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ENGINEERING ASPECTS OF FLUIDIZED BED REACTOR OPERATION APPLIED TO LACTASE TREATMENT OF WHOLE WHEY

C. Metzdorf, P.-F. Fauquex, E. Flaschel, A. Renken

Institute of Chemical Engineering
Swiss Federal Institute of Technology, CH-1015 Lausanne

ABSTRACT

An interesting possibility for the use of lactoserum in human nutrition is the hydrolysis of lactose to glucose and galactose, sugars which exhibit a better digestibility, a higher solubility, and which have a greater sweetening power than lactose. The hydrolysis is catalyzed by an enzyme, the β-galactosidase which, due to its high price, must be used continuously, preferentially in immobilized form.

The enzyme used for these studies has been immobilized on silica gel precoated with chitosan. When whole whey or partially deproteinized whey is treated, a fluidized bed reactor seems to be the most appropriate to circumvent problems with protein adsorption and reactor plugging.

However the fluidization of fine particles with a small density difference between the solid and the liquid may give rise to stability problems. In order to prevent unstable operation of the fluidized bed, the reactor has been equipped with special internals. They impose a radial distribution of the liquid and the solid phase and increase the linear velocity required to achieve a given expansion by a factor of five. Besides the resulting high solids content, the back-mixing of the liquid decreasessignificantly when static mixer-packings are used.

KEYWORDS

Liquid/solid fluidized beds; static mixers; expansion; backmixing; scale-up; lactose; lactase immobilization.

INTRODUCTION

Whey represents the bulky by-product of the cheese industry. Although it is of high nutritional value, whey has not found much application in food industry, a market with high potential demand. An extended use for nutritional purposes is prevented due to the unfavourable properties of the main whey constituant, the lactose. One possibility to circumvent this problem is given by the hydrolysis of lactose to glucose and galactose, sugars which exhibit a better digestibility, a higher solubility and which have a greater sweetening power than lactose. The lactose hydrolysis is catalysed by enzymes known as lactases (β-galactosidases). Since the productivity/price ratio for lactases is still rather low, they have to be recovered. In consequence, it is generally aimed at using the enzyme in continuous processes in immobilized form.

A severe engineering problem is encountered, when whole whey is treated with immobilized lactases. Depending on the operating pH, the whey proteins tend to precipitate or to adsorb on the catalyst. Therefore, the use of fixed bed reactors can be excluded for this purpose. Fluidized bed reactors should be less susceptible to problems arising from the presence of proteins.

Since biocatalytic reactions often are slow processes, large surface areas available for enzyme immobilization and rather long space times must be provided. This leads to catalysts of fine grain size and low linear fluid velocities. However, Oestergaard (1976) observed that the fluidization of fine particles with small density differences between the solid and the liquid is often impaired by the occurrence of hydrodynamic instabilities. Segregation of the particulate solid and a stochastic behaviour of the reactor in terms of backmixing and channeling of the fluid often lead to a reduced reactor performance or may even render the process impracticable.

Such instable operation can be overcome when the fluidized bed reactor is equipped with special internals, for example static mixers of the types SMV, SMX (Sulzer, Winterthur, CH). These internals exhibit a regular structure and a high voidage. They impose a radial distribution of the liquid and solid phase and prevent excessive channeling (Renken, Flaschel, Fauquex; 1982). Besides the effect of stabilization, the internals alter the fluidization characteristics for a given system.

The influence of internals on the behaviour of fluidized beds is reported with respect to the expansion characteristics, the stabilizing effect and reactor scale-up. This new reactor concept has been applied to the lactose hydrolysis in partially deproteinized whey by means of the immobilized lactase from Aspergillus niger.

EXPANSION CHARACTERISTICS

The expansion characteristics of numerous solids of different density and particle diameter as well as various liquids of different viscosities have been examined in the absence as well as in the presence of internals in the fluidized bed. The measurements have been carried out in a jacketed glass column of 39 mm inner diameter and a height of 150 cm. The results presented refer to internals of the type SULZER SMV with an hydraulic diameter of 9 mm, (SMV-9).

