CHAM Limited

Pioneering CFD Software for Education & Industry

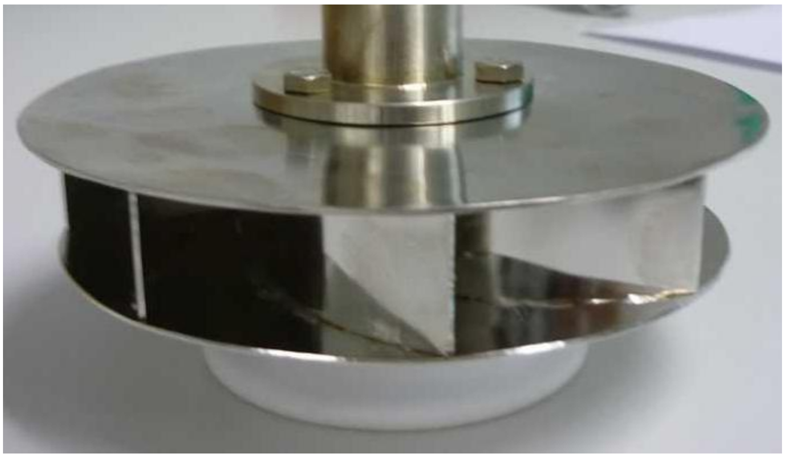
CHAM Case Study – Induced Draft Rotor

Design of a foam separator for the manufacture of human vaccines

A consultancy project undertaken in collaboration with Comberbach Consulting Ltd (www.comberbachconsulting.com) to design an "induced-draft" rotor; a device used to scavenge foam from the surface of an aerobic culture of bacteria, growing in a fermentor.

Aerobic microbial cultures can generate unwanted foam that must be controlled to avoid blocking vent-gas filters. Often, foam is destroyed with a mechanical foam breaker located in the fermentor head space, or controlled by dosing chemical antifoam into the liquid. However, in this case the foam contains one of the vaccine products, a fragile protein antigen that is destroyed by standard foam breaker designs. Chemical antifoams are extremely toxic to bacterial growth and they interfere with the vaccine purification process. The task, for a European fermentor manufacturer, was to design a foam breaker that would remove the foam from a bacterial culture without destroying the fragile vaccine product.

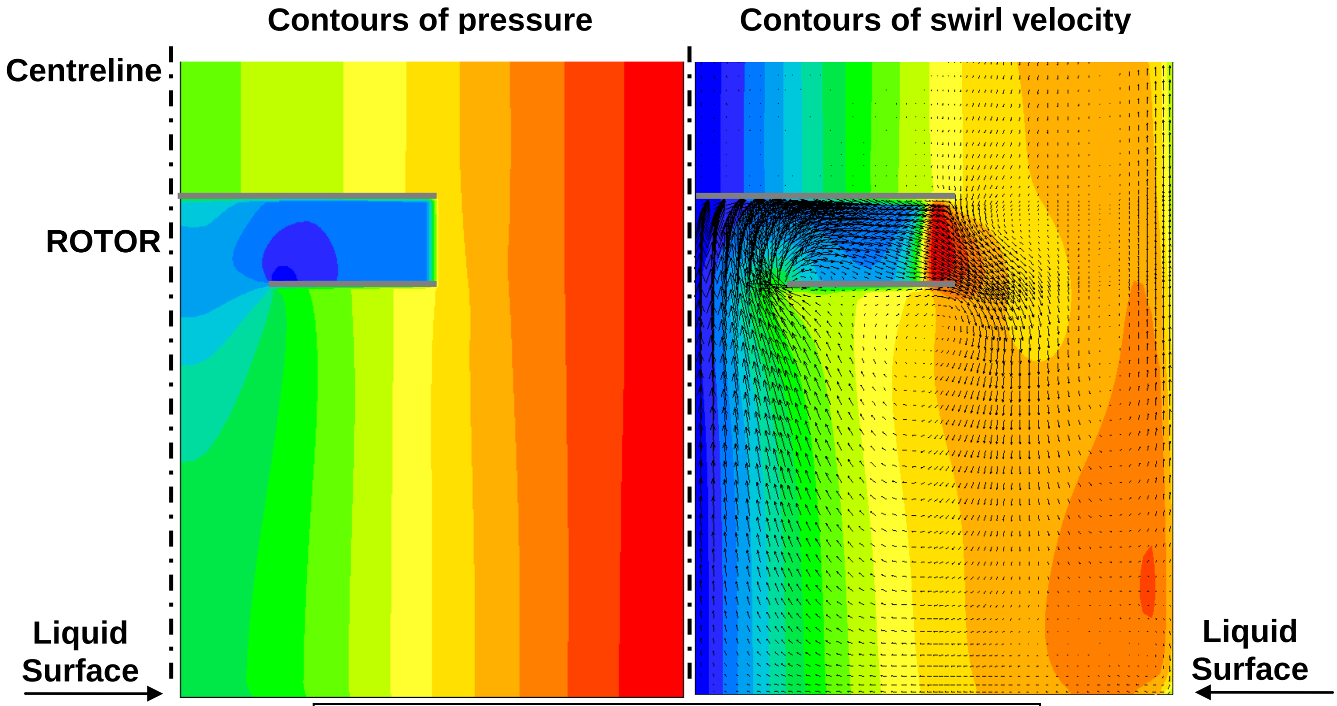
Foam reduction must involve a low-shear method and the best means of achieving this is an induced-draft rotor, commonly found in domestic vacuum cleaners. When such a rotor rotated in the head space of a fermentor vessel, it creates a low-pressure region, which sucks the foam from the liquid surface forming an 'inverted tornado.' The liquid separates from the gas inside the rotor and is thrown tangentially against the vertical fermentor wall, where it runs back into the bulk liquid under gravity. The rotor speed can be varied during the fermentation process, adapting the pumping force to the quantity of generated foam.



