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REVIEW OF THE DOCTORAL DISSERTATION

Ing. Mehmet Ayas

Investigation of Flow and Agitation of non-Newtonian fluids

Supervisor: Prof. Ing. Tomas Jirout Ph.D.

Co-Supervisor: Doc. Ing. Jan Skocilas Ph.D

1. Selection of the research topic

Non-Newtonian fluids are present in many technological processes of various industries as raw materials, semi-finished products and final products.These fluids showing many specific properties –variation in viscosity, yield stress, viscoelasticity, thixotropy - create serious problems in the design and implementation of technological processes with their participation.

Among the wide variety of technological processes, the transport and mixing of non-Newtonian fluids are undoubtedly one of the most common in industrial practice. Despite the publication of many research papers on various aspects of the mixing and flow of non-Newtonian fluids, these issues are still not sufficiently developed.

Therefore, I consider taking up these issues in the reviewed doctoral dissertation as fully justified both from the theoretical and practical point of view.
Such studies correspond to the latest research trends related to the intensification of a wide range of processes that are carried out in many research centers around the world and the latest research trends in fluid mechanics, and what is particularly important, they create wide application possibilities.

2. Characteristics of the work

The reviewed work was carried out at the Department of Process Engineering, Faculty of Mechanical Engineering, Czech Technical University in Prague under the supervision of Prof. Ing. Tomas Jirout.

The work consists of five chapters, conclusions, a list of references with 83 items, four appendices and a list of figures and tables.The entire work is contained on 140 pages.

In Chapter I, the author presents a very extensive review of literature. He discusses a wide spectrum of issues relating to the basics of rheology and rheometry, the flow of non-Newtonian fluids in channels with various cross-sectional shapes, and the basics of the process of mixing non-Newtonian fluids.The last part of the literature review deals with the basics of numerical calculations.

The presented literature review is multithreaded, but in my opinion too extensive, and in many of its elements very sketchy. It takes up almost half of the text of the work. Many issues discussed in the literature review have no equivalent in the issues that are the main topic of the work. Without prejudice to the quality of the literature review, some of the issues presented in it may be omitted. In my opinion, they include point 1-5 Thixotropy, point 1-6 Viscoelastic fluid, point 2-1 Drag flow rheometers, parallel disk rheometers, cone and plate rheometer and the source of errors (end effect, wall slip effect).

The problem of mixing non-Newtonian fluids was relatively the least developed in the literature review, basing only on a dozen basic publications published up to 2016 and six monographs (N. Harnby, 1992. W.L. McCabe,1993, E.L. Paul, 2004, R.P. Chhabra, 2008, P. Doran, 2013 and S. M. Kresta, 2016). There is no mention of many other more recent publications on mixing of non-Newtonian fluids and synthetic information on current scientific problems and research trends in this field.

In several places of the presented literature review, the author showed a misunderstanding of the issues of rheology of non-Newtonian fluids. For example, on page 15 the author writes“...Bingham model is the simplest model in order to characterize viscoplastic fluids having constant viscosity (Bingham Fluids)”, which is a misunderstanding of the essence of Bingham fluids. Bingham fluids have a variable viscosity and belong to the group of non-Newtonian shear-thinning fluids.

Similar surprising and not entirely correct statements appear on page 14 (fourth line from the top) and page 16 (line after equation (1-29).

In Chapter II, the author presents the goals of the work, which were:

1. Confirmation of the possibility of determining the rheological parameters of non-Newtonian fluids by examining their flow in rectangular channels and concentric annulus,

2. Proposing simple correlations for determining the pressure drop and the value of the friction factor in the laminar flow of power-law fluids through non-circular channels,
3. Analysis of the operating parameters of the new construction of the rotor-stator mixer designed in the Department of Process Engineering and proposing a simple method of determining Metzner-Otto coefficient for the Herschel-Bulkley fluids.

In Chapter III, the author presents his own considerations concerning the modified and simplified method proposed by him to determine shear viscosity in the flow of non-Newtonian fluids in a rectangular channel and capillary annulus. The author proposed modified relationships describing the values of shear stress (3-7) and shear rate (3-8), which made it possible to determine shear viscosity of power-law fluids. As can be seen from the form of equations (3-7) and (3-8), the advantage of the proposed method, which simplifies the calculations, is the use of one geometric coefficient C instead of two geometric coefficients a and b applied in the previously published works. The proposed method was verified analytically and experimentally using the experimental data published in the literature (Skocilas et al., 2017). The experimental medium was a water solution of bovine collagen, and the channels used in the tests had a rectangular cross-sectional geometry with a length of 200 mm, width 20 mm and two heights 2 and 4 mm. The available experimental data with very good accuracy confirmed the model equations proposed in the study (coefficient of determination R^2 = 0.98-0.99).

The proposed modified approach to the description of rheometric experimental data was extended by the author to include the problem of calculating friction factors for laminar flow of power-law fluids in non-circular channels. The author has developed a very simple correlation describing the value of the product of friction factor and Reynolds number λRe_M. It is worth emphasizing that in the presented considerations the author used the geometrically independent classical Metzner-Reed Reynolds number Re_M.

