Title

Reformer Performance for Co-current and Countercurrent Flow Mode

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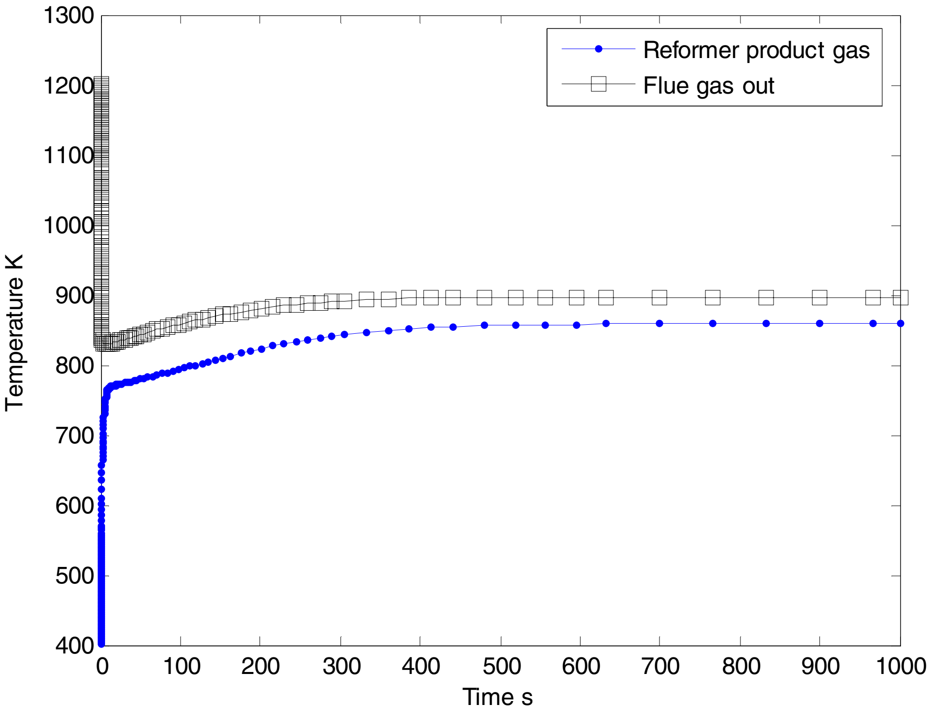
In last decade, interest in cleaner energy technologies such as fuel cells has increased significantly, particularly for power generation and automobile applications. Steam reforming of methane, which has significant potential in fuel cell applications, is also industrially important reaction that is employed in production of ammonia, methanol and in Fischer-Tropsch synthesis [1,2]. In conventional tubular reactor for production of methane from hydrogen, the required heat for reaction is provided indirectly by flue gas flowing in annulus. High endothermicity of reforming reaction and limited wall heat transfer coefficient requires considerable energy input requirement in such reactor [3]. For small scale uses the fuel processor has to be compact and at the same time has to have better heat transfer characteristics to increase the hydrogen production. In such case, understanding of influence of flow arrangement on steady state and dynamic performance of reformer is very essential. In present work, dynamic simulations are performed for both co-current and countercurrent flow arrangement and reactor performance is investigated under variation of operating conditions like steam/methane ratio, inlet gas velocities and inlet gas temperatures for both type of flow arrangement.

The reactor comprises of two concentric tubes. The inner tube is filled with Ni/MgO-Al_2O_3 catalyst where endothermic steam reforming of methane takes place. The flue gas flows inside the annulus and provides required heat for steam reforming. The kinetic information of the reforming reaction is taken from [4]. The temperature and composition dependence of viscosity of the flue gas mixture and the reformer gas mixture is incorporated in the model. The reformer is modeled as a pseudo-homogenous reactor. Axial diffusion of heat and mass in the reformer and the flue gas is neglected. Pressure inside both the burner, the reformer and is assumed to be constant. Conduction and convection are assumed to be predominant heat transfer mechanism while radiation effect is neglected. Heat loss to surrounding is neglected and both the process gas and the fuel gas are treated as an ideal gas.

