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Review Article

RTD Studies for Reactors: A Review

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ABSTRACT

Reactor design for ideal reactors with ideal flow patterns for plug flow and mixed flow reactors are very useful tools for analysis, design and operation. In plug flow reactors residence time of all the fluid elements is equal. In mixed flow reactors, complete mixing is assumed so that there is complete uniformity in composition and temperature. Development of dead zone, vortex formation and sluggish behavior of fluid near surfaces are reasons for non-ideal behavior. Investigations are reported on various aspects of non-ideal reactors, modeling and simulation of reactors. Residence time of the material inside the reactor decides performance of the reactor. The present review summarizes research and studies on non-ideality in the chemical reactors.

***Key words**: Deviation, time distribution, stirred tanks, plug flow reactors, fluid dynamics.*

INTRODUCTION

Chemical reactor design for ideal reactors with ideal flow patterns for plug flow and mixed flow reactors are very useful tools for analysis, design and operation. In plug flow reactors residence time of all the fluid elements is equal. In mixed flow reactors, complete mixing is assumed so that there is complete uniformity in composition and temperature. [1] The assumptions made for the ideal reactors cannot hold for practical conditions. Factors such as reactor type, fluid and flow characteristics cause deviation from ideal conditions.

Development of dead zone, vortex formation and sluggish behavior of fluid near surfaces are reasons for non-ideal behavior. Investigations are reported on various aspects of non-ideal reactors, modeling and simulation of reactors. [2-4] CFD tool can be used to provide movement and residence time information of a huge number of particles. [5-8] It is necessary to validate computational data before using it in practice. Residence time of the material inside the reactor decides performance of the reactor. The present review summarizes research and studies on non-ideality in the chemical reactors.

A REVIEW RTD STUDIES FOR REACTORS

Kanse and Dawande carried out an investigation on residence time distribution (RTD) studies in plug flow reactor. [9] They compared non-ideal reactors using residence time distribution function. They also predicted the number of ideal continuous stirred tank reactors (CSTR) that could represent the non-ideal plug flow reactor (PFR) in question. Their simulated results indicated that 10 numbers of ideal stirred tanks in series would represent the non-ideal plug flow reactor under study. They observed approximately 22.86% deviation between the experimental and the distribution mean residence time. A review was carried out by Gao et.al. on the residence time distribution (RTD) applications in solid. [10] They also studied the influence of the residence time profile on the unit performance. According to them, RTD offered a convenient tool for understanding material transport phenomena inside various unit operations. They summarized the industrial developments using the residence time theory for solid systems. Rajavathsavai et.al. investigated mixing behavior of CSTR using CFD. [11] In their studies, they predicted mixing behavior using age distribution function, I(θ). They used tracer injection method for finding I(θ). They found that the predicted results were in agreement with the literature experimental data. They also investigated effects of rpm of the impeller, Reynolds number and viscosity of the process fluid on the mixing characteristics. Their experimental analysis indicated that the mixing behavior changed from dispersion to ideal mixing as the rpm (N) of the impeller increases. They also observed that effect of viscosity on mixing was RPM dependent.

Kallur and Raj investigated residence time distribution (RTD) for non-ideal reactors. [12] According to them, accounting for non-ideality at the design stage using RTD is not possible. RTD studies are conducted on existing reactors. In their studies, they also analyzed causes of non-ideality in the reactors. Variation in velocity in the radial direction, diffusion and convection effects of reacting and product species are some of the reasons for non-idealities in laminar flow tubular reactor (LFTR). They proposed simple mathematical model that makes use of theoretical RTD of LFTR to predict the reactor performance. The results of the reactor performances agreed well with already well established methods. Kallur et.al. carried out investigations on modeling of laminar flow tubular reactor using velocity profile. [13] According to them, design of reactor using traditional performance equations is inadequate. Non-ideality in the reactors is not taken into account in these reactors. Residence time distribution studies (RTD) are used for quantification of non-ideality. Computational fluid dynamics (CFD) packages can be used for predicting RTD. In their investigation, they developed a model which makes use of only velocity profile to predict homogeneous reactor performance. For Laminar flow tubular reactor (LFTR), they applied algorithm of the model. They found that there was agreement between results of the model and those of LFTR. Highina et. modeled continuous oscillatory baffled reactor(OFR). [14] These reactors are used in biodiesel production from jatropha oil. By using this model, they predicted the number of serially arranged ideal stirred tank reactors (N). They found that the predicted number of tanks in series was 5.6 by the model. This was in agreement with the experimental number of tanks in the oscillatory baffled reactor. According their analysis it would be more economical to use a single OFR than using about six tanks of the CSTR.

Affum et.al. carried out investigation on the conversion of gas oil in fluid catalytic cracking risers. [15] They applied residence time distribution (RTD) concept. According to them, risers are considered vital parts on fluidized catalytic cracking (FCC) conversion units. They used residence time distribution (RTD) functions and flow-model parameters for the characterization of the mixing regime of the riser and the degree of any non-ideal flow behavior. According to these studies, the riser reactor is equal to approximately 1–2 perfectly stirred tanks in series. Nanda et.al. discussed fundamentals of reactors design for chemical reaction. [16] Reis et.al. discussed the fluid mechanics and mixing performance of a novel oscillatory flow screening reactor. [17] In their investigation, they determined a mixing coefficient k_m, for the system as a function of the applied fluid oscillation frequency and amplitude. They estimated mean residence time and a back-mixing coefficients as a function of the oscillation conditions in a continuous operation. They found that the back mixing was highly dependent of the oscillation frequency and amplitude. Also an increase in the radial mixing rates was observed with the increase of the oscillation frequency.

Demessie et.al. investigated stirred annular photo-reactor with focus on residence time distribution. [18] They studied effects of the flow rate, different stirring rates and reactor length-to-diameter ratios on the residence time distribution (RTD) in an annular photo-reactor with a magnetic stirrer at the bottom. They simulated effects of reactor mixers in an annular photo-reactor. They observed that the use of axial or mixed flow stirrer could improve the flow profile narrowing the RTD curve. It creates high Reynolds numbers and avoids back mixing. Gigola et.al. described laboratory experiment to reinforce the basic concepts of non-ideal flow. [19] They passed a gas through empty and packed bed. They carried out the residence time distribution studies. They compared experimental results with those predicted by the axial dispersed plug-flow model. In their studies, they observed deviations from plug-flow behavior in an empty and packed bed tube. They also obtained the dead volume of the connecting lines and the void volume of a packed bed. For empty vessel, they observed that the spreading of the tracer gave a less intense and nearly symmetrical peak. Adeniyi proposed a mathematical model for the operation of a non- ideal plug flow reactor. [20] In their investigations, they used the residence time distribution (RTD) analysis technique involving tracer experiments. According to their estimates 8.18 number of ideal stirred tanks in series would represent the non-ideal plug flow reactor under study.

CONCLUSION

Factors such as reactor type, fluid and flow characteristics cause deviation from ideal conditions. Development of dead zone, vortex formation and sluggish behavior of fluid near surfaces are reasons for non ideal behavior. Investigations are reported on various aspects of non ideal reactors, modeling and simulation of reactors. It is necessary to validate computational data before using it in practice. Residence time of the material inside the reactor decides performance of the reactor. Variation in velocity in the radial direction, diffusion and convection effects of reacting and product species are some of the reasons for non-idealities in laminar flow tubular reactor.

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