The proposed correlation (3-17) was confirmed experimentally and by numerical calculations and compared with similar correlations proposed in the literature by Kozicki (1966) and Delplace and Leuliet (1995). The maximum differences between the proposed correlation (3-17) and numerical calculations and Kozicki's and Delplace's methods did not exceed 5%.The proposed method of calculating the friction factor for the laminar flow of power-law fluids in non-circular channels can be used for channels with the following cross-sections: rectangular, concentric annulus, symmetrical L-shape, square duct with a central cylindrical core, eccentric annulus with low aspect ratios and elliptical.

In Chapter IV, the author presented his own research on the mixing of viscoplastic fluid in the in-line rotor-stator mixer newly designed in the Department of Process Engineering. The research was performed experimentally and by numerical calculations. In the experimental studies, the power consumption of the mixer, the drop in fluid pressure between the inlet and outlet sections and the temperature increase of the mixed fluid were measured. The tests were carried out for three rotor speeds 150, 300 and 500 rpm and three axial clearances between the rotor and stator 1, 2 and 3 mm. As experimental media 7.7% water solution of bovine collagen was used. It was a very viscous viscoelastic shear-thinning fluid showing yield stress $\tau_o = 4600$ Pa. The experimentally measured values of power consumption were confirmed with very good accuracy by numerical calculations (maximum deviation 6%). With power consumption measurements available, the value of the Metzner-Otto coefficient k_S was determined.The experimental and numerically calculated values of this coefficient presented in Table 3-4 were very similar and slightly dependent on the mixer geometry.The author also proposed a simple correlation describing power characteristics of the mixer for fluids described by the Herschel-Bulkley model.

Chapter V contains detailed conclusions summarizing the results of the work.

3. Content assessment of the work

The reviewed doctoral dissertation is a theoretical and experimental work.The work is written in intelligible language (although some parts would require linguistic correction).The graphic form of the work does not raise any objections. The presented figures and tables are legible and well prepared.

In my opinion, the title of the thesis is too general and does not accurately reflect the purpose and scope of the research.

The author proposed interesting research goals which are presented in the second point of the review. I declare that the adopted goals of the work have been fully achieved through theoretical considerations and confirmed by the results of experimental research (the author’s own ones and published in the literature on the subject) and by numerical calculations.

The most important achievements of the work that are elements of scientific novelty include:

1. Development of a modified method for determining shear viscosity of power-law fluids in rectangular channels and capillary annulus
2. Development of a simple method for determining the friction factor of power-law fluids in non-circular channels
3. Proposing a simple correlation to calculate power consumption of a mixer for Herschel-Bulkley fluids
4. Proposing a practical method to determine the Metzner-Otto coefficient for Herschel-Bulkley fluids

4. Comments and questions

While reading the thesis, I made a few substantive as well as proofreading and stylistic comments and objections, which require clarification during the defense of the thesis:

1. How can you explain that the values of Metzner-Otto coefficient k_S obtained in the model and experimental work,cf. Table 4-3, are 6 to 8 times greater than the values obtained for classic turbine mixers, for which the coefficient k_S = 10 – see Table 1-2.
2. In Fig. 4-3, the author presents a graph of changes in fluid temperature in the mixer as a function of rotational speed for three mass flow rates of 2, 4 and 6 kg/min.The author states that the most economical fluid flow rate is 6 kg/min, because for such a flow rate the lowest temperature increase of the mixed medium is obtained – see Fig. 4-3. However, the smallest increase in fluid temperature is due to the greatest flow rate and not the least energy dissipation which is evident from the fundamentals of heat transfer. By using an even greater flow rate of the fluid, we would obtain an even smaller increase in its temperature. So does it make sense to introduce the concept of the most economical fluid flow rate? Please comment on this.
3. It follows from Fig. 4-16 on page 108 that the tangential velocity was several dozen times greater than the axial and radial velocity. How to explain the fact that at the pump wall the shear rates were close to zero – see Fig. 4-18, although from a phenomenal point of view the shear rates should be the highest in this area?
4. In point 3 on page 92, the Author writes: "…Several experiments were conducted to investigate the concentration distribution of the dye in collagen...", and on p. 95 there is a statement: "..The result of the concentration distribution of die *(?)(should be* ***dye****)* in collagen is not given in this study." The question is whether the extremely

important measurements of the homogeneity of the mixture after mixing in the in-line rotor-stator mixer were not made?

5. Thirteen references cited in the text, in this number the author’s publications, were not included in the list of references.

The presented comments are polemical and, in my opinion, do not diminish the value of the work, but for its clarity, they require explanation during its defense.

5. Final conclusion

Ing. Mehmet Ayas’ doctoral dissertation concerns the difficult and complex issue of hydrodynamic elements of the flow of non-Newtonian fluids in non-circular channels and selected aspects of mixing non-Newtonian fluids.

The dissertation is written correctly in terms of form and content. Conclusions resulting from the author's own research are properly documented. The author has demonstrated knowledge of the rheology and rheometry of non-Newtonian fluids and the mixing of these fluids, and is well prepared to conduct further research in this area.

I state that the doctoral dissertation of Ing. Mehmet Ayas is an independent solution to selected problems related to the flows and mixing of non-Newtonian fluids and brings elements of scientific novelty in understanding such flows.

Summing up, I can state that the reviewed work of Ing. M. Ayas “Investigation of Flow and Agitation of non-Newtonian Fluids” carried out at the Department of Process Engineering, Czech Technical University in Prague (Study Program: Mechanical Engineering, Field of Study: Design and Process Engineering) meets the conditions set for doctoral dissertations. I recommend acceptance of Ing. M. Ayas’ dissertation and admitting it for defence