HYDRODYNAMICS OF A THREE-PHASE FLUIDISED BED BIOREACTOR WITH A NOVEL BIOMASS SUPPORT

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ABSTRACT

In this research the potential of the KMT^R *particles as a biomass support for the high-rate aerobic treatment of industrial wastewaters was assessed by investigating the hydrodynamics of a bioreactor with that support. In particular, the minimum fluidisation air velocity,* u_{gm}, *and the air holdup,* ε_g, *were measured. It was found that the values of* u_{gm} *strongly depended on the mass of cells grown on the particles and were inversely proportional to the mass. The values of* u_{gm} *also depended on the ratio of support volume to bioreactor volume* (V_b/V_r). *The values of* u_{gm} *increased with increase in* (V_b/V_r). *The values of* ε_g *depended on the air flow rate and the ratio* (V_b/V_r). *The values of* ε_g *increased with increase in the air flow rate. The largest values of* ε_g *were obtained for the* (V_b/V_r) *equal to 0.6.*

It was also established that the values of ε_g *obtained for the* KMT^R *particles were approximately 40% larger than those reported in literature for other biomass supports. The large air holdup obtained in the bioreactor with the* KMT^R *support merits application of the* KMT^R *particles as a biomass support for the high-rate aerobic biological treatment of municipal and industrial wastewaters.*

Stratification of the KMT^R *support coated with the biomass lead to movement of the particles to the base of the bed where substrate concentration was the highest. This was desirable since the substrate could penetrate far into the biofilm so most of the biomass was active.*

INTRODUCTION

A practical problem which can occur in operation of a three-phase fluidised bed bioreactor is the excessive growth of biomass on support particles. This can lead to difficulties owing to the clogging of packed beds or the channelling of bioparticles in fluidised beds. In the latter, the biomass loading can increase to such extent that the bioparticles began to be carried over from a bioreactor. The problem of overexpansion of fluidised beds due to biomass growth has generally been solved by the removal of heavily biomass-laden particles from bioreactor, followed by the addition of biomass-free particles. However, this solution complicates operation of a bioreactor and introduces the need for additional equipment external to the bioreactor, such as a vibrating screen or an incinerator.

The primary objective of wastewater treatment process is the transformation of toxic compounds in wastewater into non-toxic compounds. Concentration of the biomass which may result is a secondary consideration. With this primary objective, use of the external device for removing biomass is an added source of inconvenience to the operation, especially when one considers some of the operational problems due to blockage and breakdown which can occur when using machinery such as vibrating screens. This can be avoided if a way can be found to regulate the biomass growth on support particles by manipulating the fluid-mechanical conditions inside a bioreactor so that a steady state is reached where the rate of biomass growth is equal to the rate of biomass attrition.

Livingston and Chase [1] have demonstrated that a practically steady biomass loading can be achieved in a draft tube fluidised bed bioreactor where the shear forces, occurring between the particle and the liquid, slough off excess biomass from support particles. Another way of controlling the biomass loading can be the application of a light biomass support (matrix density lower than that of water) in a conventional fluidised bed bioreactor. Rusten et al. [2] applied a plastic support in a bioreactor used for treatment of dairy and food industry wastewaters. With this support, a considerably higher treatment efficiency was achieved than that obtained in a bioreactor with a sand support. The biomass loading was relatively low and practically constant over the entire period of three

month operation, and yet, the bioreactor performed very well with approximately 95% removal of total COD. Clogging and channelling of the bed have been eliminated through the intensive motion of the particles. Particle-particle and particle-wall collisions sloughed off excess biomass.

Analyzing the aeration characteristics of a three-phase fluidised bed bioreactor with various biomass supports, Sokol and Halfani [3] concluded that a bioreactor with the KTM^R particles can be effective for treatment of industrial and municipal wastewaters. In order to assess the potential of the KMT^R particles as a biomass support, the hydrodynamics of a bioreactor with that support was investigated. In particular, the minimum fluidisation gas velocity, u_{gm}, and the gas holdup, ε_g, were measured. The results were compared with those reported in literature for other biomass supports.

