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Evaluation of the mixing of non-Newtonian biopolymer solutions in the reactors equipped with the coaxial mixers through tomography and CFD

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HIGHLIGHTS

- ▶ Mixing of yield-pseudoplastic fluids with coaxial mixers was characterized.
- ▶ A statistical-based experimental design with response surface methodology was applied.
- ▶ Tomography data were utilized to measure the mixing time.
- ▶ The effects of the central impeller type and speed, fluid rheology, and anchor speed were quantified.
- ▶ The proposed models for mixing time and power consumption were successfully validated.

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ABSTRACT

A standard configuration of a co-axial mixer is a combination of a close clearance impeller rotating at low speed, and a central impeller rotating at higher speed to achieve efficient and instantaneous bulk and shear flows within the mixing tank. The type of the central impeller has a significant effect on the mixing quality achieved by a co-axial mixer. Thus, in this study the electrical resistance tomography (ERT) and computational fluid dynamics (CFD) were utilized to analyze the mixing of xanthan gum solution (an opaque pseudoplastic fluid with yield stress) with the different types of central impellers. The following three co-axial mixers were employed: the anchor–Rushton turbine (a radial-flow impeller), the anchor–A200 (an axial-flow impeller), and the anchor–ARI (an axial–radial-flow impeller). An ERT system with a five-plane assembly of peripheral sensing rings, each containing 16 stainless steel electrodes, was utilized to measure the mixing time for these three co-axial mixers. The sliding mesh (SM) technique with the modified Herschel–Bulkley model was applied to simulate the impeller rotation and the rheological behavior. The CFD results for the power consumption and mixing time were compared to the experimental data for the model validation purposes. The CFD and ERT data were employed to investigate the effect of central impeller type, xanthan gum concentration, anchor impeller speed, and central impeller speed on the mixing time and the specific power consumption of the coaxial impellers. A statistical-based experimental design with RSM (response surface methodology) was applied to evaluate the individual and interactive effects of the design parameters and operating conditions.

1. Introduction

The simple geometry of the anchor impeller makes it one of the most usable close-clearance impellers for the agitation of the highly viscous fluids [1]. Using numerical and/or experimental methods, several studies have been reported on the performance of the anchor impeller in the mixing of both Newtonian and non-Newtonian fluids [2–9]. However applications of the anchor impeller are limited by the fact that the vertical blades provide more tangential flow [10] and very little fluid motion is generated between the top and the bottom of the tank (axial flow) [11,12]. Therefore, to resolve this problem, the anchor impeller should be used in combination with the radial and/or axial–flow impellers. It was shown that this combination, i.e. the anchor coaxial mixer yields an efficient performance [13].

Mixing efficiency is mainly assessed using the impeller power consumption and mixing time data. Mixing time can be characterized as the time needed to reach a specific degree of homogeneity, and is usually measured by monitoring the dispersion of a small amount of a tracer within the stirred vessel through different experimental techniques. Only few articles have been published on the mixing time of the anchor coaxial mixers in agitation of Newtonian and non-Newtonian (shear-thinning) fluids [13–17].

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