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SLUDGE BLANKET COAGULATION

The influence of the coagulant type on the efficiency of removal was determined. Optimum coagulant doses were established as a function of technological effects and the quantity of the coagulant persisting in the effluent. Zeta potential for the removal of pollutants was evaluated and compared with the values obtained by conventional coagulation. The determinations also included velocity of water flow through the sludge blanket, cohesion factor, specific surface, and flocculation conditions. Analysis of results has shown that appropriate determination of the course of the sludge blanket process requires knowledge of the technological effect, as well as the hydraulics of the process.

1. COAGULANTS

Compared to volume coagulation, in sludge blanket coagulation the coagulant dose may be markedly decreased, in some instances even by 40% [1]. While alum as coagulant has found univocal acceptance, use of iron salts is still raising objections. Using iron salts yields insufficient colour removal, or sometimes even an increase of colour intensity as a result of chelating. Iron salts used as coagulants account for good efficiencies of organic matter removal. They produce flocs heavier than alum does, and these flocs have a favourable influence on the sludge blanket process. The disadvantage of using iron salts consists in the fact that generation of the sludge blanket requires rigorous pH ranges.

The efficiency of turbidity removal is similar and increases with the increasing coagulant dose, irrespective of whether alum or iron salt has been applied [1]. What makes the two coagulants differ from each other, is the amount of Al^{3+} or Fe^{3+} persisting in the effluent [2]. Hence, when the dose of the $FeCl_3$ coagulant was increased, the amount of residual Fe^{3+} ions decreased. When the $Al_2(SO_4)_3$ dose increased, so did the residual Al^{3+} ions, particularly at increased velocities of water flow in the sludge blanket. It is therefore of prime importance to take account not only of the removal efficiency desired, but also of the persistence of the "coagulant" ions in the effluent which passed to the filter beds.

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The phenomenon of coagulant ion penetration into the filter bed may sometimes advantageously affect the filtration process by contributing to the "impregnation" of the bed and, consequently, upgrading the treatment effect through an extended filtration run. The opposite process may occur particularly with an overdosage of the coagulant, when the sludge blanket layer fails to be stable, and the separation of phases in not distinct. And this makes the flocs float, thus clogging the filter bed surface.

2. pH VALUE

The optimum pH for the coagulation process differs from the natural water pH. Maintaining an optimum pH in the course of the coagulation process not only improves the treatment effect, but also accounts for a considerable (up to 100%) extension of the filter run (which is an advantageous phenomenon) [1]. The optimum pH was found to depend on the type of the coagulant used and on the water to be treated [3].

Engineering practice shows that the optimum pH for alum coagulation falls between 6.5 to 7.0. Experiments involving water samples from the Bóbr River have revealed that the optimum coagulation pH was identical to the natural pH, ranging from 6.7 to 7.5. When the experiments were conducted on water samples from the Odra River, the optimum coagulation pH was equal to, or lower than, 6.3, and its value was lower than that of the natural river water. The optimum pH for ferric chloride coagulation ranges within 5–6.5.

3. ZETA-POTENTIAL

The zeta-potential value depends on the coagulant dose. Removal of pollutants by sludge blanket coagulation requires higher zeta-potential values than volume coagulation (tab. 1). This is an indication that the destabilization of colloidal systems in the sludge blanket process may be smaller than in a conventional process, and this should be attributed to the application of lower coagulant doses.

Table 1

Optimum zeta-potential for removal of pollutants

Pollutant	Volume coagulation	Sludge blanket
turbidity	−10.0	−16.0
colour	−5.0	−10.0
COD (perm)	−5.0	−10.0

Taking all this into account, we come to the conclusion that it is the increased sorbing ability of the sludge blanket flocs which contributes to the satisfactory treatment effect obtained with decreased coagulant doses.

4. FLOW VELOCITY

Most of the investigations aim at achieving the highest possible flow velocities without disturbing the stability of the layer. Table 2 gives velocity values obtained by the author of this paper in her experimental study of the sludge blanket process. These values are compared with literature data. In engineering practice, attempts to achieve flow velocities grater than 1 mm/s have failed so far.

Table 2

Velocity of water flow through sludge blanket

Coagulant	Via ref. [4]	Via ref. [2]
	mm/s	
alum	0.6 – 1.3	0.6 – 0.8
alum + active silica	1.2 – 2.5	up to 1.0
ferric sulfate	0.8 – 2.0*	0.8 – 1.0

Note: * $+Cl_2$.

Flow velocity depends on water temperature, and is associated with viscosity variation. The rise in water temperature from 273 to 293 K accounts for a 17.5% difference in flow velocity, and this gives a 17.5% drop of treatment efficiency in the winter season. The difference may be compensated by an appropriate floc density. And this means an increase of some 1.5% [3], which can be achieved by applying polymers. The application of polyelectrolytes to improve water quality is well known in engineering practice and has a theoretical background. But this problem has never been related to the efficiency of the clarifier.

5. SLUDGE BLANKET STRUCTURE

5.1. COEFFICIENT OF COHESION

During water flow, the structure of the sludge blanket should be uniform in nature. Fuzziness or thickening of the sludge layer accounts for the abatement of the treatment efficiency. And the coefficient of cohesion is a parameter to describe the structural properties of the sludge blanket.

