

# Differentiation between different kinds of mixing in water purification – Back to basics

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## Abstract

The term mixing is confusing because it is used to describe transport mechanisms for both flash mixing (reagent dispersion and homogenisation with water mixing) and agitation (flocculation mixing) because each of these mechanisms requires different flow characteristics in order to take place with maximum efficiency. Flash mixing should take place under conditions of mixing on macro-scale with macro-turbulent eddies being formed and agitation under conditions of mixing under micro-scale with micro-turbulent eddies being formed. Agitation takes place under high- or low-intensity agitation. Only the conditions of agitation can be characterised by velocity gradient. Differentiation between flash mixing and agitation is discussed.

**Keywords:** mixing, agitation, mixing intensity, homogenisation, flocculation

## Introduction

Mixing is an important operation in any water purification process. It facilitates dispersion and homogenisation of added reagents with water and contacts between the particles leading to their combining into readily separable flocs. The efficiency of the water purification process is, therefore, dependent on the mixing conditions under which the formation of flocculent suspension takes place.

When designing a flocculation system, the mixing conditions, which include uniform distribution of a velocity field in the agitated volume of water, are not optimised in respect of the most effective utilisation of the added destabilisation reagent and the formation of flocs, the properties of which should be most suitable for the method that is selected for their separation. The reasons are that the importance of the mixing intensity, its duration and flow characteristics on the properties of formed flocs such as their shape, size and compactness (density), are not yet fully appreciated and/or understood in engineering practice.

In waterworks design practice, which prevails to date (Schutte, 2006), the processes of the reagent dispersion and homogenisation with water and the floc formation take place in two separate chambers under the conditions of rapid and slow mixing:

- Rapid mixing is intended for dispersion and homogenisation of added reagent with water and, therefore, is considered a suspension not forming mixing. It takes place with a mean-root-square velocity gradient  $\bar{G} = 80$  to  $100 \text{ s}^{-1}$  over a period of  $T = 10$  to  $60 \text{ s}$  (Amirtharajah and Trusler, 1986; Claus, 1967; Fair and Geyer, 1958; Hudson, 1965).
- Slow mixing is intended for the formation of flocculent suspension. It takes place with a velocity gradient  $\bar{G} = 20$  to  $60 \text{ s}^{-1}$  for a period of  $T = 15$  to  $30 \text{ min}$  and even longer (Fair and Geyer, 1958; Hudson, 1965). Generally, the resultant flocs formed are of a wide range of sizes, densities and settling

velocities. These slow mixing conditions are referred to in this paper as the customary flocculation conditions.

It follows from the above that the difference between these two mixing conditions is only in the mixing intensity, characterised by velocity gradient  $\bar{G}$ .

The rapid and slow mixing conditions as described above are suitable for jar tests, i.e. a batch process, but not for the waterworks through-flow process. In a through-flow system the character of mixing applied to the dispersion and homogenisation of added reagent with water is different to that of the floc formation, should these two processes take place most efficiently. Theory assumes that the final products of homogenisation of hydrolysing destabilisation reagent with water, which takes place in a rapid mixing chamber, are destabilised particles of impurities, and that these destabilised particles are transformed in the subsequent floc-formation process, which takes place in slow mixing flocculation chamber, into readily separable flocs. However, these theoretical assumptions are seldom obtained under current design practice and operational conditions. The likely causes for deviations from theory have their origin in defects of a hydrodynamic nature. These include inability to complete dispersion and homogenisation of the added reagent with water in the rapid mixing chamber and formation of suspension within the flocculation chamber. This results in a functional shifting of the individual processes into subsequent unit operations, where the optimum conditions for such processes no longer exist. For instance, the dispersion of reagent and its homogenisation with water continue in the flocculation chamber and the floc formation process in the sedimentation tanks/clarifiers and filters and sometimes even into the reticulation system. Obviously, this adversely affects the performance efficiency of the works in its entirety as well as the quality of the purified water. Therefore, in through-flow system, the rapid and slow mixing cannot be differentiated by mixing intensity only but by different transport mechanisms applicable for each of these processes. Regrettably, this is not always respected in waterworks design.

The lack of differentiation between different characteristics of flow required for rapid and slow mixing often results in both

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these processes taking place in the same unit operation (the rapid mixing stage is totally omitted), where the optimised conditions do not exist for either of them.