EXPERIMENTATION

Experimental set-up

Experiments were performed in the apparatus shown in Fig.1. The fluidised bed section *9*, constructed from the Duran glass, had a 20 cm internal diameter and was 6 m high. It was ended by a disengaging cap *10* with 60 cm internal diameter and a height of 80 cm. A growing medium, stored in reservoir *1*, was pumped into the bottom of the bed by a centrifugal pump *5*. Before entering the bed, the liquid was mixed with the air by means of a sprinkler. The air was introduced to the bed through a distributor *7* whose plate had 200 x 4 mm diameter holes on a triangular pitch. The air flow rate was measured with a rotameter *11* and was controlled by a needle valve. The liquid recycle flow rate was measured with a rotameter *4* and was controlled by a ball valve. The temperature control system *2* consisted of a coil with cold water and an electric heater coupled with a contact thermometer. The pH was adjusted by a control system *3*, consisting of a pH-meter and micropumps supplying base or acid as required. Sterile conditions were not maintained, the philosophy being that the experiments shall be performed at the same conditions as a full-scale wastewater treatment plant is to be operated.

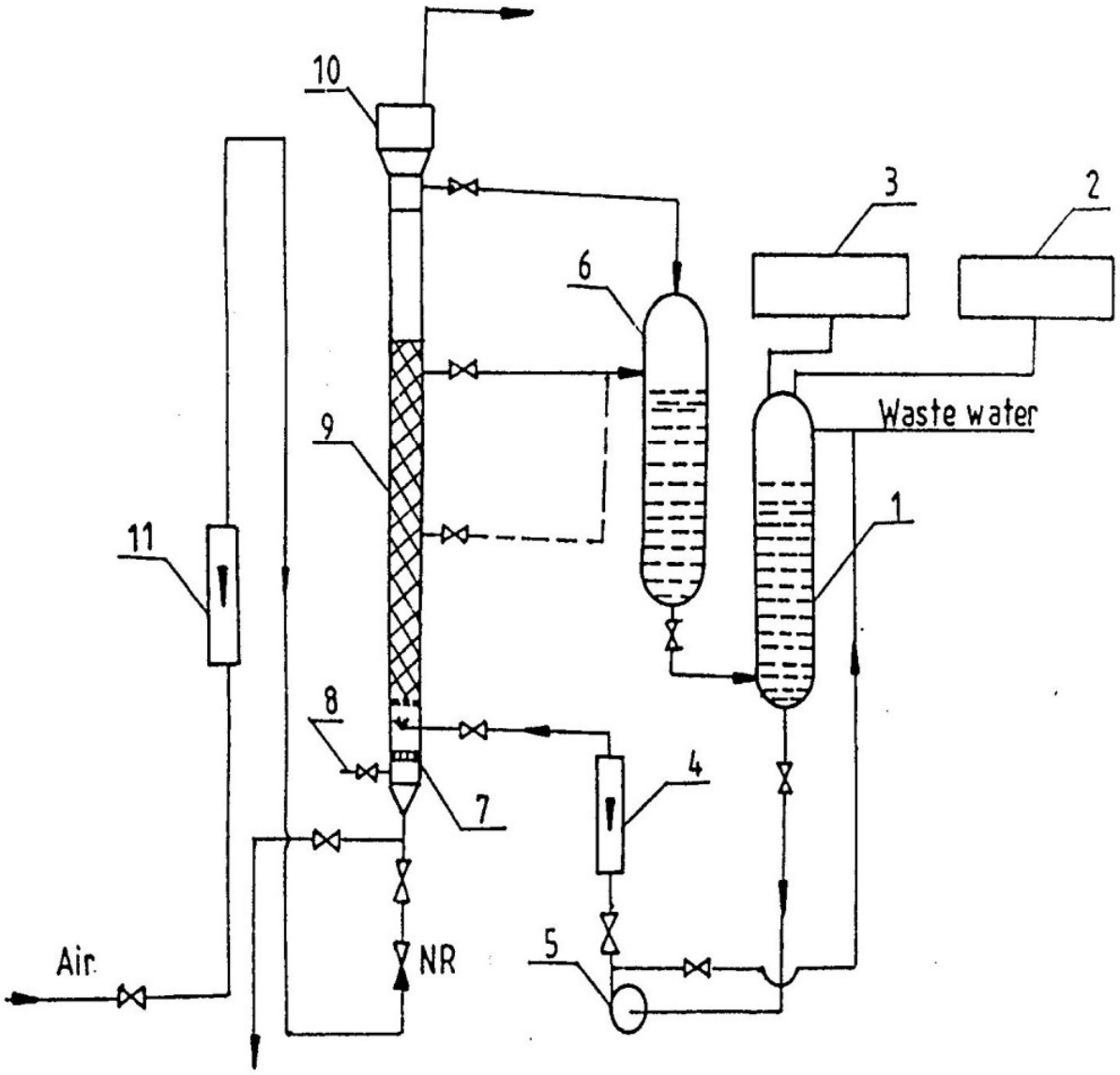

