



## **THE INFLUENCE OF THE VELOCITY GRADIENT ON MORFOLOGICAL PROPERTIES OF AGGREGATES**

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**Summary:** *This paper summarises the preliminary results concerning an influence of the agitation conditions on the aggregation processes. The properties of formed aggregates affecting the efficiency of separation processes are studied as well. The results show that the applied velocity gradient  $G$ , the period of its action  $T$  and the distribution of velocity field in an agitated volume of water significantly influence the number of aggregates, their size and shape. Smaller and denser aggregates of a homogeneous size and more resistant to breakage are formed under a higher velocity gradient.*

### **Introduction**

The process of aggregation of destabilised particles resulting in formation of separable aggregates belongs to the basic technological processes of water treatment. Conditions of aggregation and magnitude of adhesive and tangential forces interacting between aggregating particles in contact affect resulting characteristics of formed aggregates, their shape, size and internal structure. In complex, they determine physical characteristics of aggregates, substantially affecting the efficiency of the separation processes commonly used in water treatment technology.

In the past, a great number of studies were dedicated to investigate the influence of the physical factors on the kinetics of the aggregation process and a number of relationships were derived to describe it. With the practical application aimed at controlling the performance of the works and its design, these relationships are applicable in a very limited extent only. Very few studies enabling the determination of conditions of agitation and its influence on the properties of aggregates, which influence the efficiency of the separation processes and the properties of produced sludge, were published (Hudson, 1965; Tambo and Watanabe, 1979; Francois and Van Haute, 1985; Francois, 1988; Tambo and Hozumi, 1979; Tambo, 1990; Amirtharajah and Tambo, 1991).

The applicability of the research results is dependent on the methods of their evaluation. This is particularly important with flocculent aggregates, because their size, shape and density are not easily definable and measurable. In addition, the applicability of the results obtained is even more difficult because there is no similarity between the conditions of agitation in jar tests and a full size plant. As a result, the differences in the properties of formed aggregates are commonly ascribed to differences in the character of flow.

The preliminary results obtained from the research aimed at studying the influence of the conditions of agitation on the progress of the aggregation process and certain properties of aggregates from the point of view of the efficiency of separation processes are summarised in this contribution. In this research natural surface waters were used.

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The experimental work was carried out using water from the impounding reservoir Vrchlice, Czech Republic, in summer seasons, when the organic pollution was increased by the products of biological life (metabolic extracellular organic matter - EOM) and its destruction (intracellular organic matter – IOM).

The suspension that was investigated was prepared in a Couette type reactor with the inner cylinder rotating (Pivokonsky et al., 2003; Selomulya et al., 2004). The velocity gradient in the Couetter is defined for a laminar flow only ( $Re < 2200$ ). The values of the Reynolds and Taylor numbers and the applied velocity are summarised in Table 1.

Table 1. The hydraulic conditions of agitation

G [ $s^{-1}$ ]	Re [-]	Ta [-]
40	3349	1123
60	5024	1835
80	6699	2446
100	8373	3058
150	12560	4586
200	16747	6115
250	20933	7644
300	25120	9173
350	29307	10701

Ferric chloride was used as the destabilisation reagent. Its dosage was optimised by jar tests. The development of aggregates was recorded at predetermined intervals with a Pentax K 100D digital camera. After processing the digital images obtained from a defined area, which was the same for all tests, the number of aggregates formed was counted (Pivokonsky et al., 2003) and longitudinal dimensions in the direction of rotation and that perpendicular to it as well as the area of the individual aggregates were measured.

## Results

Studying the influence of the magnitude and period of action of the applied velocity gradient on the course of the formation of flocculent aggregates in a Couette reactor enables one to obtain a comprehensive understanding of how each of these parameters effect the kinetics and the mechanism of the aggregation process and the properties of the aggregates formed.

Since aggregation is a time dependent process, the kinetics of this process is most realistically described by the changing number of aggregates in the system. The course of these changes of tests is illustrated in Fig.1. This Figure shows that the most significant changes occur at the beginning of the aggregation process and the destabilisation of the particles of impurities is completed immediately after the addition of reagent and that, irrespective of the value of the velocity gradient employed, the number of aggregates being formed drops to a minimum  $N_{min}$  in this phase of the process. The time  $T_{min}$  required to achieve this minimum decreases with an increasing agitation intensity  $G$ ; from  $T_{min} = 5$  min with  $G = 40 s^{-1}$  to  $T_{min} = 30$  s with  $G = 350 s^{-1}$ . The formation of aggregates of an identifiable size is completed within the time required for the aggregates to grow to a size where the influence of their movement, producing the tangential forces, becomes effective. The influence of the increasing agitation intensity on the rate of decrease in the number of the particles of impurities, in this phase of the aggregation process, is partly the result of a faster and more efficient dispersion and homogenisation of the added reagent with the water being treated.

