

Simulation of entrained air separation from paper machine circulation water using CFD

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Abstract

Separation of entrained air bubbles from paper machine circulation water is studied both experimentally and by CFD simulations. The objective of the current study is the development of a multiphase CFD model which takes into account the complex interaction between bubbles including coalescence and breakage. The interaction of the moving bubbles, fibres and fines is also important and can be considered by using a homogeneous model with characteristic rheological properties describing the additional viscous forces in fibre containing solutions. The models and results presented in this report are the first step towards this objective. In the current study a constant bubble size is used characterizing the average bubble size present in the channel. Viscous properties are described by using a constant viscosity measured from the corresponding water. It was found that at least a qualitative agreement between the measured and simulated flow fields can be obtained. It is demonstrated that in the flow cases like this CFD is a valuable tool which allows structural optimization of the channel geometry to maximize air removal efficiency.

Keywords: entrained air, paper machine, degassing, CFD

1. Introduction

Entrained air is a common problem in paper and pulp industry. It can cause detrimental effects, for instance, on product quality, machine runnability, and pumping and washing efficiencies (Stoor 2006). Different methods are used in paper mills to remove entrained air. Entrained air can be removed in stock deaerator (DeculatorTM) using partial vacuum or using passive deaeration in white water silo (Matula and Kukkamäki 2000). Air can be also removed by special centrifugal pumps designed for air removal (Helle, Meinander & Paulapuro 1998, Helle et al. 1999) or

by using a flow channel or flume, in which bubbles are removed from white water in steady flow conditions with their own buoyancy (e.g. Stoor 2006).

Separation of gas bubbles from typical paper making process waters that have e.g. fibres, fines, fillers and various colloidal and dissolved materials is much more difficult than the deaeration of pure water. One reason for this is that in the paper machine circulation or white water the air bubbles are often stabilized by surface-active agents which hinder the bubble coalescence and keep the overall bubble size small. Common stabilizers are resin and fatty acids, sizing chemicals, surfactants for deinking and deposit control chemicals. Furthermore, hydrophobic material and dirt agglomerate on gas bubble surfaces making gas separation even more difficult. Chemical deaerators are often used to destabilize the small bubbles, which increases bubble size and makes their separation easier (Belouadi, Bluma and Lorz 2001). Small bubbles may also be trapped by the fibres in wood pulp suspensions by mechanical forces (Pelton and Piette 1992). This entrapment effect is dependent on the suspensions fibre type and consistency.

The objective of the current work is to develop multiphase CFD models, which can be used to design and optimize efficient gas removal equipment for industrial use. The development of CFD models requires that accurate and reliable phenomenological models are available to encounter the complex interactions of gas bubbles in the multiphase systems. The development of such models requires experimental data, which can be used to verify the developed models.

Experimental

For this study, two different air removal channels in laboratory and pilot scales were available for experiments. One of them, located in the Lappeenranta University of Technology (Laboratory of process and product development), was built especially for the purpose of flow field measurement using Particle Image Velocimetry (PIV). Another, larger scale equipment was built in the University of Oulu (Laboratory of fibre and particle engineering). This equipment was designed for the measurement of local gas contents and overall deaeration efficiency of channel flow using different process waters from paper mills.

PIV measurements

The separation channel for PIV measurements was constructed from transparent polyacrylate plates. The length of the rectangular air separation channel is 2.06 m, its height is 0.22 m and depth 0.05 m. The studied solution is circulated by pump from the circulation tank back to the air separation channel through a 50 mm pipe connection. Before the entrance, a controlled volumetric flow of gas is fed and dispersed into the pumped solution using a sintered porous plug. The size of the dispersed bubbles is measured by photometrical method. Figure 1 shows a photograph taken from the feed position. The liquid in the experiments is tap water with 100 mg/dm³ n-propanol added to reduce bubble coalescence. As shown in Figure 1 the bubble size is small in average. However, at the feed the liquid jet enhances

coalescence and near the feed position some larger bubbles are created. The bubble size in the figure ranges from 50 μm up to 2 mm.

Measurements for gas and liquid flow fields in the gas separation channel were carried out by using Particle Image Velocimetry (PIV). The PIV equipment provided by LaVision consists of a double pulsed NdYag laser, two CCD cameras and PIV software.

In the gas separation equipment the position of the laser and the cameras was arranged so that the laser was located under the channel throwing a thin laser sheet to the studied flow through the bottom of the channel. The two cameras were located in a near rectangular position to the laser sheet. Both the laser and the cameras were connected to a 2D translation stage, which allows the cameras and the laser to be moved synchronously along the channel to the wanted measurement position.

