): Inflow, u = v = 0, w = 1 m/s.
  - o Outlet (z = 0.425 m): Normal flow/Pressure [P = 0]
  - o Side faces: Slip/Symmetry
  - o All other boundaries: Logarithmic wall function
- ***For convection and diffusion model:***
  - o Entrance (at r < 0.016 m: C_o = 17000 gmole/m^3, at r > 0.016 m: C_o = 0), all at z=0.
  - o Outlet: Convective flux
  - o All other boundaries Insulation/Symmetry.

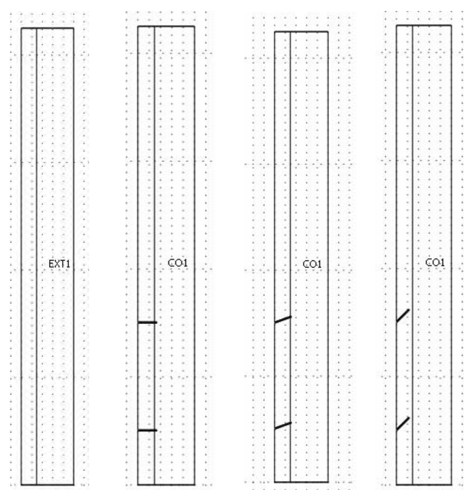
Models were solved at the following order: (I) Solving the k-ε model using a maximum mesh size of 0.02, (II) Solving convection and diffusion model using a mesh size of 0.002 and using current solution of k-ε model. It is worth mentioning that having small mesh size is crucial to obtain satisfactory results, specially in the latter model.

Expected Results

Different mixer configurations were modeled in this work. The 1st configuration is the empty pipe with no mixing tabs (i.e. no inserts), while the 2nd, 3rd and 4th configurations include tabs with angles of 90, 110 and 135 degrees, measured as outlined in **Figure 1**. The following subsections discuss the velocity profile, turbulent kinetic energy profile, pressure drop and concentration profile for the different configurations.

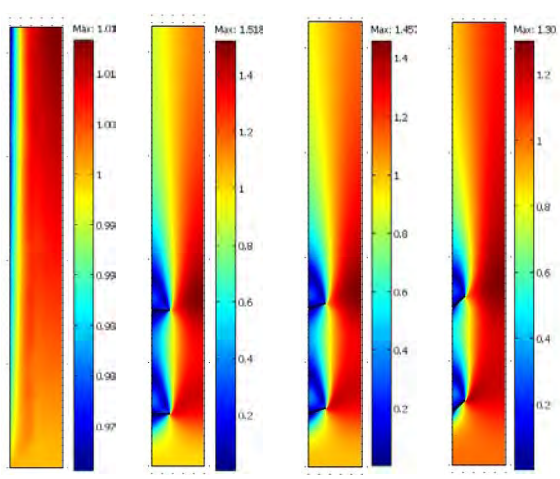
Velocity Profile

Figure 3 represents the velocity field profile for the four configurations at the vertical side plane passing by tab center line. It is apparent that the velocity is more uniform in the absence of the mixing tabs, while the mixers with tabs show a noticeable increase in velocity – as compared with empty pipe - towards the center of the pipe and stagnation areas around upstream of the tabs. The increase in the velocity occurs in the axial and radial velocities, as illustrated in **Figures 3** and **4**. The increase in radial component of the velocity is probably more important, since it initiates radial mixing, while the axial mixing is already taking place due to high velocity in axial direction.



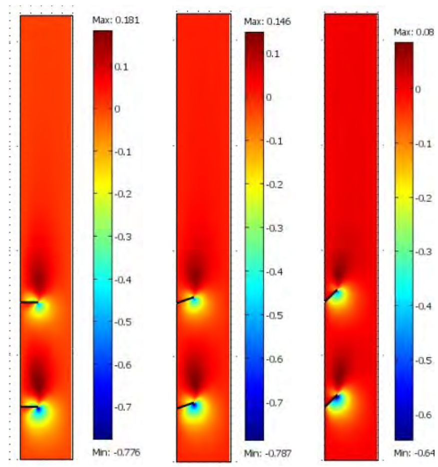
(a) (b) (c) (d)

Figure 2. Different Mixer Configurations. (a) Empty pipe, (b), (c) and (d) HEV mixers with tabs angles of 90, 110 and 135 degrees, respectively.



(a) (b) (c) (d)

Figure 3. Velocity field (m/s) profile for the different configurations (a) Empty pipe, (b), (c) and (d) HEV mixers with tabs angles of 90, 110 and 135 degrees, respectively.

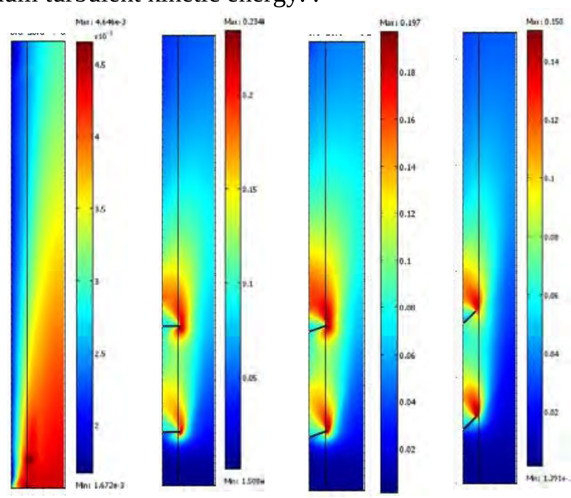


(a) (b) (c)

Figure 4. Radial component (m/s) of velocity for the different configurations (a), (b) and (c) are HEV mixers with tabs angles of 90, 110 and 135 degrees, respectively.

Turbulent Kinetic Energy Profile

Figure 5 shows the profile of turbulent kinetic energy. It is apparent from the figure that the regions behind the tabs exhibit the highest turbulent kinetic energy. It is noticed as well that the tab angle affects the intensity of turbulent kinetic energy. The maximum values of turbulent kinetic energies are 4.5 10-3, 0.234, 0.197 and 0.15 for empty pipe, 90, 110, 135 degree mixers, respectively. We conclude that the greater the angle, the lower the maximum turbulent kinetic energy. .



(a) (b) (c) (d)

Figure 5. Turbulent kinetic energy (m^2/s^2) profile for the different configurations (a) Empty pipe, (b), (c) and (d) HEV mixers with tabs angles of 90, 110 and 135 degrees, respectively.

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