Fig. 1 Schematic diagram of the apparatus. 1 - reservoir; 2 - temperature control system; 3 - pH control system; 4 - liquid rotameter; 5 - pump; 6 - intermediate reservoir; 7 - air distributor; 8 - sampling; 9 - fluidised section; 10 - disengaging section; 11 - air rotameter.

The growing medium was the wastewater from the Tanzania Italian Petroleum Refinery (TIPER) at Dar es Salaam, enriched in mineral salts as recommended by Livingston and Chase [1]. An inoculum was the

activated sludge taken from a biological treatment plant operated at TIPER.

The biomass support were the KMT^R particles whose dimensions are shown in Fig. 2. The particles were made of polypropylene of density 910 kg/m^3. The specific biofilm surface area could have been regulated, by adding the particles, up to approximately 400 m^2/m^3.

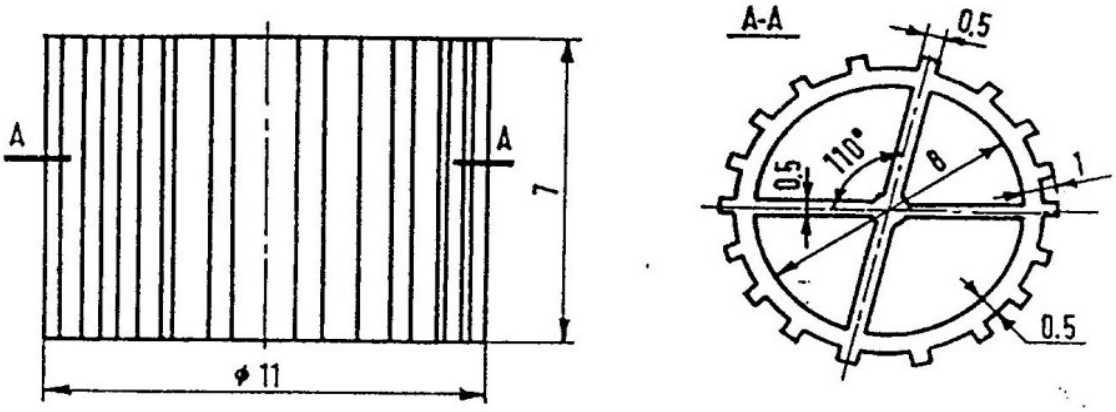

Fig. 2 The KMT^R biomass support.

Measurements

The experiments to determine the minimum fluidisation gas velocity, u_{gm}, were conducted for the biomass-free and the biomass-laden particles. The measurements were performed for various values of ratio of support volume to bioreactor volume.

The experiments to establish the air holdup, ε_g, were carried out for various values of the support volume to bioreactor volume ratio.