Certain misunderstandings and misconceptions with respect to the importance of the different character and intensity of mixing and its duration that are applicable to these two processes have their roots in the term mixing. The term mixing is indiscriminately used to describe the different characters of mixing (transport mechanisms) required for both of these processes. In order to avoid confusion as to which transport mechanism is referred to, there is a need to differentiate between the two kinds of mixing and to identify them under different names, namely (Polasek, 1980a; 1981):

- Flash mixing (dispersion/homogenisation mixing)
- Agitation (flocculation mixing).

The character of mixing that suits best the requirements of these processes can be defined as follows:

- Flash mixing (dispersion/homogenisation) – mixing on macro-scale, in which partial volumes of water are transferred over long distances and macro-turbulent eddies are formed.
- Agitation (floc formation) – mixing on micro-scale, in which partial volumes of water are transferred over short distances and micro-turbulent eddies are formed, and uniform distribution of a velocity field throughout the volume of agitated water is produced.

It should be emphasised that flash mixing influences the efficiency of the destabilisation process, which determines the quality to which the water is purifiable by the works under the reaction conditions applied, whilst the conditions of agitation under which the flocculation process takes place profoundly influence the separability of formed flocs in general, and the attainable settling velocity in particular, as well as the processing of the produced sludge.

### Flash mixing

Effective flash mixing is required in terms of the chemical reactions point of view because homogenisation of the hydrolysing destabilisation reagent with water is accompanied by many chemical reactions such as hydrolysis, polymerisation of the products of hydrolysis and the diffusion of polymers to the surface of particles of impurities. Some of these reactions are irreversible. The most important reaction is adsorption. The hydrolysing reagent particles have a tendency to mutually bind to one another when there is no free particle surface area in their vicinity. This leads to the formation of precipitates or to the binding of the particles of the hydrolysing reagent onto the surfaces of particles of impurities already occupied by the hydrolysing reagent, thereby causing restabilisation of these particles. In both instances, these particles become inactive resulting in ineffective utilisation of the destabilisation reagent dosage applied.

The principle task of the dispersion and homogenisation processes is the maximum utilisation of the added reagent in the chemical reactions. Therefore, achieving the highest uniformity in the concentration of the added reagent and the pH in the water being purified in the shortest period of time is essential. The mixing conditions required are attained in a flash mixer that provides for the transfer of small quantities of destabilisation reagent over long distance and their dispersion inside the turbulent eddies.

Ineffective dispersion / homogenisation results in the forma-

tion of local under- and over-dosed volumes of water. In the under-dosed volumes of water an insufficient amount of reagent prevents sufficient destabilisation of impurities. In the over-dosed volumes of water excessive amounts of the reagent result in the restabilisation of the just-destabilised particles of impurities. This results in lowering the efficiency of the purification process, or in the need for increasing the reagent dosage. Consequently, the water contains a mixture of particles in different stages of destabilisation, i.e. destabilised, non-destabilised, partly destabilised and restabilised particles. Homogenisation then continues under sub-optimal conditions in the subsequent unit operations, which are intended for the formation of flocs and their separation and not for the homogenisation of the destabilisation reagent with the water. This is the reason why a separate, adequately sized flash mixer should always form a separate unit operation of any waterworks. Furthermore, with respect to homogenisation efficiency, it is equally important that the addition of the reagent is continuous, steady and free of pulsation.

The flash mixing of organic polymers is a specific problem. Their stock solutions are usually highly viscous and cannot be easily dispersed and homogenised with water. In addition to this problem organic polymers also have a tendency to mutually bind to one another or onto surfaces already occupied. This necessitates intensive flash mixing over a longer period. On the other hand, the mixing must be carefully controlled in order to avoid breakage of the polymer chains through prolonged flash mixing. This problem can be overcome by dosing a solution of low concentration that is more readily dispersible.

When pretreatment of water with alkali or acid is required, the limiting requirement for the homogenisation mixing is not the velocity of homogenisation but the completion of the reactions of added reagent(s) with water together with the adjustment of water pH prior to the addition of destabilisation reagent.

When pretreatment of water by oxidation is required, an adequate contact period under the conditions of turbulent flow is required for the completion of oxidation reactions. Its efficiency is dependent on the oxidizing agent as well as on the type and arrangement of the oxidation chamber.

### Agitation

The agitation of water is brought about by hydraulic or mechanical means. Since non-uniform distribution of a velocity field exists in the agitated volume of water, the magnitude of tangential forces varies throughout the flocculating system. This results in considerable differences in the magnitude of tangential forces that are affecting the flocs being formed. Consequently, flocs of different sizes and structures and of a broad range of sedimentation velocities are formed, which unfavourably influence the sizing of the sedimentation plant. In case of the mechanical agitation these variations are influenced by the type, size and speed of rotation of the stirrer, geometry of the basin and character of the flow induced by the stirrer. In the case of the hydraulic agitation, these variations are influenced by water velocity in flume, geometry of the flume and changes in the direction of flow.

