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The effect of pressure on the specific resistance of yeast filter cakes during dead-end filtration in the range 30–500kPa

A.A. McCarthy, H. Conroy, P.K. Walsh and G. Foley*

School of Biotechnology, Dublin City University Dublin 9, Ireland
FAX: +353–1–7045412, email: greg.foley@dcu.ie

Suspensions of *Kluveromyces marxianus* var. *marxianus* NRRLy2415 and active dry bakers' yeast were dead-end filtered in the range 30–500kPa. In all cases, the specific cake resistance, α, could be related to pressure, ΔP, through the expression $\alpha = \alpha_0(1 + k_c\Delta P)$ where α_0 and k_c are empirical constants. For *K. marxianus*, the values of k_c were 1.67×10^{-5} Pa^{-1} and 2.39×10^{-5} Pa^{-1} for suspensions with mean cell aspect ratios of 2.98 and 7.33 respectively. Values of k_c for active dry yeast were 10.56×10^{-5} Pa^{-1} in the case of unwashed cells with a mean aspect ratio of 1.21 and 7.94×10^{-5} Pa^{-1} for washed cells with a mean aspect ratio of 1.20.

Introduction

The relation between pressure and the specific resistance of non-microbial filter cakes has traditionally been described by the power law expression

$$\alpha = a\Delta P^n \quad [1]$$

where α is the specific cake resistance, ΔP is the applied pressure and a and n are empirical constants (Grace, 1963). In keeping with this approach, researchers have used equation [1] to correlate specific resistance data for microbial suspensions (Nakanishi *et al.*, 1987; Tanaka *et al.*, 1994). However, recent research in our laboratory (McCarthy *et al.*, 1998) has shown that for both yeast-like and filamentous suspensions of the dimorphic yeast *Kluyveromyces marxianus* var. *marxianus* NRRLy2415, the specific cake resistance is a linear function of pressure in the range 30 to 180kPa. The data were correlated with the expression

$$\alpha = \alpha_0(1 + k_c\Delta P) \quad [2]$$

where α is the specific cake resistance and α_0 and k_c are empirical constants. The constant, α_0, represents the specific resistance of an unstressed cake while k_c is a measure of cake compressibility. Linearity has also been observed by Tanaka *et al.* (1997) for a range of yeast suspensions filtered between 25 and 125kPa, and by Riesmeier *et al.* (1989) during filtration of *E. coli* suspensions at pressures between 5 and 70kPa.

The problem of relating specific resistance to pressure is important for two reasons. Firstly, process calculations are dependent on accurate predictions of the specific cake resistance. For example, it would appear from the studies mentioned above that the use of equation [1] in microbial filtration is likely to result in seriously underestimating the specific cake resistance at low pressures. Secondly and from a more theoretical perspective, it is possible that the applicability of equation [2] rather than equation [1] to microbial filtration is indicative of fundamental differences between the mechanisms of microbial and non-microbial cake compression.

The work reported in this paper is an experimental investigation of the effect of pressure on the specific resistance of yeast filter cakes over a wide range of pressures (30–500kPa). The aim of the work was to verify that the linear relation is not simply an artefact of the relatively narrow ranges of pressure employed in previous studies.

Materials and methods

Microorganisms

The microbial suspensions used in this study were (i) culture broths of the dimorphic yeast *Kluyveromyces marxianus* var. *marxianus* NRRLy2415 (Northern Regional Research Laboratories, IL), and (ii) rehydrated active dry bakers' yeast (Distillers Company Ltd., Scotland).

Cultivation of *K. marxianus*

This microorganism was cultivated on a whey medium in shake flasks and a 2L bioreactor as described previously

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Table 1 Yeast suspensions.

Microorganism	Code	L_{dm}	Wet cell Conc (g/L)	Method of preparation
K. marxianus	KM1	2.98	28.9	Batch, bioreator*, washed
K. marxianus	KM2	7.33	23.4	Batch, shake flask, washed
Unwashed ADY	ADY1	1.21	25.7	Dissolved in UF water
Washed ADY	ADY2	1.20	24.0	Dissolved in UF water, washed

*Agitator speed: 800 rpm; Air flowrate: 1.0vvm.

(McCarthy *et al.*, 1998). A summary of cultivation conditions is included in Table 1.

Reconstitution of active dry yeast

'Unwashed' suspensions of active dry yeast were prepared by dissolving 45g of dried yeast in 300ml of ultrafiltered water. The mixture was agitated magnetically at room temperature for 20 minutes.

Washing of suspensions

With the exception of 'unwashed' active dry yeast, suspensions were washed prior to filtration. A 500ml volume of *K. marxianus* broth or a 300ml volume of active dry yeast suspension was filtered in the apparatus described below. The filter cake was thoroughly washed with 1% saline and then resuspended to its original volume in 1% saline.

Filtration

Filtration was performed using a 200ml dead-end filtration cell (Gelman Sciences, Dublin, Ireland). The cell was pressurised with nitrogen gas. A new 0.45μm Supor (polysulphone) membrane was used in each run. Filtrate fluxes were measured by weighing with an electronic balance (Mettler, Germany). The pH of all suspensions was adjusted to 7 with 10% NaOH or HCl prior to filtration which was performed at 20°C in all cases. The membrane resistance was determined before and after filtration by measuring the flux of ultrafiltered water at 30kPa. Membrane fouling was found to be negligible in all cases.