The flow was seeded with fluorescent particles (polyamide, 20-50 μm). One of the cameras was fitted with a standard PIV filter. This camera can acquire images from the reflected light from the bubbles. An additional grey filter was used to decrease the light intensity. The other camera was fitted with a high pass filter, which allows the emitted light from the fluorescence particles to pass the filter and be recorded by the camera. This arrangement allows the simultaneous measurement of both the liquid and gas flow fields.

The size of the measurement window is 179.3×133.1 mm. The measurements were made from 16 measurement windows arranged according to figure 2, two windows on top of each other and 8 windows in a row. The total measurement area shown in the figure covers a length of 1430 mm starting from the feed position in the downright corner of the channel.

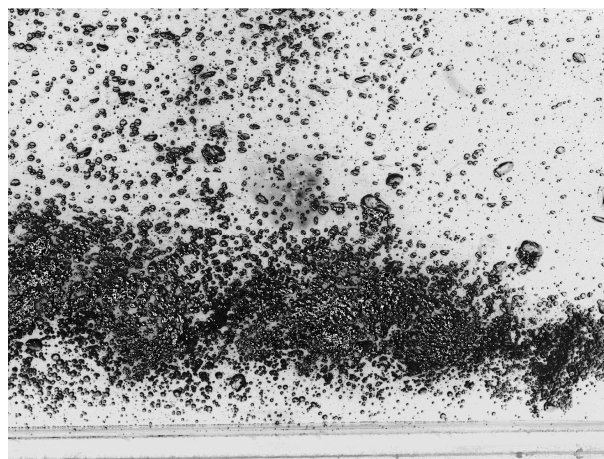


Fig 1. Photograph of the bubbles near the feed position.

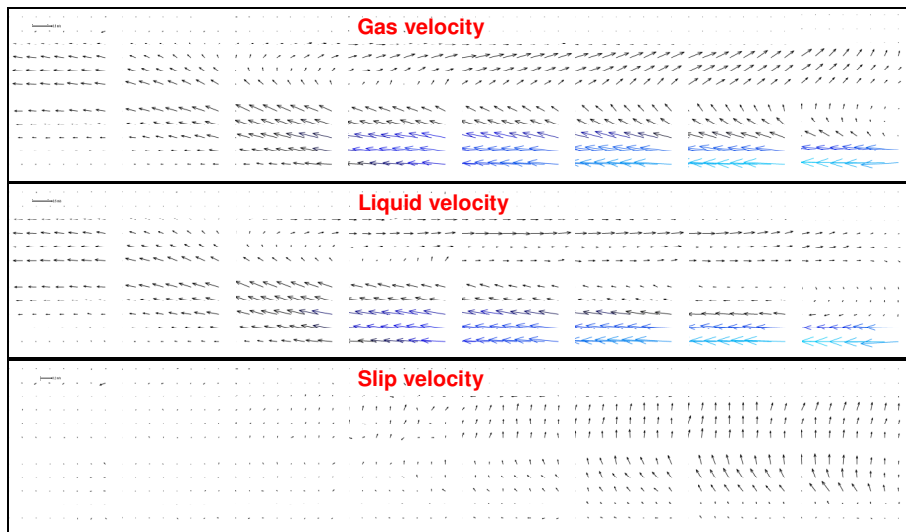


Fig 2. The measured average flow fields for gas, liquid and slip velocity.

The measured slip velocity shows that near the feed point the bubbles are relatively large and tend to rise and escape from the channel relatively quickly. Further away from the feed point in the channel the bubbles are much smaller and have a low slip velocity.

Entrained air measurements

The gas separation channel used for the entrained air measurements has a height of 0.5 m and depth of 1 m (see Fig. 4). The length of the channel can be varied between 3 and 5 meters. The water containing from 0.5 to 3 % of volume of entrained air bubbles was fed to the channel with a rate of 40 dm³/s through a feed pipe with a diameter of 110 mm. The average residence time of gas in the channel is 50 s during which most of the bubbles have time to rise to the liquid surface and escape from the water through the open surface. The entrained air content was measured from the feed pipe and from the exit using a microwave air volume analyzer (Metso MCA). The measured air contents are presented in table 2.

Paper machine process water obtained from a Finnish fine paper mill using kraft pulp and PCC filler was used in the measurements. The tested white water had the characteristics presented in table 1.

Table 1. Water characteristics.

