Investigation of Geometry Simplifications and a Poly-Dispersed Phase Distribution in the Numerical 3D RANS Simulation of Gas-Liquid Multiphase Flow in a Centrifugal Pump with an Euler-Euler Approach

Long Abstract

Tim Müller, Chair of Hydraulic Fluid Machinery, Ruhr-Universität Bochum, Germany
Phillip Limbach, Chair of Hydraulic Fluid Machinery, Ruhr-Universität Bochum, Germany
Romuald Skoda, Chair of Hydraulic Fluid Machinery, Ruhr-Universität Bochum, Germany

Introduction

In many cases the task of a centrifugal pump is not only limited to handle pure liquids but also several mixtures, e.g. two-phase flow of water and gas. Due to economic reasons the complex separation process of the phases has to be avoided as far as possible. Examples for transporting a multiphase flow mixture, are the production of crude oil and the paper industry.
Previous studies of the two-phase flow characteristics of radial pumps have shown a decrease of head at even low gas loadings. Low gas loading can even cause a sudden decrease of head in part- and overload operating conditions, whereas slightly higher gas loadings can be realized at nominal load [1]. Phase separation and large gas accumulations within the blade channel due to the Coriolis force, the slip between the liquid and the bubbles as well as the pressure gradients in the cross-flow direction have been identified as a source of head drop [2][3].
In the past studies have mostly been conducted experimentally. The recent attempts of numerical simulation of the liquid-gas mixture in radial pumps show a significant deviation between predicted and experimentally determined head drop for higher gas load [4][5]. Hence, the present investigation will contribute to figure out possible sources of mismatch of the simulation results to the data.
In our previous study [5] we evaluated the head drop vs. inlet gas volume fraction (IGVF) in a single-channel model of a radial pump using a state of the art CFD code. The qualitative trend of the head characteristics is captured well up to an IGVF of 3 %, whereas for higher IGVF the deviation between simulation and experiment increases. For all investigated IGVF the gas accumulation is predicted at the even qualitatively wrong location in the blade channel, namely in the centre of the channel and neither at the blade wall nor in the vicinity of the leading edge as expected from the experimental data. Different reasons are assumed for the mis-location of the gas accumulation:

- Simplification of the radial pump geometry to a single-channel model
- Neglect of the lift forces
- Assumption of a mono-dispersed phase distribution

Therefore, the aim of this paper is the assessment of the influence of the radial pump geometry simplification to a single channel model in comparison to a full geometry and a first investigation on the location of gas accumulation depending on the bubble size distribution.

1. Methodology

In the present study a numerical analysis of a radial pump (n_q = 32 1/min) is performed with a commercial 3D RANS CFD-solver (ANSYS CFX 15) at design and off-design conditions for various IGVF up to 7 %. In comparison to our previous study [5] in which a single-channel model of the pump has been investigated, we have set-up a full geometry model, in which the side chambers of the pump are neglected and the annulus chamber is simplified by a radial outflow surface. A confuser is added at the radial outlet flow section to avoid flow separation. For validation of the full geometry model, a full geometry model without simplifications of the radial pump is used, containing the impeller, the annulus chamber, side chambers and suction as well as pressure pipes. To ensure the numerical quality a mesh sensibility analysis is performed for the single-phase and two-phase flow simulations of the full geometry model.

For the single-phase flow steady-state simulation a frozen-rotor approach and for the two-phase flow transient simulation a transient rotor-stator model is used. Furthermore, a mono-dispersed phase distribution and a constant bubble diameter size is compared to a poly-dispersed phase distribution considering five bubble size groups. Bubble interaction models, i.e. breakup and coalescence, as well as the lift forces are neglected, since to the knowledge of the authors, no validated models are available for the flow conditions in a radial pump.

For the single-phase flow (water) global performance parameters of the pump such as head, inner power and inner efficiency and for the two-phase flow (mixture of water and gas) head are determined, and validated against experimental data.

2. Results

In our single-phase flow calculations using the full geometry model the head curve is well predicted and matches the calculated head of the single-channel model. In contrast to single-phase flow, the head of the two-phase flow calculations assuming a mono-dispersed as well as a poly-dispersed phase distribution is not predicted equally well. For low IGVF up to 3 % the qualitative trend of the head vs. flow rate is well captured by the simulation compared with the experimentally determined head. With increasing IGVF the difference between simulation and experimental head becomes more obvious.

For assessing the influence of the simplified radial pump geometry, the single channel model, the predicted pump head and blade pressure profiles as well as the gas accumulation regions are compared to the full geometry model. In addition, head and blade pressure profiles are compared to the experimental data. A poly-dispersed phase distribution is considered to locate the preferred accumulation regions of gas depending on the bubble size distribution in the blade channel. Therefore, the gas volume fraction (GVF) of each bubble size group is compared to the total GVF in the blade channel.

References

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