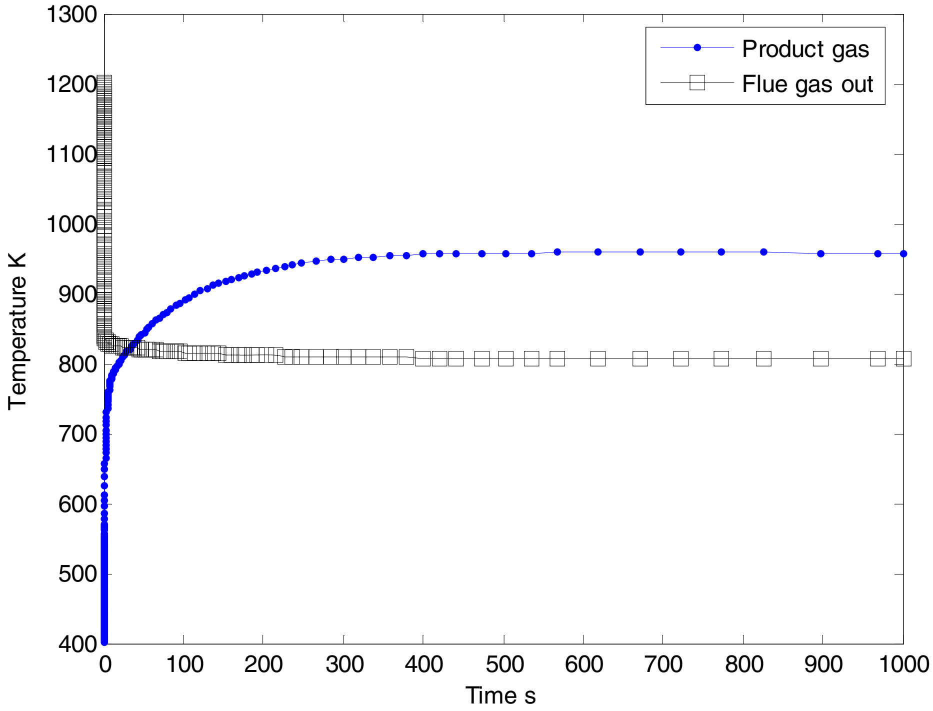
The material and energy balance equations result in a set of 8 partial differential equations (in time domain) along with 9 boundary conditions which are discretized using orthogonal spline collocation on finite elements [5]. The reactor length is divided into 8 intervals with 3 collocation points in each interval. Discretized partial differential equations along with boundary conditions form system of differential algebraic equations which are solved using stiff integrator that utilizes variable order solver based on numerical differentiation formulas. The computations are performed using MATLAB programming environment. Dynamic effects of various operating conditions like steam/methane ratio, inlet gas temperatures and gas inlet velocities are investigated by numerical simulations. From results, reactor performance is analyzed based on methane conversion for above stated operating conditions.

Dynamic and steady state simulations for the base case

Results for only base case simulations are presented and discussed here. Fig. 2(a) and Fig. 2(b) show dynamic profiles of the reactor product gas. Results show that higher heat recovery can be obtained in countercurrent flow arrangement. Dynamic simulations are followed the steady state simulations. The profiles are shown in Fig. 3(a) and Fig. 3(b). As shown in figure, counter-current flow arrangement results in higher methane conversion due to higher heat recovery. Calculations show that methane conversion in co-current arrangement is 49.89 % while counter-current flow arrangement gives 63.02% conversion