Water properties	Value
pH	7.70
Consistency, %	0.23
Conductivity, mS/cm	1.5
Ash (600 °C), %	22.2
Ash (900 °C), %	16.4
Surface tension (55 °C), mN/m	40.5
Viscosity (55 °C), mPa s	0.59

Table 2. Measured air content in the water.

channel length, m	air at inlet, %	air at outlet, %	removal efficiency, %
3	1.23	0.76	38.2
4	1.22	0.43	64.8
5	1.19	0.22	81.5

CFD simulations

Computational Fluid Dynamics (CFD) is nowadays an important and useful method to study complicated multiphase flow problems. However, in multiphase flow the accuracy and reliability of flow simulation is in many cases limited by the lack of experimental data, which could be used to verify the flow models. Moreover, multiphase CFD models require phenomenological models to describe the complex phase interaction, such as bubble-bubble interactions, bubble coalescence, bubble breakage and bubble-solids interaction.

CFD simulations were carried out by using ANSYS CFX 10.0. In the simulations, the upper boundary of the gas removal domain is defined as a degassing boundary. This boundary definition allows gas bubbles to escape from the liquid phase. Runs were simulated using different feed rates, bubble sizes and volume fractions. The results were compared to experimental results for flow fields and gas removal efficiency. A reasonable agreement between the measured and calculated values was found to exist.

Some results from the simulations are shown in Fig. 3. Liquid and gas feed enters the channel from the downright corner. Feed rate is 1.0 m/s, gas volume fraction 0.2 and bubble size 200 μm . The liquid feed generates a vortex near the entrance with liquid and gas flowing backwards at the channel surface. Most of the gas bubbles are separated at this vortex. Further downwards in the channel the flow is laminar which allows the rest of the bubbles to escape from the system. At the end of the channel some bubbles are sucked into the feed tank where a liquid circulation holds them captured.

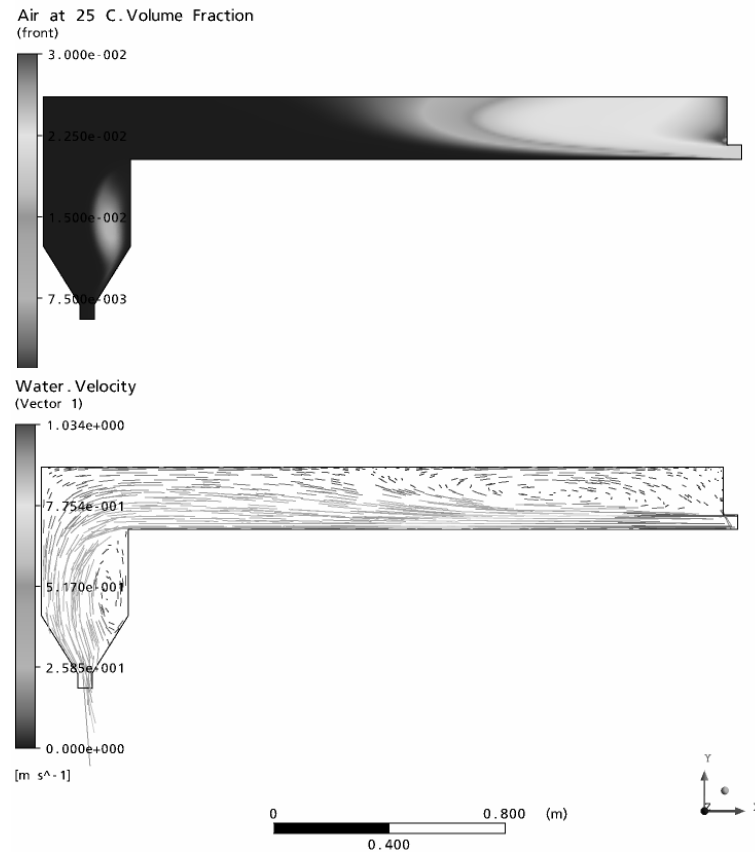


Fig 3. Simulated air volume fraction and liquid velocity field in the gas separation channel. Feed rate is 1.0 m/s, gas volume fraction 0.2 and bubble size 200 μm .

Figs. 2 and 3 show that there exists at least a qualitative agreement between the measured and calculated flow fields. Both experiments and calculations show a distinct recirculation flow at the top of the channel.