The influence of internals on the expansion characteristics can be deduced from Fig. 1. Silica gel (GRACE, type 432, Worms, D), a typical support for the immobilization of enzymes, with an apparent density of 1470 $kg \cdot m^{-3}$ and a mean diameter of 0.14 mm is fluidized with demineralized water at 25 °C. In a classical fluidized bed (FB-39) the expansion increases rapidly with increasing fluid velocity whereas in a fluidized bed equipped with internals (FB/SMV) this dependence is much less pronounced. The required fluid velocity to obtain a given bed expansion increases by a factor of 5 when internals are used.

This difference in fluidization behaviour may be quantified by the ratio of the superficial fluid velocities which are necessary to achieve an expansion of $h/h_0 = 2$ in both reactors $F_{SMV} = u(FB/SMV)/u(FB)$. This ratio depends on the physical properties of the system and can be described as a function of the Archimedes number. Various Archimedes numbers were obtained by changing particle diameters from d_p : 0.05 to 0.5 mm, apparent solid density from ρ_s : 1270 to 8700 kg/m^3 and liquid viscosity from μ : 0.45 to 7.8 mPas.

In the region of low Archimedes numbers ($1 < Ar < 50$), the velocity ratio is found to attain an approximately constant value of 5. This region is characterized by the fact that a stable operation of the classical fluidized bed without large recirculation patterns is hardly observed.

In an intermediate range of Archimedes numbers ($50 < Ar < 2000$), the velocity ratio decreases from 5 to a value of about 2. This means that the influence of the internals ceases gradually with in-

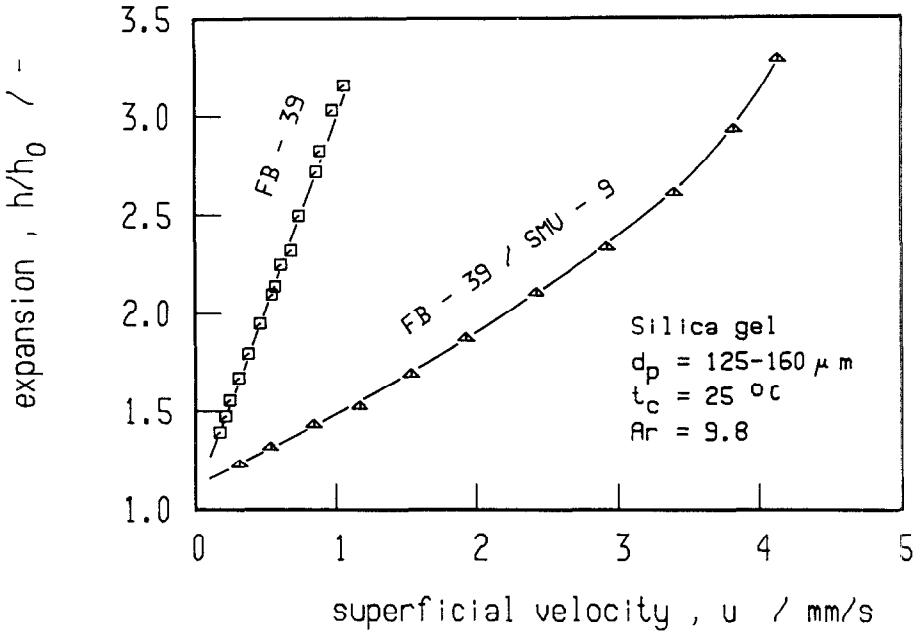

Fig. 1: Expansion characteristics of liquid/solid fluidized beds with and without internals

creasing Arhimedes number. At Archimedes numbers beyond 2000, the influence of the internals ceases completely, indicated by a velocity ratio of unity.

These findings indicate that internals augment considerably the operating range of fluidized bed reactors in terms of fluid throughput. The greatest effect is observed with fluidized systems of low Archimedes numbers (Ar<50). These systems are of particular interest for processes employing immobilized biocatalysts.

REACTOR STABILITY

Fluidized liquid-solid systems of low Archimedes number hardly show a stable behaviour. Channeling accompanied by particle segregation can be observed as well as large recirculation patterns. Tracer experiments reveal the stochastic behaviour of such systems.

