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Investigation of the flow behaviour of sourdoughs in a continuously operating fermentation system

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The flow behaviour of sourdoughs with varying degrees of ripeness had to be described so as to be able to determine the operating parameters of a continuously operating fermentation system and to design its tanks, tubes and pumps. A tube viscometer was built for this purpose by which the flow behaviour of the sourdough in the system could be imitated. The drop in pressure within the viscometer's tube was used to calculate the apparent viscosity of the sourdoughs and to investigate its flow for wall slip behaviour. The measurements showed that the swelling capacity of the flour components has a decisive influence on the viscosity of the sourdoughs. The investigation of wall slip effects revealed a typical slip behaviour with cooled, ripe sourdough and with fresh sourdough, whereas no wall slip could be detected with ripe sourdough.

PROBLEM

Sourdoughs with varying degrees of ripeness are pumped through the processing stages of a newly designed and computer assisted fermentation system. For this, the flow behaviour of the sourdoughs had to be described so as to be able to determine the operating parameters of the system. The description had to be made in such a way that the results gained by determining the viscous, flow and wall slip properties could be directly used for the calculation of the mass streams in the system.

METHODS

A tube viscometer was built for this purpose with which the flow behaviour of the sourdough in the system could be imitated (Fig. 1). The dimensions of the viscometer corresponded to the size of the tubes which were used in the fermentation system. Along the length of the tubes pressure gauges were installed (Rosemount, 1151 GP6 Smart, 0–7 × 10^5 Pa, 4–20 mA, and WIKA, Wika Tronic 891.34.500, 1–40 × 10^5 Pa, 4–20 mA). The gauges give analogue current signals which correspond to pressure. The signals were registered by a data acquisition system. The gauge with the smallest pressure range was a pre-calibrated model which showed, according to the calibration certificate, a maximum current deviation from the minimum current signal of ±0·002 mA, corresponding to 0·004 × 10^5 Pa. This gauge was used to calibrate the two others attached to the tube by simultaneously applying water pressure to the system. The current deviation of these gauges was ±0·02 mA, corresponding to 0·03 × 10^5 Pa. From this follows that the small error in the measurement of pressure with the gauges used could not interfere with the accuracy of the determination of the viscosity of the sourdoughs, as this ranged from 9 to 37 Pa s.

The apparent viscosity of sourdough was determined by calculating the shear stress and apparent shear rate, using the following equations:

$$\tau = R\delta p/2L$$

$$\gamma_a = 4V_f/\pi R^3$$

where τ = shear stress
R = tube radius
γ_a = apparent shear rate
δ_p = pressure drop
L = tube length
V_f = volumetric mass flow

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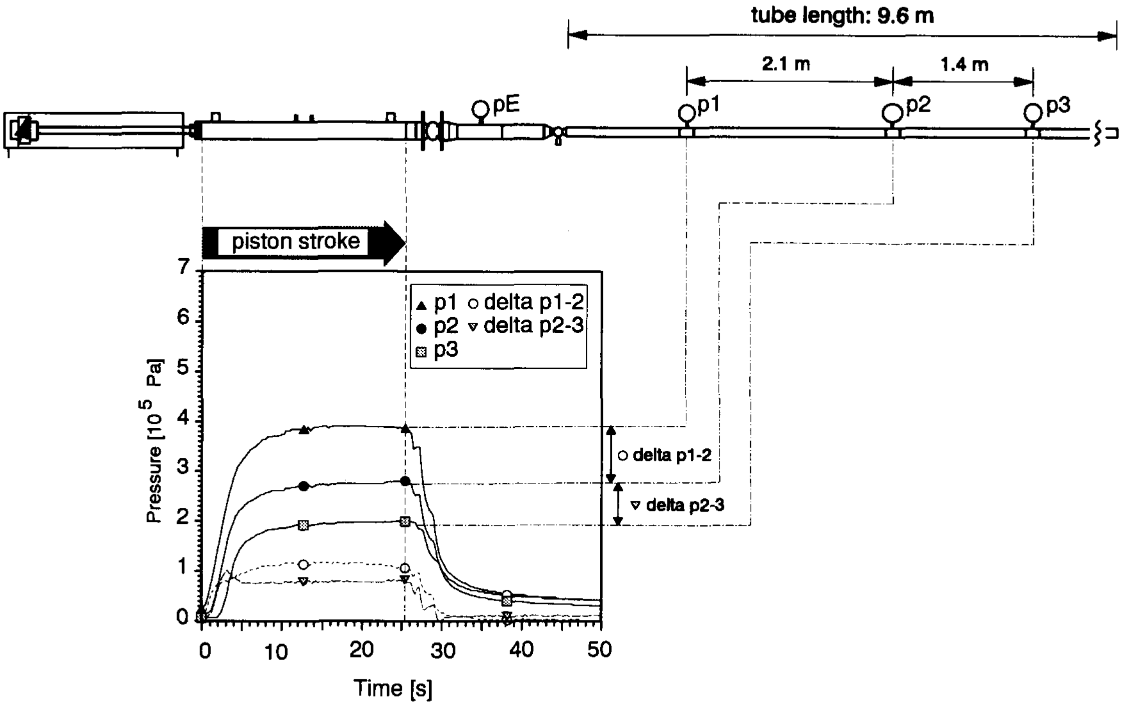

Fig. 1. Pressure curve gained by pressing sourdough through the tube viscometer.

