Influence of whey protein aggregation on the residence time distribution in a helically holding tube during heat treatment process

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Influence of whey protein aggregation on the residence time distribution in a helically holding tube during heat treatment process

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INTRODUCTION

Elements of fluid flowing through a processing unit usually take different path and length of time. Knowing the distribution of these times is one of the essential concepts for the design and optimization of processes. This concept, called residence time distribution (RTD) study, is widely used in heat treatment processes to adequately evaluate the thermal processing and/or to understand the fluid flow behaviour. RTD in heat treatment processes, particularly in holding tube, is nowadays well known, but it concerns only processes where the product is not under transformation [1]. There is less knowledge of flow fields and RTD inside equipment in thermal processes where the product is under structural transformations during heating or cooling processes. In such processes, the rheological properties change significantly and consequently modify the flow behaviour and the velocity profile inside the equipment. This is the case for whey protein (WP) heat treatment processes where WP molecules, particularly the β-lactoglobuline (β-lg), unfold and aggregate depending on the time-temperature-shear rate history. The aggregation phenomena induce an increase of the protein volume fraction and of the fluid apparent viscosity, which can modify the fluid age dispersion.
The purpose of this paper is the experimental determination of the RTD in holding tubes of a heat induced whey protein aggregation process. We aimed to compare the fluid age dispersion inside the pipe under aggregation conditions with the one obtained without aggregation.

MATERIALS & METHODS

The experimental setup is an ultra high temperature (UHT) pilot with a nominal capacity of 20 – 50 L/h. Residence time distributions were investigated in the holding tube which has an internal diameter of 7.08 mm. A WP (6% β-lg) solution was used to carry out the RTD experiments. They were conducted using a colorimetric method with Methylene blue (MB) as tracer. Isothermal conditions allowing any WP aggregation (T = 60°C) and allowing aggregation (T = 87°C) were explored at a holding time of about 60 sec and at two different flow rates (20 L/h and 49 L/h). We worked with a volume of 342 ml for the low flow rate (20 L/h) and of 756 ml for the higher one (49 L/h) in order to maintain a holding time in a same order of magnitude (~ 60 sec) for the two flow rates. Continuous cup sampling was made at the outlet of the holding tube and samples analysed with a spectrophotometer. Experimental runs were conducted in triplicate for each condition of temperature and flow rate to obtain the RTD of the holding tube. The age distribution function E(t) also called E-curve were determined assuming a pulse injection.

RESULTS & DISCUSSION

The measured RTD show significant differences depending on whether there is aggregation or not for any flow rate. The minimum residence time is about 11% shorter when WP aggregation takes place for both flow rates for 87°C treatment. However, no difference was found between the mean residence time at 20 L/h under aggregation and under no aggregation conditions, and it is slightly shorter at 49 L/h in aggregation conditions. Such behaviours can be explained by the modification in flow inside the holding tube when aggregation occurs. Figure 1 shows the evolution of the fluid velocity profile in pipes for fully developed laminar flow, and under aggregation conditions (T = 87°C). It represents the velocity parabolic profile at the entrance of the duct and how this profile is modified further when aggregation phenomena occur. The relatively high shear rate located near the wall implicates that aggregation is more important at the wall and both volume fraction and viscosity locally increase more rapidly at this point. The local viscosity

enhancement leads to a decrease of the velocity close to the tube wall and its increase near the axis. As a result, the velocity distribution is gradually modified in comparison to the parabolic profile at the entrance of the duct. Thereby, WP aggregation reduces the minimum residence time and slows down the flow close to the pipe wall inducing a tailing effect on the RTD curves.
The secondary flow circulation can also explain the delay on the minimum residence time obtained in this work. Indeed, the theoretical value of the ratio of the minimum residence time to the geometrical residence time (breakthrough time) is 0.5, for Newtonian fluids flowing in laminar regime in a straight tube without radial diffusion. But, the ratios are above 0.5 for all conditions explored in this study. This result denotes a flatter axial velocity profile than the parabolic one and/or radial mixing.

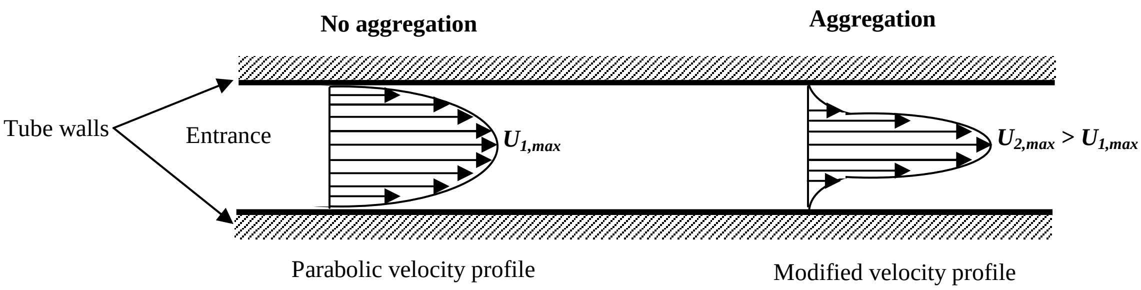

Figure 1. Evolution of velocity profile in laminar regime inside a cylindrical tube during flowing of WP fluid subjected to aggregation

Fitting the experimental RTD curves obtained with the generalized laminar model aided to reinforce the results about the difference in the breakthrough time depending on whether there is WP aggregation or not. As expected, the model corroborates the experimental result and show that the minimum residence time is shorter when WP aggregate during their flowing inside a tubular system. However the generalized laminar model failed to represent the peak obtained in experimental RTD curves while the tail is better fitted. The radial mixing induced by the secondary flow can explain the dispersion observed around the peak of the E-curves by comparison with the sharp peak of the laminar E-curve, which denotes an absence of any radial dispersion. However a more appropriate approach with a model describing the whole flow pattern with accuracy is currently developed.

CONCLUSION

The RTD study in the helically holding tube of a heat treatment pilot plant has shown high differences in the fluid age dispersion when transformation occurs during the thermal process. The present work demonstrates that isothermal WP aggregation modify the velocity field inside the holding tube inducing a different RTD. The principal result is a reduction of the minimum residence time with the aggregation phenomena due to the increase of the maximum axial velocity. The generalized laminar model provided a good fit for the breakthrough time and for the tail on the E-curve, but don’t give a good representation of the radial mixing peculiar to the curved tubes. A general model able to describe all the flow pattern in no aggregation and aggregation conditions is at the moment in development. Results of this work bring valuable tools to help the understanding of the aggregate size dispersion which is closely linked to the RTD.

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