Picture of a typical "induced-draft rotor" used for foam separation

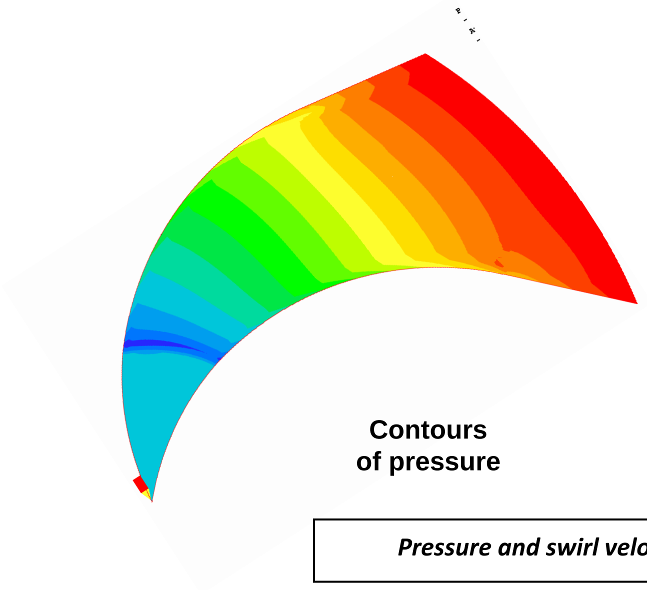
This is significantly different from conventional foam breaker designs in that the upper plate of the impeller is a solid disk, forcing the exhaust gas to flow upwards and outwards through the existing vent filter. Most conventional foam breaker designs are more complex, where exhaust gas exits through a hollow rotor shaft. In this case, CFD analysis was used to help optimise rotor design variables for maximum pumping capacity at the lowest rotational speeds. Rotors for 20- and 200-litre fermentor vessels were required.