The results for the CFD simulations for the entrained air contents are shown in figures 5-7. Fig. 5 shows that the bubbles start to rise and separate from the liquid flow after 2 m in a 5 m channel. At the bottom of the channel there is a region which is virtually free of gas. Near the outlet slit the flows are again accelerated and the liquid flow carries gas bubbles with it through the slit. Fig. 7 presents the liquid flow at the surface of the channel. At the surface, the liquid flow direction is from the walls towards the centre of the channel. The air removal efficiency can be calculated from the mass flow rates through the inlet and outlet boundaries. The calculated air removal efficiency is compared to the measured one in Fig. 8. According to Fig. 8 the simulated efficiency is quite near to the measured one for the bubble size of 100 μm .

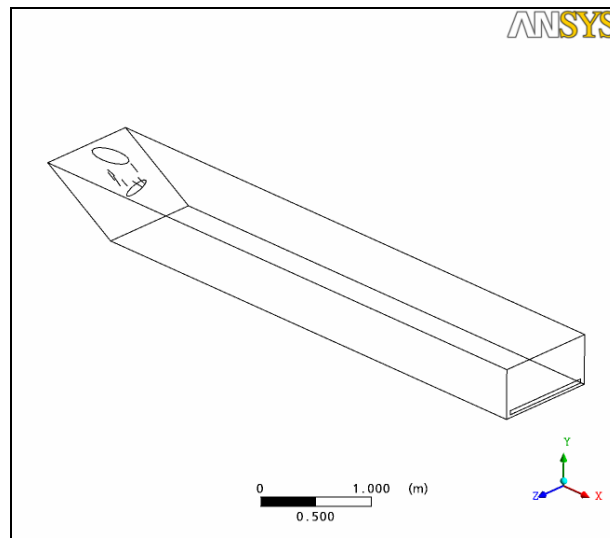


Fig. 4 Gas separation channel used for the air removal experiments (University of Oulu). Water and air enter the channel through a feed pipe at the left corner. Water leaves the channel through a narrow slit at the downright corner.

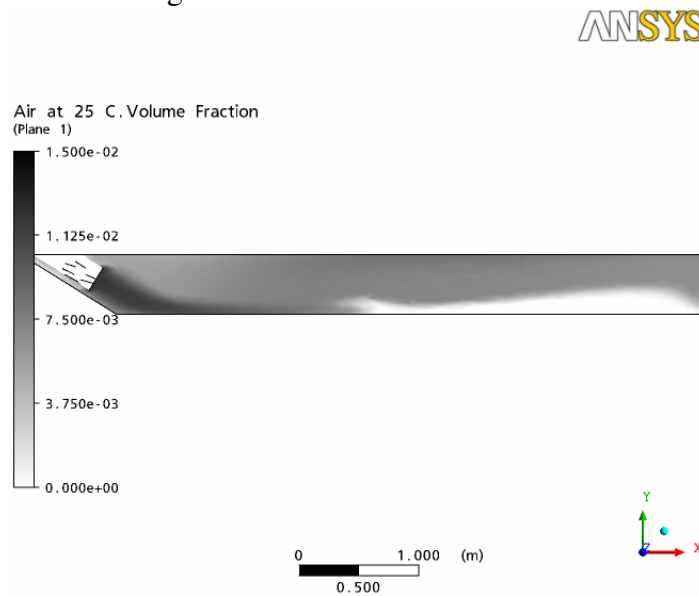


Fig 5. Simulated air volume fraction in the centre of the channel. Feed rate is $40 \text{ dm}^3/\text{s}$. Air content in the feed is 1.19 %. Bubble size is $100 \mu\text{m}$.

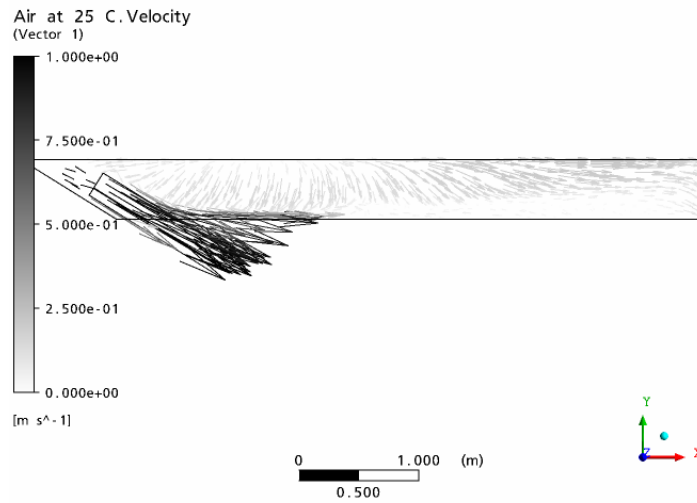


Fig 6. Simulated air velocity field in the centre of the channel. Feed rate is 40 dm³/s. Air content in the feed is 1.19 %. Bubble size is 100 μm.