The specific cake resistance was measured using the single pass, steady state method as described earlier (McCarthy *et al.*, 1998), i.e., using the expression

$$\alpha = \frac{A(\Delta P - J\mu R_m)}{J\mu c V_s} \qquad [3]$$

where α is the specific cake resistance, A is the membrane area, ΔP is the applied pressure, J is the filtrate flux, μ is the filtrate viscosity, R_m is the membrane resistance, c is the wet cell concentration and V_s is the volume of filtered suspension.

Determination of cell concentration

Wet cell concentrations were determined by centrifugation as described elsewhere (McCarthy *et al.*, 1998).

Image analysis

The mean cell aspect ratio, L_{dm}, (defined as the mean ratio of length to equivalent cylindrical diameter) was determined for each suspension using a Leica Q500MC (Leica Cambridge Ltd., Cambridge, England) image processing and analysis system as described previously (McCarthy *et al.*, 1998). Aggregated cells, which were observed in the active dry yeast suspensions (particularly the unwashed ones) were excluded from all measurements. The mean aspect ratio of cells in each suspension as determined by image analysis, along with cultivation conditions, is summarised in Table 1.

Filtrate viscosity

Filtrate viscosities were determined at 20°C using a Brookfield V1 (Harlow, England) cone and plate viscometer.

Results and discussion

Figures 1 and 2 are linear plots of specific cake resistance *versus* pressure for the suspensions used in this study.

It is clear that there is a linear relationship between pressure and specific cake resistance for all the suspensions filtered. The solid lines in each figure represent fits of equation [2] to the data. Regression coefficients equalled or exceeded 0.999 in all cases.

The effect of cell morphology on the compresibility parameter, k_c, is summarised in Table 2. Very significant differences in cake compressibility are seen to occur. As found in our previous work (McCarthy *et al.*, 1998), the compressibility of *K. marxianus* cakes increases as the cells become 'less spherical'. The enhanced compressibility of the ADY suspensions may reflect greater deformability of cell walls damaged by the yeast drying processes (Herrera *et al.*, 1956). The reasons for the particularly high com-

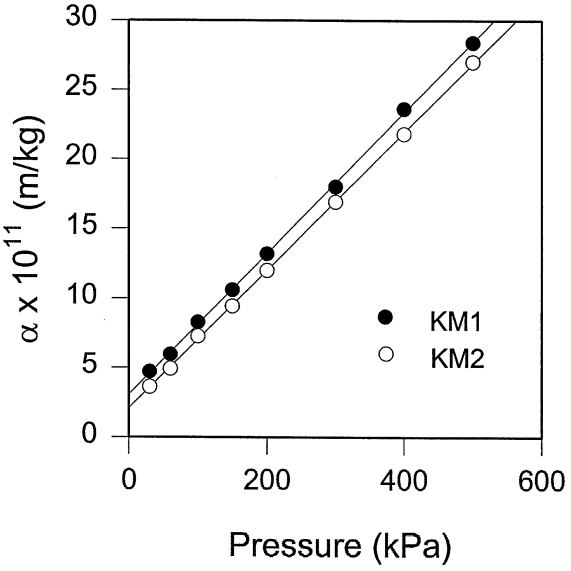

Figure 1 Specific cake resistance *versus* pressure for *K. marxianus*.

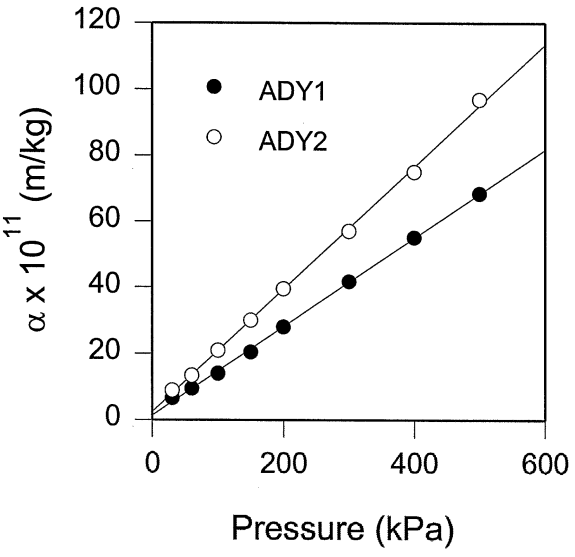

Figure 2 Specific cake resistance *versus* pressure for active dry yeast.

pressibility of the unwashed suspension (ADY1) are unclear at present but may be due to the presence of aggregates which can breakdown under the action of pressure, causing an increase in specific cake resistance (Tiller *et al.*, 1987).

Table 2 Specific resistance parameters

Microorganism	L_{dm}	$k_c \times 10^5$ (Pa^{-1})
KM1	2.98	1.67
KM2	7.33	2.39
ADY1	1.21	10.56
ADY2	1.20	7.94

Conclusions

The data presented in this paper have demonstrated that the specific cake resistance of a number of yeast suspensions is a linear function of pressure over a wide range of pressures. Previous studies of microbial filtration which have employed the power-law expression should be re-evaluated (Nakanishi *et al.*, 1987; Tanaka *et al.*, 1994). Indeed it is clear in the work of Nakanishi *et al.* (1987) that log-log plots of α versus ΔP are non-linear over the range of pressures studied even though equation [1] was used to describe the data.

It has been confirmed in this paper that increasing cell aspect ratios leads to increased cake compressibility. The condition of the cell wall and the presence of cell aggregates may also have a substantial effect on filtration characteristics. A comprehensive study of the filtration characteristics of microbial suspensions is now required, as is a theory which explains the mechanism of microbial cake compression.

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