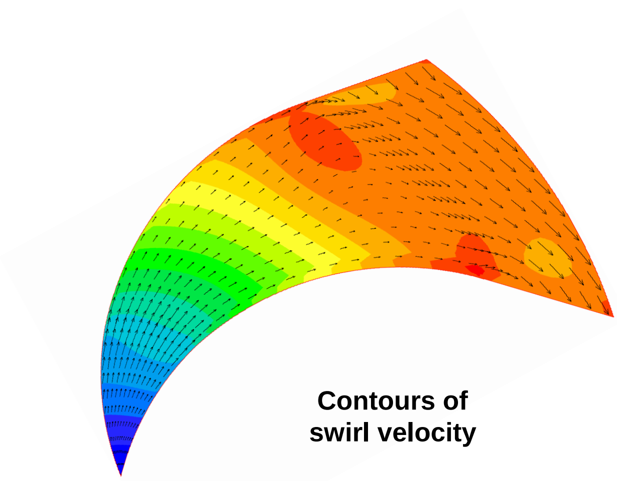
The CFD analysis was performed in two stages, firstly a 2-D axi-symmetric (polar) model of the fermentor headspace in a static co-ordinate system, followed by a 3-D model of a single rotor blade passage using a body-fitted mesh in a rotating co-ordinate system. The 2-D model simulated the flow induced in the vessel head space by the rotor and predicted the strength of the induced swirl, the up-flow velocity distribution below the inlet and the pressure rise across the rotor to pump at the prescribed volume flow rate. The 3-D model predicted the pressure rise for a given rotor design at a specified flow rate. The type of rotor considered here has a 'drooping' characteristic - i.e. the pressure rise which can be generated decreases with increasing flow rate - over most of its operating range. However if the flow rate decreases too far, or too high a pressure rise is demanded, the rotor can stall leading to a rapid loss of performance. The results of this model indicate whether the rotor is capable of pumping the required flow rate against the pressure difference generated by the induced swirl. Also the flow distribution in the rotor blade passage indicates the effectiveness and pumping efficiency for each rotor design. Both 2-D and 3-D models were run over a range of prescribed volume flow rates for each rotor design, with the flow rate vs. pressure rise relationship for each model plotted to find the intersection - thus giving the operating point or 'match point' for the rotor.



Pressure and swirl velocity contours from 2-D analysis

Several design parameters (e.g. blade height, number, angle, inlet and outlet diameter) were varied in order to provide maximum suction at the liquid surface below the rotor for a minimum air volume flow rate. In general, the most powerful design parameters in terms of suction (or pressure rise) are rotational speed and tip diameter. Increasing the number of blades reduces the load per blade, and is likely to increase the rotor effectiveness across a large flow range. Changing the inlet hub diameter does not necessarily provide extra suction at the liquid surface itself, but it does change the operating point along the rotor characteristic. Once the main design parameters were set to give a reasonable overall rotor performance, fine tuning was performed to optimise the blade curvature, inlet and outlet angle. This ensures that the blade inlet angle is matched well to the angle of the inlet air flow, to avoid too high a positive or negative blade incidence; and the air is turned by the correct amount. Under-turning will result in too little pressure-rise, but over-turning might cause boundary layer separation and hence higher losses with less pressure rise.





Pressure and swirl velocity contours from 3-D rotor analysis

The effect of baffles (used to prevent vortexing in the liquid stirring process) extending into the vessel head space was investigated. These were found to have a detrimental effect on the rotor performance. Also, the use of an inlet fairing to the rotor was investigated, and showed an improvement in the flow entering the rotor smoothly, reducing any early separation on the lower hub plate. However, the inlet fairing does move the rotor operating point along the characteristic, so for it to be beneficial overall, it is better to optimise the rotor design from the start including the fairing.

The design principles for aeration and mixing of liquid bacterial cultures in fermentor vessels have changed little over the last 50 years but the methods for control of foam have been largely empirical. Too often, fermentor manufacturers install 'standard-design' mechanical foam breakers at their clients' request, without knowing whether they will work in practice. A CFD study of fluid flow in the fermentor headspace can give the client and fermentor manufacturer more confidence that its mechanical foam separator is fit for purpose. CHAM's project was successfully concluded with two new rotor designs produced and analysed using PHOENICS, meeting the required specifications, and delivered ready for manufacturing.

CHAM Ltd, Bakery House, 40 High Street, Wimbledon Village, London SW19 5AU, UK
Tel: +44 (0)20 8947 7651 Fax: +44 (0)20 8879 3497 Email: phoenics@cham.co.uk
Web: http://www.cham.co.uk