The sourdough viscosity was calculated from the viscometer readings. In order to get usable readings, the gauges were placed over the measuring distance in such a way that the pressure drop between the first and last measuring points was linear. Figure 1 exemplifies the measuring procedure.

In order to distinguish between the sourdough's flow and wall slip within the tube, trials were carried out by which sourdoughs were moved through tubes differing in diameter. The volumetric mass flow was so adjusted that an equal shear stress resulted in the tubes. From the values determined for the apparent shear rate the velocity with which sourdough slipped along the wall of the tubes was calculated according to the equation given by Mooney (1931):

$$v_s = 0{\cdot}25 \times (\gamma_{a1} - \gamma_{a2})/(1/R_1 - 1/R_2)$$

where v_s = velocity of slip
γ_a = apparent shear rate

and subscripts 1 and 2 indicate tube diameters of 50 and 80 mm, respectively. Application of the formula requires the fluid to have a stationary flow.

RESULTS

Apart from the microbial and enzymic activity taking place in the sourdoughs during a fermentation time of 3 h, the swelling capacity of the flour components has a decisive influence on the viscosity of the sourdoughs (Table 1). This was indicated by the variation of the values for the apparent viscosity of the sourdoughs at the outlet of the fermentation tank and of the freshly

Table 1. Apparent viscosity of rye flour sourdoughs as measured under the conditions given by the fermentation process

Source of sample	Rye flour sourdough, Dough yield: 200 (d.s. = 43%) Acidity (°A)[a]	pH	Temperature (°C)	App. viscosity (Pa s)
Inlet	10·2	4·1	30·3	37·73
Inlet	10·5	4·2	28·8	16·33
Inlet	10·4	4·2	29·3	27·43
Outlet	13·6	3·9	29·5	14·14
Outlet	13·3	3·9	30·1	16·20
Outlet	13·4	3·8	28·6	11·08

[a](°A): ml 0·1N NaOH/10 g diluted sourdough.

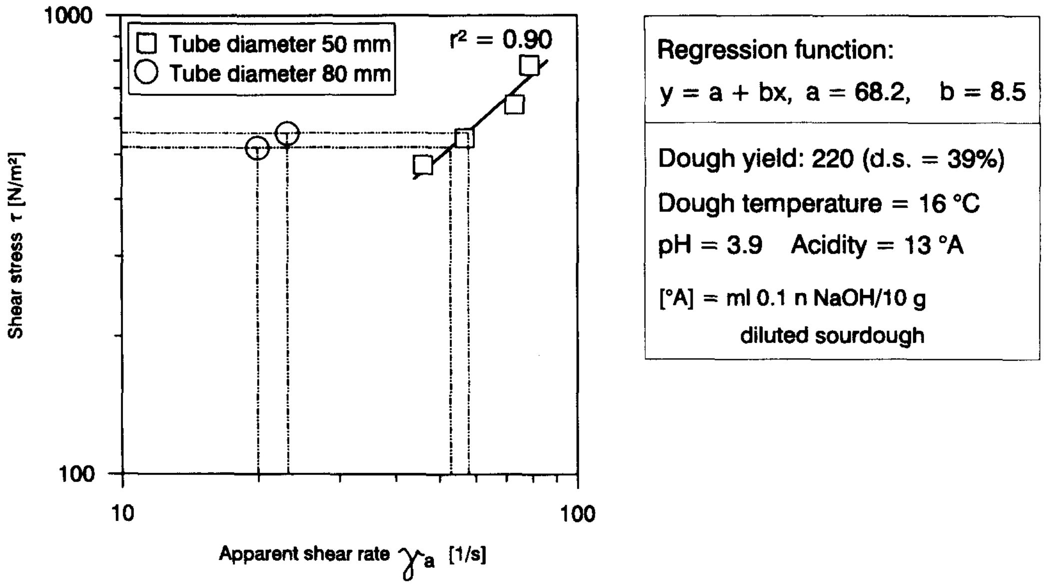

Fig. 2. Determination of the velocity of slip of cooled rye flour sourdoughs flowing in tubes.

prepared sourdoughs at the tank's inlet. At the inlet the maximum value was 130% of the minimum value, whereas at the outlet this variational range was only 30%. This led to the conclusion that it is mainly the mixing of ripe sourdough from the tank's outlet with flour and water to sourdoughs of an equal acidity and temperature that influences the state of swelling of the flour components of the freshly prepared sourdoughs. This in turn results in differences in viscosity of the sourdoughs at the tank's inlet.

The investigation of wall slip effects revealed a typical slip behaviour with cooled, ripe sourdough (Fig. 2) and with fresh sourdough, whereas no wall slip could be detected with ripe sourdough. Applying the Mooney equation to the results of the investigation for fresh sourdough and cooled, ripe sourdough, however, led to values of the velocity of slip which were higher than the flow velocity actually measured. This points to a flow behaviour of these sourdoughs which does not follow the conditions for the application of the Mooney equation. Instead, a stick-slip flow (Lim & Schowalter, 1989) can be assumed which could not yet be verified. Further investigations have to be made to clarify this point.

CONCLUSIONS

The results contributed to the understanding of the flow behaviour of sourdoughs in the fermentation system. This was an important precondition for the design of the fermentation tanks, tubes and pumps of the system. The values gained were used to determine and fix the parameters for the mass streams in the single stages of the process taking into consideration the viscous, flow, and wall slip properties of the sourdoughs developing under the fermentation conditions.

REFERENCES

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