LOCAL GAS HOLD-UP MEASUREMENT IN STIRRED FERMENTERS.
I. DESCRIPTION OF THE MEASUREMENT APPARATUS AND SCREENING OF VARIABLES

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SUMMARY
A simple apparatus to measure local gas hold-up in stirred fermenters and its detailed operation are described. The device operates on the principle of separation of phases. To undertake the characterization of the local gas content in a commercial stirred fermenter, a preliminary study of the three main variables affecting hold-up is reported.

INTRODUCTION
The volumetric gas hold-up, $H_0$, is defined as the volume fraction of gas in a gas-liquid dispersion. It is an important parameter in characterizing aerated media, like those of the aerobic submerged fermentations. The liquid volume available for the reaction in an aerated broth is determined by the factor $(1-H_0)$ applied to the working volume. Fluid dynamics and mixing behaviour depends largely on gas content. In addition, gas hold-up determines the interfacial area for gas-liquid mass transfer, which is often the limiting factor for aerobic processes.

The overall gas hold-up of a reactor can be measured by comparing the liquid level before and after aeration, or by installing a stand pipe in which the liquid level can be viewed and compared with the level inside the aerated vessel (manometric method). In both cases, because of oscillating level, low accuracy is achieved in stirred cultures. Another way to determine the overall gas hold-up is the so-called overflow method. Firstly, the liquid above a suction probe attached at a fixed depth in the fermenter is collected; aeration is only started when no more liquid can be withdrawn. The volume of liquid collected in this second suction is equal to the voidage volume due to aeration. Accurate measurements by this method demands enough large suction time to reach the equilibrium, which is clearly tedious and time-consuming for stirred cultures or foaming media.

In comparison with the overall hold-up, more information can be obtained by measuring the local gas hold-up (CALLERBANK, 1958; NISHIKAWA et al., 1976). Two kinds of probes developed for this purpose are conductivity and optical probes. Conductivity probes (SERIZAWA et al., 1975) take advantage of the rise in electrical resistance when a gas bubble is passed through the tip of the probe. Optical probes (GALAUP and DELHAYE, 1976; MILLER and MITCHE, 1970) use
the difference in the optical density of liquid and gas to measure the gas content. In both cases, rather complex construction probes and measurement devices must be utilized.

In this paper a simple, inexpensive apparatus developed for local gas hold-up measurement in stirred fermenters is described and a study of the variables involved in the gas hold-up characterization of a commercial stirred fermenter is reported.

MATERIALS AND METHODS

Apparatus and principle for gas hold-up measurement

The apparatus (Fig. 1) consists of a sampling probe to withdraw gas-liquid dispersion from different vessel locations and a measurement device, in which the gas and liquid phases of the sample are separated and determined.

The sampling probe is a stainless steel tube of 2.2 mm inner diameter connected to a reversible peristaltic pump. The measurement device consists of two concentric glass tubes forming two volumetric chambers, a three-way valve and tubing connections with the sampling probe, the peristaltic pump and a free-gas liquid reservoir. Fig. 2a shows the state of the device immediately before a gas hold-up determination. Both chambers are filled with degassed liquid at zero marks of their scales, graduated in mm. Gas-liquid sample from fermenter is fed into the bottom of the inner chamber (gas phase chamber) which is closed with a clamp in its top; gas raises up and accumulates in the graduated zone of the gas phase chamber. Simultaneously a liquid volume equal to total volume (liquid plus gas) of the sample is displaced to the outer (liquid phase) chamber. The state of the hold-up meter after determination is shown in Fig. 2b. In this way, volumes of gas and liquid phases present in the sample can be separately determined from levels reached in gas (HG) and liquid (HL) chambers, and gas hold-up is subsequently calculated.

Fermenter

A commercial stirred fermenter (BIOTEC 1601 Ulroferm, LKB, Sweden) was used in the gas hold-up determinations. The vessel was 160 mm in diameter (D) and 353 mm in height, with a working volume of 4.2 L. It was equipped with a six-bladed flat turbine (0.5 D in diameter), four baffle plates (0.1 D in width) and a ring sparger.

Liquid media

The characterization of the local gas content of the fermenter was initially intended for further research in acetification processes. Consequently, the liquid medium employed was wine vinegar, with 10.53% (w/v) acetic acid and 0.66% (w/v) ethyl alcohol. All the measurements were carried out at 30 °C, the same temperature used in acetification processes.

Operational procedure

The peristaltic pump, working at 18 ml/min., was started up and the gas-liquid mixture was pumped, through the three-way valve, to the gas-free liquid reservoir. The pumping to the reservoir was maintained in order to renew the content of tubing and connections and to reach thermal equilibrium in the system. With the same objective the measurement device was filled and emptied several times with liquid from the reservoir. Liquid content of the liquid chamber was varied by means of the reversible peristaltic pump, operating in direct or reverse mode. Suction and discharge was used for the gas chamber, like for a pipette. Once the equilibrium was reached in the system and liquid levels were adjusted to zero marks in the scales of both chambers, a hold-up determination could be started by turning the three-way valve in such a way that the measurement device was fed with fermenter sample. Before gas content in gas chamber could surpass the graduated volume, the feeding was again directed to the reservoir. Readings of gas and liquid levels were then registered and so the gas hold-up could be determined. The content of the gas-free liquid reservoir was frequently returned to the fermenter in order to