COMPUTATIONAL FLUID DYNAMIC ANALYSIS OF COOLING IN A MIXED VESSEL USING A NON-NEWTONIAN MEDIUM

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INTRODUCTION

The increasing social and economic importance of food production, in addition to more complex production technologies requires a more detailed investigation as further development in the quality of the food or in the production efficiency. Creating fruit prep for yogurt production especially in large amounts can have lot of pitfalls, which can lead to either an inefficient, long production time or/and a lower level of food quality. The challenge of the process optimization increases with the higher starch, sugar and pectin content of the food prep which has a high impact of the behaviour of the medium. In case of pasteurization, the medium has a final temperature of 90 °C which has to be cooled down fast to 35 °C to make it ready for further operations. The hot medium will be cooled down during a complicated mixing process with built in heat-exchanger where the viscosity of the non-Newtonian (shear thinning) medium strongly increases with decreasing temperature. To investigate the behaviour of the medium, the operating parameters and their influence on the process in complex cooling vessels Computational Fluid Dynamics (CFD) can be applied.

COMPUTATIONAL FLUID DYNAMICS (CFD)

Computer based simulations allow a detailed analysis of fluid systems. This tool is known as Computational Fluid Dynamics or CFD[1] and it is suitable for solving a wide range of industrial and non-industrial applications e.g.: fluid flow, mass transfer, heat transfer, etc. For the presented problem the non-commercial open source software OpenFOAM®[2] was applied.

MATERIAL MODEL

Due to the non-Newtonian behavior and temperature dependent thermophysical properties a complex property model was needed. The temperature dependence of heat capacity, thermal conductivity and density were modelled by the consideration of the Brix number (44,8 °Brix) of the medium using the experimental results from Carbal[3]. The experiment results for 46,1 °Brix were chosen and approached with polynomial functions in the case of specific heat, thermal conductivity and in the case of density. The value of the specific heat were controlled at few points with the help of calorimetry measurements and in the case of density with pycnometer measurements. The experimental data approached with polynomial regression were applied in the material model.

MEASUREMENTS

Although CFD is a powerful tool, it is important, that the user has a proper knowledge regarding the investigated field. For validation reasons it is helpful to accomplish lab scale measurements parallel to the computation to compare and develop the solver, to obtain reliable results. The CFD simulations and measurements were accomplished on a small mixed vessel, called macro-viscosimeter developed by TU Wien[4]. This device was initially developed to measure viscosity of mediums with large particles and filaments. It has a 10 L volume, a heating/cooling jacket and a simple mixer blade in the centre. This was considered as an ideal device to test and later validate the CFD model. To obtain as much information as possible about the cooling process 8 pieces of

PT 100 temperature sensors were installed into the vessel to investigate the temperature field. The temperature sensors were placed at different wall positions and also in the medium at different heights and radius. An additional help to support the validation process was the torque measurement of the mixer blade during the cooling using a Viscopakt measurement device.

RESULTS AND DISCUSSION

Considering the inefficient mixer blade and the weak cooling power the process time is longer as in industrial cases[5]. Because of the high computational need and relatively small time steps the simulation was calculated only for 25 minutes real time. The result of the comparison of the torque and selected contour plots of the results are shown in Figure 1. The streamlines of the velocity field in the vessel show that the medium is sucked in at the top and at the bottom of the rotating blade and it is pushed out in radial direction at the middle of the blade. This makes it possible that the colder medium at the bottom and at the top reaches the core of the vessel. This progress is clearly visible in the temperature field. The heat exchange and the gradient near to the wall can be also seen as expected. The non-Newtonian rheology can be recognised in the viscosity field - the shear thinning in the vicinity of the mixer blades adversely affects the mixing behaviour.

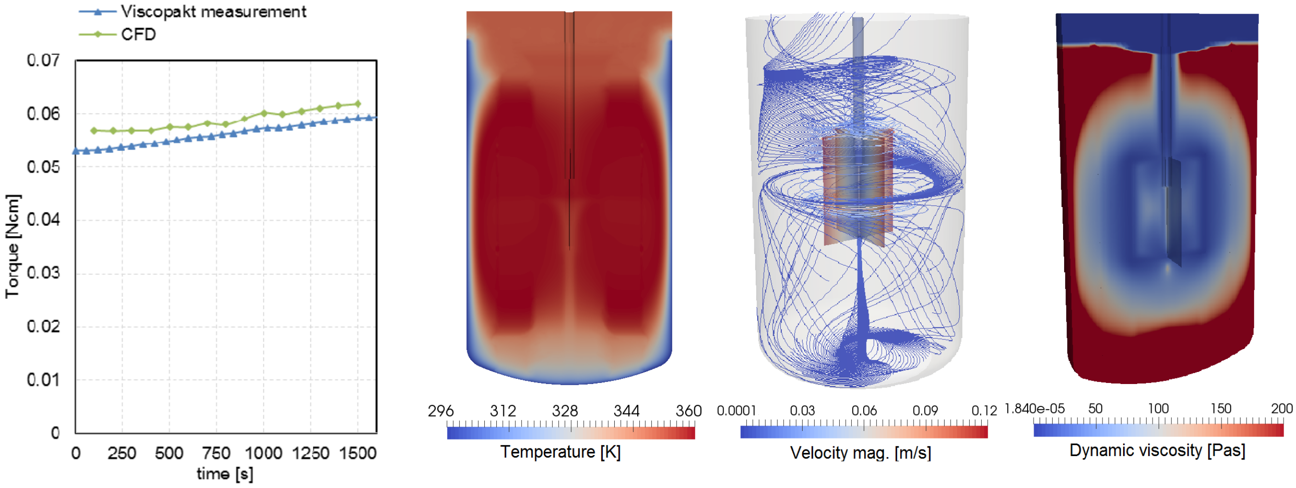

Figure 1 Comparison of the calculated and measured value of the torque (left), selected contour plots[6] of the CFD simulation at t = 1500 s (righ)

CONCLUSION

The comparison of the simulation and the measurement showed promising results using the created material model. To control the reliability of the model, the computation should continue until the end of the cooling process. If the function of the torque and the temperature show the same agreement as in the first 25 minutes, the material model can be used with confidence in other more complicated cooler mixed vessels.

REFERENCES

[1] Fletcher, C.A.J., Computational techniques for fluid dynamics 1, 1988

[2] *OpenCFD Ltd*. <www.openfoam.org> accessed 20.02.2017

[3] Carbal R.A.F., Orrego-Alzate C.E., Gabas A.L., Telis-Romero J., 2007,Rheological and thermophysical properties of blackberry juice, Food Science Technology, 589-596

[4] Pohn S., Kamarád L., Kirchmayr R,. Harasek M., Design Calibration and numerical investigation of a macroviscosimeter. Czech Society of Chemical Engineering (ČSCHI), 1099–1100, 2010

[5] Scargiali F., Busciglio A., Grisafi F., Brucato A., Influence of Viscosity on Mass Transfer Performance of Unbaffled Stirred Vessels, Chemical Engineering Transaction, 32, 1483-1489, 2013

[6] Paraview.org <www.paraview.org> accessed 20.02.2017