BIOREACTORS WITH THIN-LAYER CHARACTERISTICS
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SUMMARY
In this paper an alternative to the stirred tank type of bioreactors is presented, which is characterized by a low ratio of liquid-to-gas-volume. In different constructions high interfacial areas are created by thin layers of liquid at low degree of "hinterland" in the liquid phase. The physical characteristics like fluid dynamics, OTR, mixing and the degree of hinterland are discussed together with some applications to bioprocessing. In conclusion, the interesting features of thin-layer-bioreactors for proper process kinetic analysis are recognized.

BIOREACTOR CONSTRUCTIONS
To facilitate transports in bioprocessing Gorbach (1969) described a reactor, where thin layers of liquid and/or solid are created on the surface

FIG. I: Bioreactors with Thin -Layer Characteristics:
TLF = thin-layer fermenter, TLFF = thin-layer film fermenter
ATF = agitated tubular fermenter, HRF = horizontal rotary fermenter

of a drum rotating in a liquid bulk inside a horizontal tube. Three configurations can be distinguished: the TLF, using microbial flocs, the TLFF with biofilms growing on the surface of a rotating drum and the ATF as a sort of G/L-fluidized bed with a foamlike consistency (Moser, 1977a). Another equipment creating thin layers of liquid originally used by Phillips et al. (1961) was later elaborated by Ghose and his group at IIT (Ghose and Mukhopadhyay, 1976; Mukhopadhyay and Ghose, 1976, 1978; Mukhopadhyay and Malik, 1980). The physical characteristics of these constructions, shown on FIG.1, will be discussed together with some applications to bioprocessing (Moser, 1980c).

PHYSICAL CHARACTERISTICS
As the basic behaviour of TLF's was already summarized in literature (Moser, 1977a) only the most important facts are given here.

Bioreactors of the TLF-type exhibit a film thickness of L-phase, which was calculated as much greater than the penetration depth of O₂ if the rotational speed n > 30 rpm. The G/L-interfacial area is constant and only dependent on geometry, while the L-surface is permanently renewed by a surface renewal rate s (sec⁻¹), which is the reciprocal value of the G/L-contact time t₃: s = n(1 - ∞/100)⁻¹ for the TLF and for the HRF s = n.θ/360, with θ angle formed by the surface and the center of the vessel (θ = 2α). So the mass transfer coefficient at G/L-interface, kₚ,L, is directly correlated with the rotational speed: kₚ,L = √D.s.απn.

The application of Danckwerts' surface renewal theory was confirmed by a theoretical analysis in the TLF (Moser, 1973b). At higher rotational speeds, however, deviations were observed due to adsorption, which lead to modified equations for OTR (Phillips et al., 1961; Moser, 1977a).

As a further consequence of the construction, i.e. concentric cylinders with a small gap, these types of equipment (TLF, TLFF) offer approximately constant shear rate across the annulus (Kreiger and Maron, 1954). As shearing forces and exposure time are both active in the case of shear sensitive cells, the TLF is advantageous for the use in continuous operation in shear experiments, as the residence time distribution exhibits plug flow to a high degree even at high values of OTR.

Measurements of OTR were carried out with the aid of the sulfite-oxidation method and kₚ,L.a-values are reported up to 1300 h⁻¹ at 400 rpm in the ATF at V = 20 l, but only 300 h⁻¹ in TLF and TLFF and 200 h⁻¹ in the HRF at 200 rpm with V = 11. More recent data on OTR were realized in a laboratory pilot-plant of ATF, comparing kₚ,L.a-values from sulfite method with actual