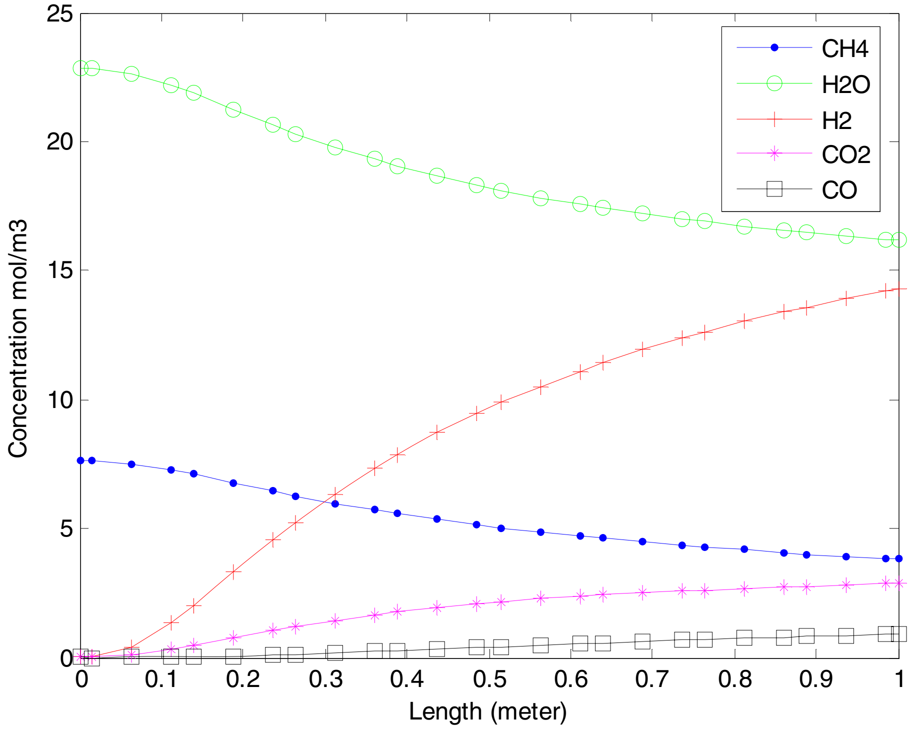


(a)

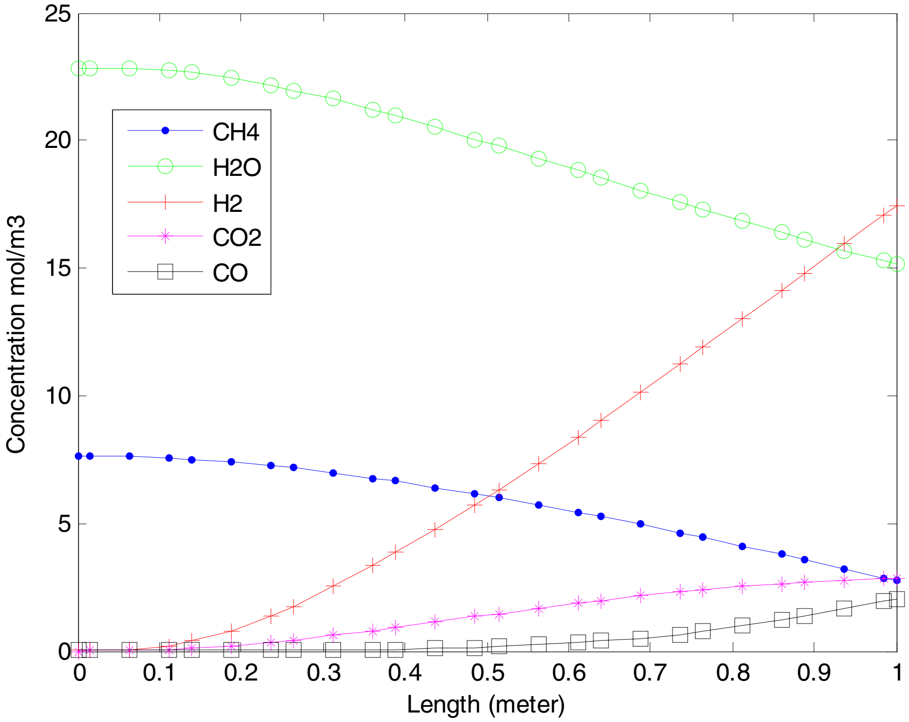


(b)

Fig. 2. Dynamics of product gas temperatures for (a) co-current flow (b) countercurrent flow.