Experimental studies have been performed to find out whether the use of internals would permit to employ catalysts of low Archimedes number in fluidized bed reactors. For this purpose, residence time distribution measurement have been carried out in a column of 39 mm inner diameter and a height of 250 cm, divided into three sections. In order to avoid excessive channeling at the column entrance, a conic packed bed of glass beads (d_p = 1 mm) was used as a flow distributor. Water at 25 °C was employed for fluidization. Dilute HCl and KCl solutions were used as tracers and have been injected as a pulse at the bottom of the column. An input tracer signal was measured by conductimetry at a location 70 cm downstream from the entrance, and an output tracer response at 30 cm upstream from the column exit resulting in a reactor test section of 150 cm. The experiments have been evaluated by means of the convolution method combined with the parameter estima-

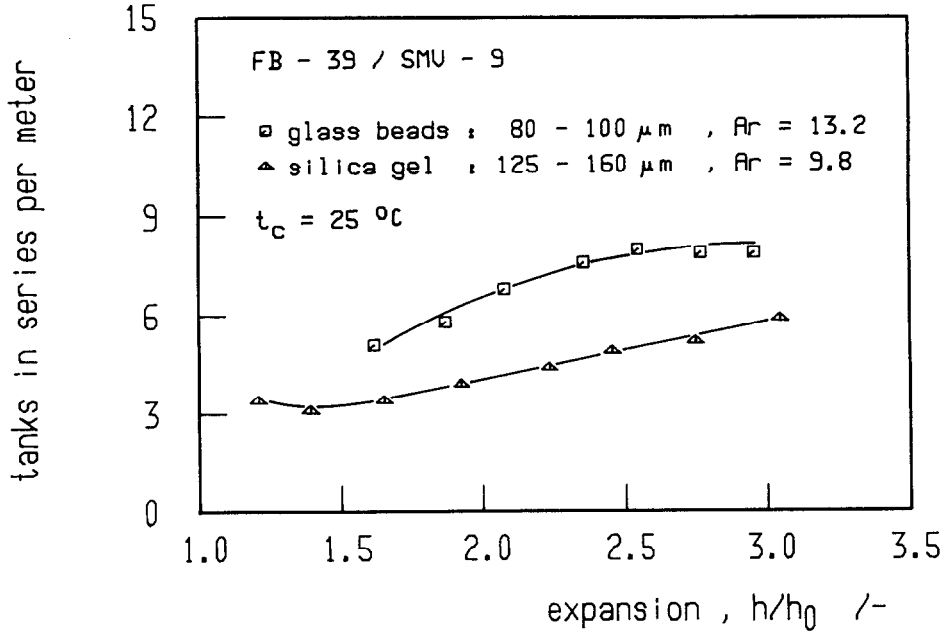

Fig. 2. Dispersion in fluidized beds equipped with internals

tion algorithm of Marquardt (1963). The tanks-in-series model was applied to characterize the axial dispersion.

Figure 2 gathers some of the experimental results. The dispersion of the liquid phase in a fluidized bed reactor is given as a function of bed expansion for silica gel particles of 125 - 160 µm in diameter, a typical support for enzyme immobilization, and non porous glass beads of 80 - 100 µm in diameter, a high surface area biofilm support. Both particulate systems have been chosen to exhibit similar Archimedes numbers. The backmixing induced by the glass beads is less important than that induced by the silica gel. This phenomenon may be attributed to the shape of the particles, the glass beads beeing spherical whereas the silica gel particles are bricks. The entrainment of liquid with particles is further enhanced in the case of silica gel due to its porosity. This phenomenon, which can be observed by measuring the residence time distribution, is due to diffusion of the tracer into the particles, and its influence increases with increasing space time of the liquid phase.

REACTOR SCALE-UP

For the study of solid-liquid fluidized beds on a larger scale, a column with a diameter of 150 mm and a height of 150 cm has been used. Internals of the type SMV with hydraulic diameters of 16 and 32 mm, respectively have been applied.