Biomass-free particles

The bioreactor was filled up with the growing medium and a set-up volume of the support was introduced into it. Then, the air flow rate was

started. Since the matrix density of the KMT^R particles was smaller than that of water, the particles floated in the liquid and conventional upward-flow fluidisation was not possible. Therefore, the air flow was smoothly increased until pseudo-fluidisation (downward-flow fluidisation) was induced by air bubbles. The bubbles made the bed expanding downwards into the less dense mixture of air and liquid. There was no flow of the liquid through the bioreactor. The smallest superficial air velocity which was sufficient to induce movement of the whole bed was considered as the minimum fluidisation air velocity u_{gm}. As established during the experimentation, the experimental error was 8%. The experimental results are shown in Fig. 3.

The gas holdup, ε_g, was established following a standard procedure given by Fan [4]. The values of ε_g were obtained as the difference between the volume of the contents in the bioreactor at fully developed pseudo-fluidisation and at no air flow through the bioreactor. The experimental values of ε_g are shown in Fig. 5.

Biomass-laden particles

After completion of the experiments for the biomass-free particles, the inoculum was introduced into the bioreactor. The biomass was cultured for 48 hours in order to encourage the cell growth and the adhesion of freely suspended biomass on the particles. The air was introduced at 4 m^3/h and this was found to be sufficient for the biomass growth. The pH was controlled in the range 6.7 - 6.9 and the temperature at 30°C. When the biofilm had begun to grow on the particles, the growing medium was pumped into the bioreactor at a dilution rate of 0.2 h^{-1}. The culturing had been continued until the required biomass loading was achieved.

The minimum fluidisation gas velocity, u_{gm}, was established following the same procedures as described above. The experimental results are shown in Fig. 3.

RESULTS AND DISCUSSION

It can be seen in Fig. 3 that the values of u_{gm} strongly depended on the mass of cells grown on the particles. For example, an increase in the mass from 18 to 26 mg biomass (BTS)/particle (approximately 45% increase), caused a decrease in u_{gm} almost three times. As can be noted in Fig. 3 the values of u_{gm} increased with increase in the ratio (V_b/V_r). For the (V_b/V_r) larger than 0.7, movement of the whole bed was impossible: the particles either remained at the top or settled at the bottom of the bioreactor. The values of $(V_b/V_r)_{cr}$, above which this was happening, depended on the mass of cells grown on the particles. The values of $(V_b/V_r)_{cr}$ decreased with increase in the biomass.