The hydrodynamic conditions of aggregation affect the size and shape of the aggregates and these changes define the mechanism of the process. The basis for the evaluation of both these

characteristics is the measurement of the longitudinal dimension of aggregates  $l_l$  and perpendicular dimension to it  $l_p$  together with the cross section of aggregates  $A$ .

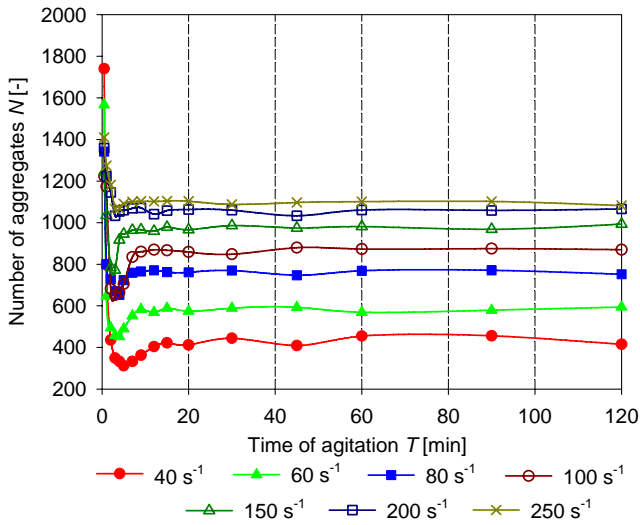


Fig. 1. Influence of  $G$  and  $T$  on  $N$

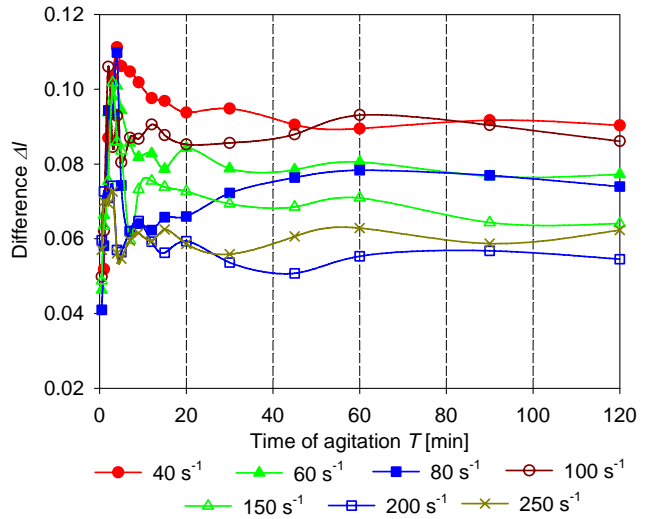


Fig. 2. Influence of  $G$  and  $T$  on  $\Delta l$

The effect of the intensity and duration of agitation on the shape of aggregates for individual velocity gradients is illustrated in Fig.2 by the dependence of difference in length  $\Delta l = l_l - l_p$  on time of agitation for different  $G$  values. The aggregation curves show that in the initial phase of aggregation the aggregates are of a non-homogeneous shape with the longer dimension being oriented in the direction of flow. Their shape can be described as an ellipsoid of rotation. The difference in length between the axis as well as the ratio of dimensions defining the shape of the aggregates of a stabilised size balances as the aggregation progresses. In an ideal case, the dimensions of axis equalise and the aggregates become spherical. The equalising of the aggregate dimensions, with exception of the lowest velocity gradient, was completed within 15 minutes of agitation. The agitation lasting over 15 minutes did not significantly change the shape of aggregates formed. Fig.2 also shows that the sphericity of aggregates is dependent on velocity gradient and its duration.