Experiments were run to evaluate the cohesion coefficient. The sludge blanket was produced in order to increase the velocity range from 0.5 to 10 m/h. At velocities ranging from 3.6 to 4.5 m/h, a washout of flocs occurred, whereas velocities between 9 and 10 m/h brought about a destruction of the sludge. The coefficient of cohesion for alum determined experimentally varied from 0.98 to 1.15 m/h. Sludges of a good structure quality display cohesion coefficient values falling between 1.2 and 1.5 m/h, which indicates that the sludge used in the experiments is of inferior quality.

5.2. WATER CONTENT

Water content was measured on various levels of the sludge blanket at a given water flow velocity, and was found to be constant (99.8 to 99.9% at a velocity of 0.8 to 1.1 mm/s) over the entire depth, except the near-bottom layer.

The cohesion coefficient may be related to water content in terms of the following formula

$$k = v\left(\frac{U-U_0}{1-U}-1\right)^{-1}$$

where k is cohesion coefficient, v denotes water flow velocity, U indicates water content and U_0 stands for water content at expansion $E = 1$. The relation enables evaluation of the cohesion coefficient for a sludge blanket operated under industrial conditions.

5.3. SPECIFIC SURFACE

Specific surface (determined by the glycerol method) amounted to 290 m^2/g over the entire depth, except the near-bottom layer, which displayed the value of 70 m^2/g.

5.4. COMPRESSIBILITY

The compressibility values for the sludge blanket are listed in tab. 3. Knowing the specific surface and compressibility of the sludge blanket is of little use (if at all) when optimizing the sludge blanket process.

Table 3

Coefficient of compressibility for sludge blanket

Clarifier	Compressibility	Coagulant
model clarifier, water samples from the Bóbr River	0.67–0.87	alum
clarifier, water samples from storage reservoir	0.79	alum
model clarifier, water samples from the Odra River	0.97	ferric sulfate

6. FLOCCULATION CONDITIONS

Flocculation conditions are described by the velocity gradient of fluid motion. The values of the velocity gradients are low (up to 5 s^{-1} [3]) which indicates that the flocculation process runs under favourable conditions. When the velocity gradient values are analysed, it becomes obvious that the application of contact bed clarifiers is useless if treating water of a low pollution level ($\varrho_k \approx 0$). Velocity gradient becomes $G = 0$, and no flocculation is found to occur. But analysis of the velocity gradient also indicates that it is advisable to use polymers in order to increase the G value and, consequently, the coagulation effect.

Combining the velocity gradient with the equation of flocculation gives support to the validity of the adopted sludge blanket depth, which ranges from 2.0 to 2.5 m. The velocity gradient values at which satisfactory treatment effects are achieved do not markedly differ from those at which destruction occurs. In this particular case, velocity gradient as a flocculation criterion becomes insufficient for the estimation of the process. To overcome this shortcoming there was adopted an additional parameter, i.e., the tangential stress, which had been determined from the equilibrium of resisting and shearing forces acting in the sludge layer.

The calculated tangential stress values [3] amounted to 0.44 N/m^2 and 1.5 N/m^2 for good structure quality and for destroyed sludge blanket, respectively. At increased floc strength, which may be achieved by using polyelectrolytes, the value at which destruction occurs will also increase.

7. CONCLUSIONS

1. The technological parameters of sludge blanket coagulation should be considered in conjunction with the hydrological parameters of the process.

2. The model of sludge blanket flocculation explains some of the phenomena involved in the water treatment process; it also facilitates the design of the process itself.

3. Some of the sludge blanket parameters are of little use when attempting and optimization of the process.

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KOAGULACJA W OSADZIE ZAWIESZONYM

Określono wpływ rodzaju koagulantów na efekty usuwania zanieczyszczeń. Ustalono dawki optymalne koagulantów w zależności od efektów technologicznych i ilości koagulantów pozostałych w wodzie. Wyznaczono wartości potencjału dzeta dla usuwania zanieczyszczeń i porównano je z wartościami uzyskiwanymi w metodzie konwencjonalnej koagulacji. Ustalono zakres prędkości przepływu wody przez warstwę osadu zawieszonego, określono współczynnik kohezji, powierzchnię właściwą osadu oraz warunki flokulacji w osadzie zawieszonym. Wykazano, że ustalenie właściwego przebiegu procesu osadu zawieszonego wymaga określenia zarówno efektów technologicznych, jak i hydrauliki procesu.

КОАГУЛЯЦИЯ В СУСПЕНДИРОВАННОМ ОСАДКЕ

Определено влияние вида коагулянтов на эффекты удаления загрязнений. Были установлены оптимальные дозы коагулянтов в зависимости от технологических эффектов и количества коагулянтов оставших в воде. Определены значения потенциала дзета для удаления загрязнений и сравнены со значениями, получаемыми в методе конвенциональной коагуляции. Установлены пределы быстроты течения воды через слой суспендированного осадка, определен коэффициент когезии, удельная поверхность осадка, а также условия флокуляции в суспендированном осадке. Обнаружено, что установление соответствующего хода процесса суспендированного осадка требует определения как технологических эффектов, так и гидравлики процесса.