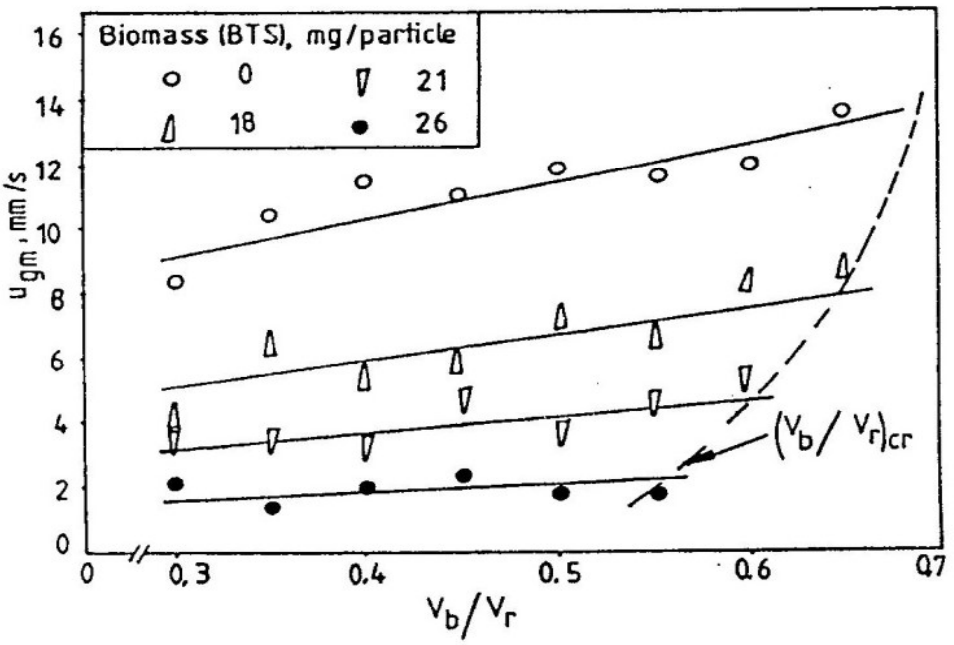

Fig. 3 Relationship between the minimum fluidisation air velocity, u_{gm}, and the ratio (V_b/V_r) for various mass of cells grown on the KMT^R particles (mg biomass(BTS)/particle).

Comparison of the values of u_{gm} obtained in this research for the KMT^R particles with those reported by Walker and Austin [5] for the polypropylene 53 x 13 x 20 mm toroids is shown in Fig. 4. As can be seen in Fig. 4, the values of u_{gm} for the KMT^R support and the toroids, both biomass-free, were in the same range. However, the values of u_{gm} for the KMT^R support were more affected by the growing cells than those for the toroids. Approximately two and half times more biomass was required to grow on the toroids to observe the same decrease in u_{gm}. The values of $(V_b/V_r)_{cr}$ for the toroids were practically independent of the biomass grown on the support.

During the experimentation it was observed that stratification of the particles coated with the biomass lead to movement of the support to the base of the bed where substrate concentration was the highest. This was desirable since the substrate could penetrate far into the biofilm so most of the biomass was active [6].

It can be seen in Fig. 5 that for a given ratio (V_b/V_r), the values of ε_g strongly depended on the air flow rate. Since the bubble size little varies with the air flow rate [7], the interfacial

area was mainly determined by the air flow rate. The largest values of ε_g were obtained for the (V_b/V_r) equal to 0.6.

CONCLUSIONS

The values of the minimum fluidisation air velocity, u_{gm}, strongly depended on the mass of cells grown on the particles and were inversely proportional to the mass. The values of u_{gm} also depended on the ratio of support volume to bioreactor volume (V_b/V_r). The values of u_{gm} increased with increase in the (V_b/V_r). The values of u_{gm} for the KMT^R particles and the toroids, both biomass-free, were in the same range. However, the values of u_{gm} for the KMT^R particles were more affected by the growing cells than those for the toroids. About two and half times more biomass was required to grow on the toroids to observe the same decrease in u_{gm}.