The influence of these internals on the expansion characteristics depends on their hydraulic diameter. The static mixer SMV-16 shows almost the same range enlarging effect as does the SMV-9 in smaller scale (Fig. 1), whereas the range enlarging effect of the SMV-32 is significantly lower.

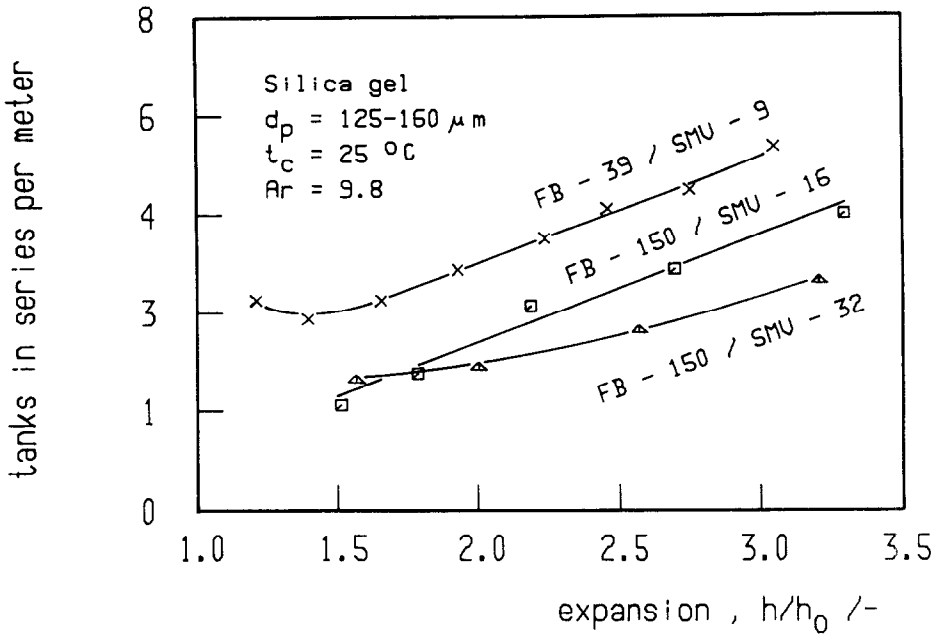

Fig. 3. Backmixing in fluidized beds of different diameter equipped with internals

Systems of low Archimedes number fluidized in columns of 150 mm in diameter exhibit a chaotic hydrodynamic behaviour as has been found in smaller scale, too. Tracer experiments reveal severe bypassing and recirculation.

On the contrary, tracer experiments in fluidized beds of 150 mm in diameter equipped with internals gave reproducible results owing to the stabilizing effect of the static mixers. Fauquex (1983) developped and applied a radioactive tracer method for studying the backmixing of the liquid phase. Some results are shown in Fig. 3. Silica gel particles with a diameter of 125 - 160 µm were fluidized with water at 25 °C. The degree of dispersion is given according to the tanks-in-series model and is plotted as a function of bed expansion. Enlarging the hydraulic diameter of the internals favours the axial backmixing of the liquid phase. But the number of static mixer elements per meter reactor length should also be taken into account. The column of 39 mm in diameter contains 25 elements per meter, whereas that of 150 mm not even 7.

OPERATIONAL STABILITY OF IMMOBILIZED LACTASE

The fluidized bed reactor equipped with internals has been applied to the lactose hydrolysis in whey by means of an immobilized lactase from A. niger. Fauquex (1983) immobilized lactase on chitosan coated silica gel particles (125 - 160 µm) with glutardialdehyde. The reactor had a diameter of 39 mm, a height of 6 m and was equipped with static mixers of the type SMV-9.

Partially deproteinized whey, still containing about 35% of its original protein content, has been used. This substrate was applied at 50 °C, a pH of 3.5 and a lactose concentration of 135 $mmol \cdot l^{-1}$. The reactor contained 910 g (dry weight) of immobilized lactase which corresponds to a fixed bed height of 3 m. It has been fed with a flow rate of 180 l/d, resulting in a bed expansion of 1.6, a space time of 26.6 min and an initial lactose conversion of 60%.