The intensity of agitation also influences the volume of aggregates formed. Fig.3 shows that the volume of aggregates initially increases and after reaching a maximum volume  $V_{max}$  it drops. The rate of this drop gradually decreases until the size of aggregates stabilises at a value  $V_{stab}$ . Fig.6 shows that a continuous step decrease in the volume  $V_{max}$  takes place in the range of  $G = 40-80 \text{ s}^{-1}$  and  $G = 100-200 \text{ s}^{-1}$  and in the range of  $G = 80-100 \text{ s}^{-1}$  and for  $G > 200 \text{ s}^{-1}$  it remains almost unchanged. In contrast, the volume  $V_{stab}$  slowly reduces up to  $G = 200 \text{ s}^{-1}$  and for a higher  $G$  it remains almost unchanged.

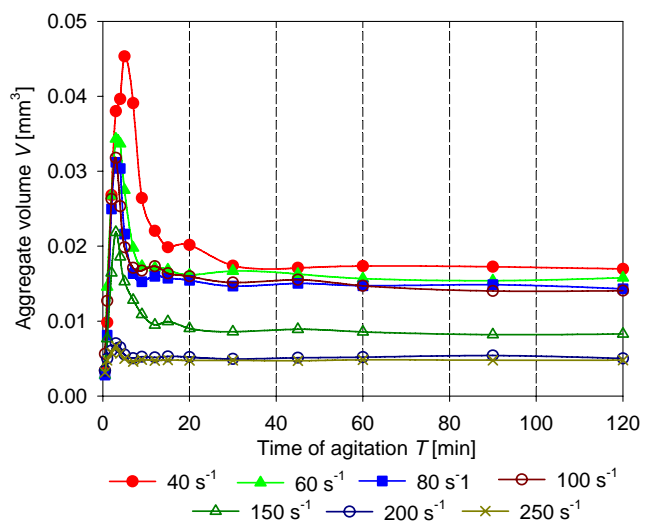


Fig. 3. Dependence of  $V$  on  $T$  and  $G$

## Conclusions

The conditions for the formation of separable aggregates are determined by the ratio of adhesion and tangential forces acting on the destabilised particles and on aggregates being formed during their formation.

The effect of the magnitude and period of action of the tangential forces on the number of aggregates and their size begins to manifest itself in the range of aggregates size around  $d = 10^{-6}$  m. With increasing velocity gradients the magnitude of the tangential forces increases and the mutual ratio of adhesion and tangential forces decreases. With all individual  $G$  the size of aggregates grew to a maximum and their number dropped to a minimum. The minimum number and the maximum size of the formed aggregates were dependent on the magnitude of the velocity gradient applied and water quality. The form of the curves illustrating the dependence of changes in the number of aggregates, their size and shape on velocity gradients showed that there is a range of gradients where both the number of aggregates and their size does not change ( $G = 80-100 \text{ s}^{-1}$ ). In this region, with the magnitude of the tangential forces exceeding that which is binding the destabilised particles together in the aggregates being formed, the relatively loose bonds between the particles produced in the initial stage of the aggregation process, by means of thermal motion, are subjected to the action of tangential forces and the particles shift into an energetically more stable positions. This results in a more compact inner structure of the aggregates, which corresponds to the velocity gradient applied. This inner restructuring of aggregates is accompanied by a significant change in their size and shape which is evident from the decreasing differences of the lengths of axes of an ellipsoid circumscribed of the aggregates, their decreasing concentration and reducing rate in the changes of their size. In the range of lower velocity gradients the restructuring of aggregates does not take place and aggregates of a greater range of size-distribution are formed. In the range of higher velocity gradients the restructuring takes place from the beginning of the aggregation process. This is evident from the formation of aggregates of a smaller size, with their shape approaching spherical and gradually increasing concentration.

In the compaction phase, depending on the period of agitation, the size of aggregates decreases, their concentration increases and the area occupied by the aggregates formed increases until a state of equilibrium is reached. The magnitude of these changes corresponds to the magnitude of the velocity gradients applied. The most profound changes occurred with low velocity gradients over a longer duration.

In the steady state phase the number, size and shape remained almost constant with prolonged period of agitation and the difference between the magnitudes of these parameters decreased with increasing velocity gradients. With high velocity gradients the difference between them was almost unnoticeable.

In the surface erosion phase the aggregates are exposed to a prolonged action of the tangential forces. This is causing surface erosion of the aggregates that result in a very slowly decreasing size of aggregates.

From a practical point of view the results prove that, the velocity gradient together with the duration of its action and especially the uniform distribution of a velocity field, represent important parameters for the designing of unit operations for the formation of separable suspensions. With high velocity gradients and the uniform distribution of a velocity field, the aggregates formed are more compact and homogeneous in size and resistant to breaking up.

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