Under the customary flocculation conditions, slow mixing is considered to be instrumental for the formation of readily settleable suspension. Its purpose is to facilitate the formation of large, kinetically unstable flocs. The idea that the formation of large flocs is beneficial is associated with the belief that the intensity of agitation should not exceed a certain limit beyond which floc breakage occurs. Therefore, slow mixing is often designed such that its intensity decreases as the process of flocculation progresses (tapered flocculation).

The basic changes taking place during the flocculation process include the changes in the number of the destabilised particles of impurities, the number of flocs being formed from these particles and in the size, shape and density of the formed flocs. The flocs formed under the accustomed flocculation conditions are large, voluminous and of a geometrically loose, widely branched, spatially extended lattice structures containing large volumes of voids filled with water. They are of low density and very fragile with a tendency to fragment. Such flocs are grossly non-homogeneous in size as well as in density (Tesarik, 1967; Hereit et al., 1983). Since sedimentation tanks must be sized for the finest suspension, such flocs are not particularly suitable for rapid sedimentation.

In contrast to the customary flocculation conditions, the inline high-density suspension (IHDS) flocculation process takes place with high agitation intensity over the entire flocculation process until flocculation optimum is reached. As a result the compaction of the formed flocs and thereby their density are very favourably influenced. The floc densification is a result of reduced volume of voids in the micro-flocs filled with entrapped water (Polasek, 1980b; Polasek and Mutl, 2003; 2005a; 2005b; Polasek and Van Duuren, 1981). Depending on the resultant size of flocs required, their formation can take place under two different agitation intensities:

- High intensity (high energy) agitation with  $\bar{G}_H > 50 \text{ s}^{-1}$
- Low intensity (low energy) agitation with  $\bar{G}_L < 50 \text{ s}^{-1}$

The high and low agitation intensities involve the same transport mechanism and differ only by the agitation intensity, i.e. the magnitude of the  $\bar{G}$ -value.

When the micro-flocs are required these are formed with a high agitation intensity preferably with a  $\bar{G}_H = 100 - 500 \text{ s}^{-1}$  in the first flocculation phase. When rapidly settleable macro-flocs are required these are formed in the second flocculation phase with a low agitation intensity, preferably with a  $\bar{G}_L = 5 - 20 \text{ s}^{-1}$ , from the micro-flocs formed with high  $\bar{G}_H$  in the preceding first flocculation phase (Polasek, 1980b; Polasek and Mutl, 2003; 2005a; 2005b). The resultant macro-flocs are much denser than those formed under the customary flocculation conditions because they are formed from much denser micro-flocs.

The agitation intensity together with its duration should be optimised with respect to the properties of flocs that are required in view of the separation method selected. The character of flow induced by agitation must be designed such that the most uniform distribution of the velocity field throughout the flocculation chamber is achieved, if maximum separation efficiency at the highest settling velocity of the formed flocs is to be attained.

## Conclusions

The term mixing as currently used does not differentiate between the transport mechanism required for the dispersion and homogenisation of added reagent with water and that for flocculation of destabilised particles into larger flocs, even though their characters are entirely different. Therefore, it is necessary to differentiate between:

- Flash mixing (reagent dispersion and homogenisation mixing) – the mixing on macro-scale, in which partial volumes of water are transferred over long distances and macro-turbulent eddies are formed inside which the added reagent is dispersed

- Agitation (flocculation mixing) – the mixing on micro-scale, in which partial volumes of water are transferred over short distances and micro-turbulent eddies are formed which facilitate formation of readily separable flocs. Depending on the ultimate size of the flocs required, which is determined by the selected method of separation, agitation takes place in one or two consecutive phases differentiated by different intensities of agitation (IHDS flocculation process), namely:
  - High-intensity (high energy) agitation aimed at the formation of micro-flocs,  $\bar{G}_H > 50 \text{ s}^{-1}$  applied over the entire flocculation process until flocculation optimum is reached
  - Low-intensity (low energy) agitation aimed at the formation of large and rapidly settleable macro-flocs,  $\bar{G}_L < 50 \text{ s}^{-1}$ .

The high- and low-agitation intensities involve the same transport mechanism and differ only by the agitation intensity, i.e. magnitude of the  $\bar{G}$ -value. Irrespective of the agitation intensity, the conditions of agitation must be designed to create uniform distribution of a velocity field throughout the volume of agitated water.

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