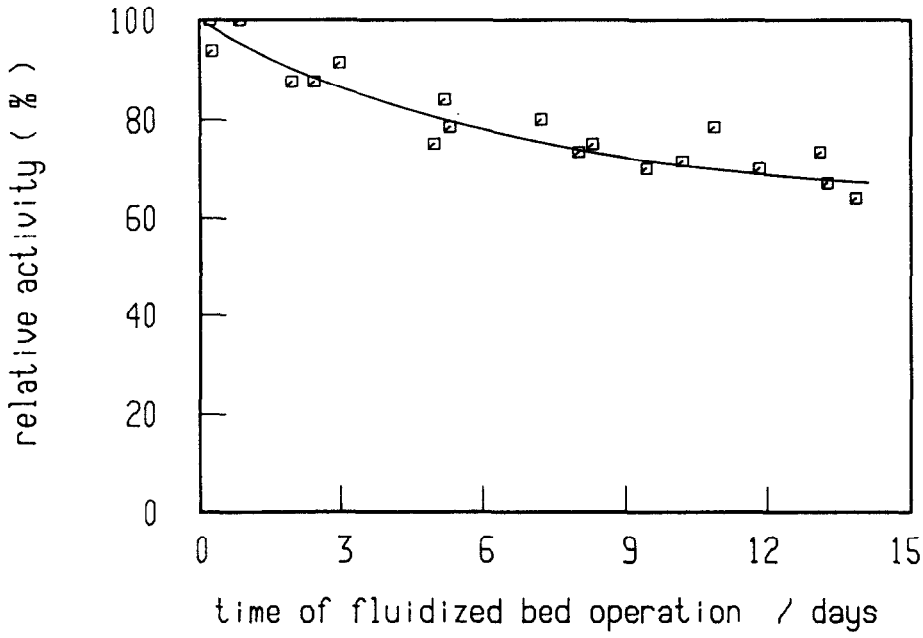

Fig. 4. Operational stability of immobilized lactase in a fluidized bed equipped with internals

Figure 4 shows the stability of the immobilized lactase for a reactor operating period of 14 days. The half-life of the immobilized lactase can be estimated to attain 27 d. Precipitating proteins did not disturb the operation of the reactor, but some protein adsorption occurred tending to aggregate the catalyst particles. Therefore, the reactor has been cleaned in intervals of 2 days by passing a protease containing detergent through the fluidized bed.

CONCLUSION

The aim to enable the exploitation of the advantages of the liquid-solid fluidized bed reactor has led to the introduction of static mixers in the fluidized bed. These internals stabilize the bed by preventing channeling and large recirculation zones to occur. In addition, the operating range of fluidized bed reactors is increased by a factor of five with respect to the fluid throughput for systems of low Archimedes number ($Ar < 50$). This range is particularly interesting in biotechnology, since a stable reactor operation with immobilized biocatalysts or adhering cells can be achieved even when carriers of high external surface area are applied.

The lactose hydrolysis in partially deproteinized whey with an immobilized lactase has shown that precipitating proteins did not directly affect the reactor operation. Problems with adsorbing proteins can be overcome by washing the catalyst from time to time with an appropriate detergent. If lactases were employed which are active in the neutral pH-range, the adsorption of proteins would be of minor importance.

NOMENCLATURE

Ar	-	Archimedes number ($g\ d_p^3\ (\rho_s - \rho)\ \rho/\mu^2$)
d_p	µm	particle diameter
F_{SMV}	-	fluid velocity ratio u(FB/SMV)/u(FB) for an expansion of $h/h_0 = 2$
g	$m \cdot s^{-2}$	acceleration due to gravity
h	m	height of the fluidized bed
h_0	m	height of the fixed bed
h/h_0	-	expansion of the fluidized bed
t_c	°C	temperature
u	$mm \cdot s^{-1}$	superficial fluid velocity
ρ_f	$kg \cdot m^{-3}$	density of the fluid phase
ρ_s	$kg \cdot m^{-3}$	density of the solid phase
µ	mPas	dynamic viscosity

ABBREVIATIONS

FB - n	fluidized bed, n means the diameter of the column in mm
SMV - n	static mixer of the type SMV, n means the hydraulic diameter of the mixer in mm

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