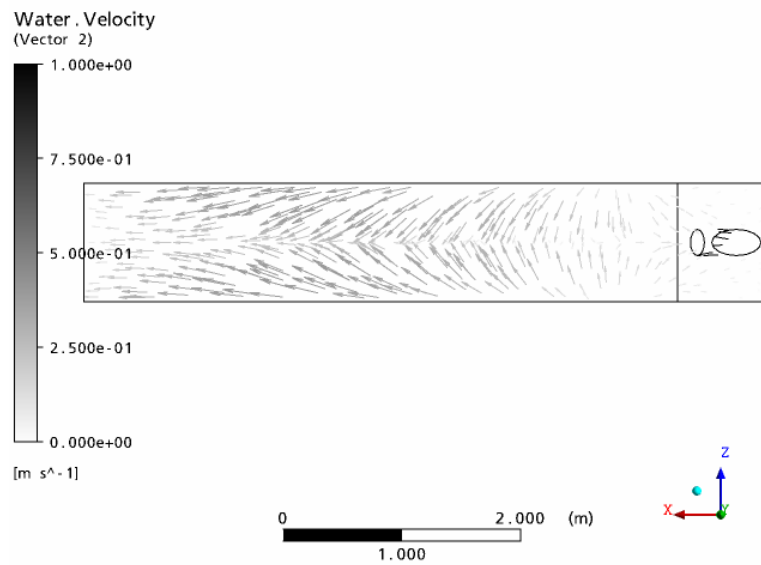


Fig 7. Simulated water velocity field at the channel surface. Feed rate is 40 dm³/s. Air content in the feed is 1.19 %. Bubble size is 100 μm.

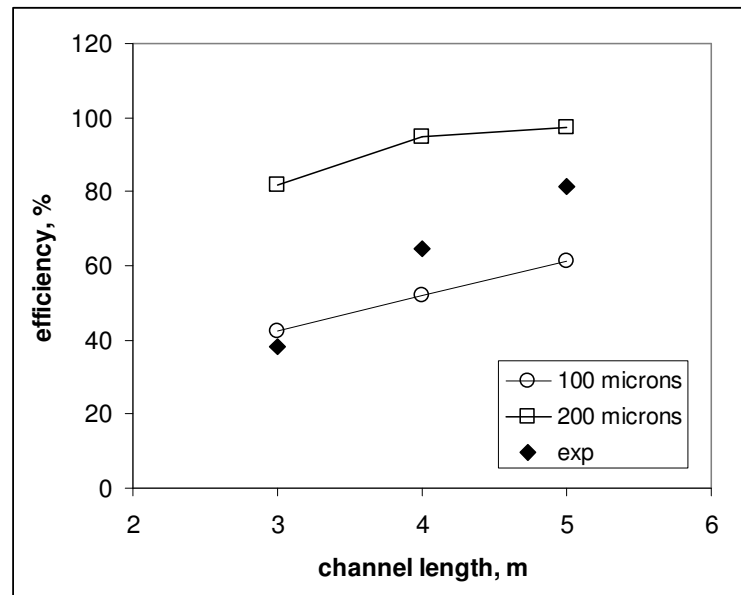


Fig 8. Comparison of the simulated and measured air removal efficiencies.

Conclusions

A multiphase CFD model was developed for the simulation of entrained air separation in a gas separation channel. At the current state the models are preliminary in the sense that they do not include the solution of population balances or interactions between bubbles and fibres. However, CFD simulations have proven themselves very useful giving information about the effect of flow fields on gas separation. The 3D CFD simulations in the large scale unit clearly show distinguished possibilities for structural improvements in the channel using, i.e., baffles to control flow circulations. Considerable improvements in the efficiency may thus be expected.

PIV measurements were carried out in a flat separation channels using coalescence inhibiting chemicals to make the bubble size small. Comparison to PIV measurements shows at least a qualitative agreement between the measured and calculated flow fields.

The air removal efficiency simulated for the bubble size of 100 μm is quite near to the measured air removal efficiencies. However, detailed comparison is not possible because bubble size was not measured in the experiments. At the current state the model does not take into account the variation of bubble size nor the interaction or agglomeration with fibres and other fines. The work will be continued by including the solution of population balances together with bubble coalescence and breakage to the model. Also, the interaction of bubbles, fibres and fines will be taken into account by developing corresponding viscosity models.

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