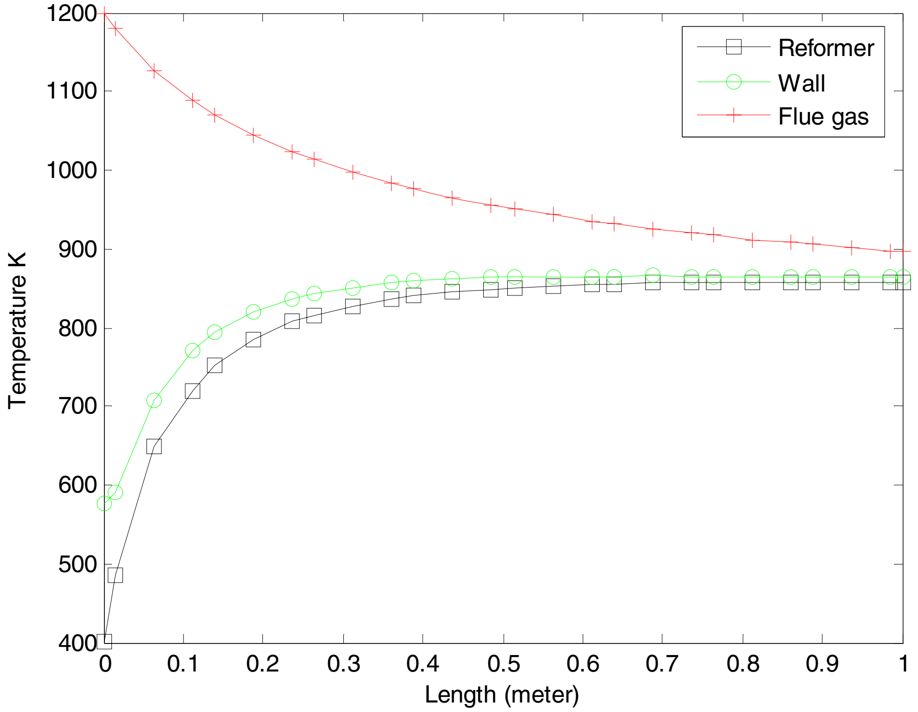


(a)



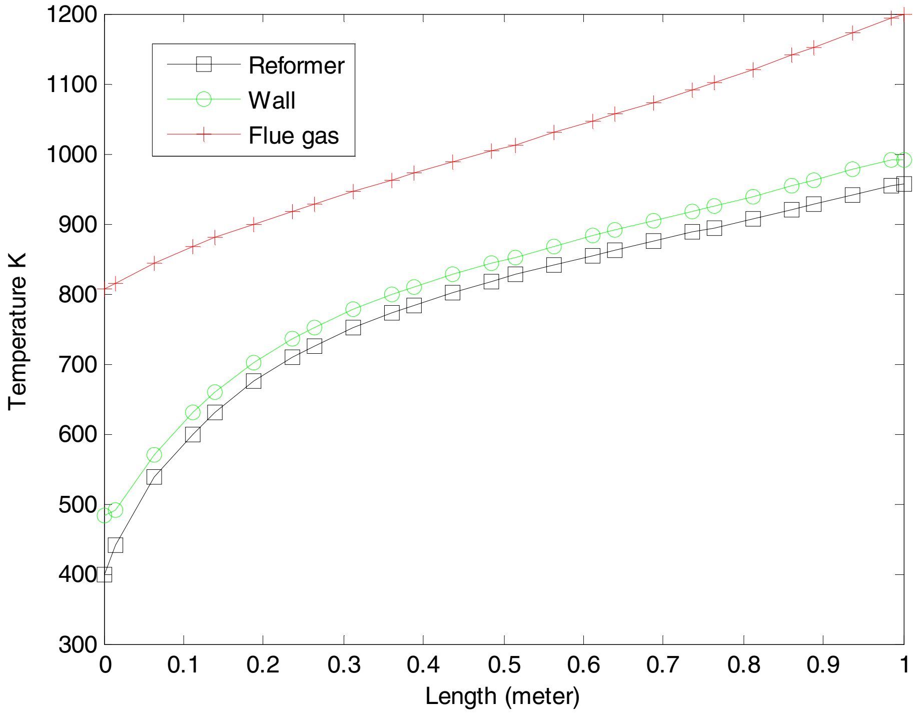
25
20
15
10
5
0
Concentration mol/m3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Length (meter)
CH4
H2O
H2
CO2
CO

(b)



1200
1100
1000
900
800
700
600
500
400
Temperature K
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Length (meter)
Reformer
Wall
Flue gas

(c)



(d)

Fig. 3. Steady state simulations for the base case (a) concentration profiles for co-current flow (b) concentration profiles for countercurrent flow (c) temperature profiles for co-current (d) temperature profiles for countercurrent flow.

After the base case simulations, dynamic effects of change in various operating conditions like steam/methane ratio, inlet gas temperatures and gas inlet velocities are investigated by numerical simulations successfully. Such information is very important for devise the suitable control strategy for the reactor. Results are also helpful to analyze the performance of the reactor based on the methane conversion for various operating conditions.

References

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