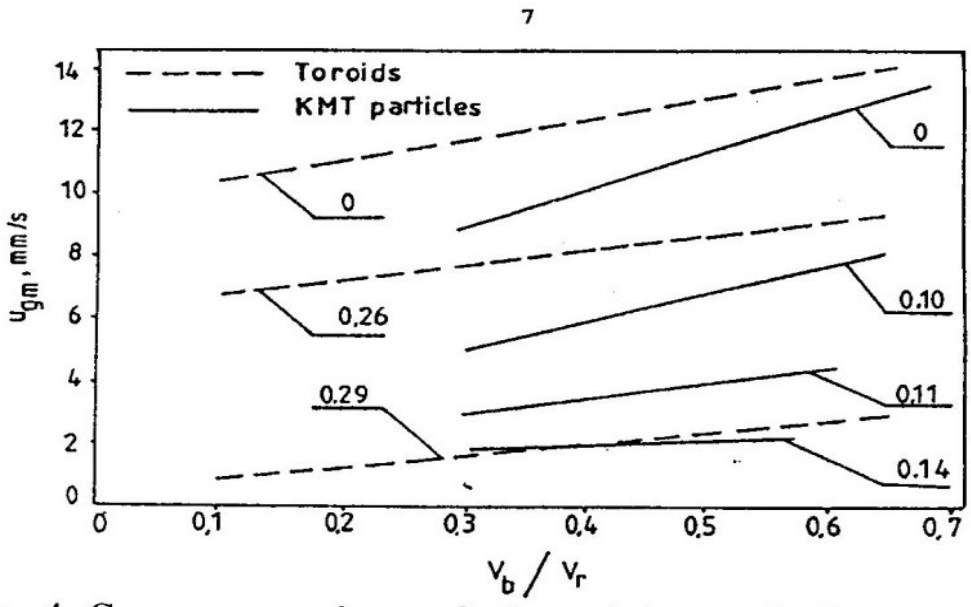

Fig. 4 Comparison of the minimum fluidisation air velocity, u_{gm}, for the KMT^R support and the toroids (53 x 13 x 20 mm) for various values of the ratio (V_b/V_r) and the biomass grown on the support (g biomass (BTS)/g particle).

The values of the air holdup, ε_g, depended on the air flow rate and the ratio (V_b/V_r). The values of ε_g increased with increase in the air flow rate. The largest values of ε_g were obtained for the (V_b/V_r) equal to 0.6.

Analysis of the air holdup, ε_g, established in this research for the KMT^R particles and those reported by Cooper and Atkinson [7] for other biomass supports showed that the values of ε_g obtained for the former were about 40% larger than those for the latter. The large air holdup achieved in the bioreactor with the KMT^R support makes the particles a high potential biomass support for the high-rate aerobic biological treatment of industrial and municipal wastewaters.

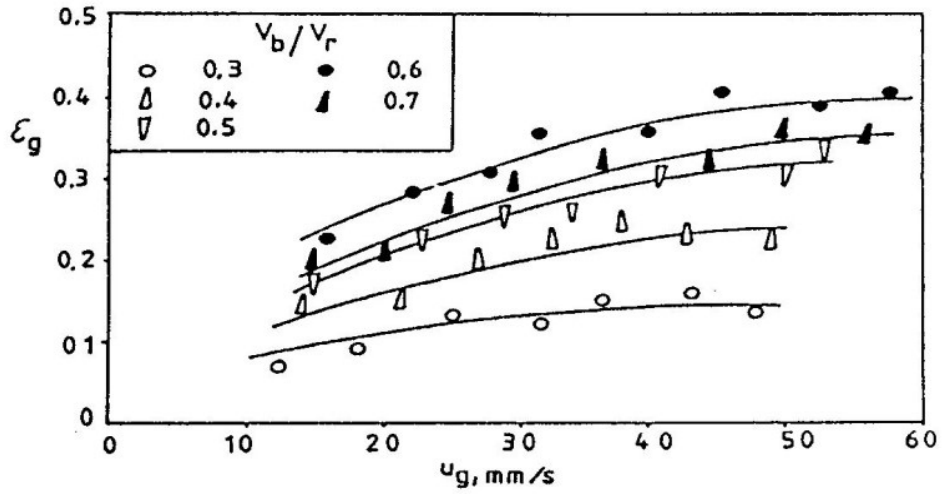

Fig. 5 Dependence of the air holdup, ε_g, on the superficial air velocity, u_g, for various values of the ratio (V_b/V_r).

The values of ε_g obtained for the KMT^R particles were approximately 40% larger than those reported in literature for other biomass supports. The large air holdup achieved in the bioreactor with the KMT^R support merits application of the KMT^R particles as a high potential biomass support for the high-rate biological treatment of industrial and municipal wastewaters.

Stratification of the KMT^R particles coated with the biomass lead to movement of the support to the base of the bed where substrate concentration was the highest. This was desirable since the substrate could penetrate far into the biofilm so most of the biomass was active.

NOMENCLATURE

u_g	air velocity, mm/s
V_b	support volume, m^3
V_r	bioreactor volume, m^3
ε_g	air holdup

Subscripts

cr	critical
m	minimum

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