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V. G. PONOMAREV*

RESEARCH TRENDS IN MECHANICAL WASTEWATER TREATMENT

The paper presents the objectives and trends in research work based on the achievements in science, assembling works and experience of operating processes and facilities used for mechanical wastewater treatment.

Mechanical treatment is one of the most commonly used methods in wastewater treatment. Depending on the kind of pollutants and the required level of purification, it can be used both as preliminary and final treatment steps. At present mechanical treatment can be performed in sedimentation tanks, hydrocyclones, centrifuges, flotation units and filters.

The application and selection of the method and facility depends on wastewater characteristics: its quantity, concentration, content of dispersed matter and the nature of pollutants. The capacity of facilities and the efficiency of the process taking place depend on fluid hydraulic and hydrodynamic characteristics of the facilities.

At the present time there is not common design procedure for mechanical treatment facilities in which all basic parameters affecting separation process would be incorporated. Analysis of the world literature shows that the available relations used in design are, as a rule, empirical or semiempirical and that no adequate attention is given to the nature of pollutants and their interaction during separation process. In relations recommended for design of various mechanical facilities, water and contaminants characteristics are described, however, by practically the same values, so thus a single model of wastewater separation can be developed. The research conducted indicates that while evaluating the characteristics of wastewater pollutans, their physical, chemical and surface properties, fully defining the separability of wastewater suspensions, should be taken into account.

Up today mechanical impurities are mainly characterized by their settling properties, illustrated by diagrams of sedimentation kinetics obtained from laboratory experiments by settling wastewater under steady conditions.

* VNII, VODGEO, Moscow, USSR.

The diagram of sedimentation kinetics (fig. 1) is essentially a graphic representation of grain size distribution of mechanical impurities present in wastewater. However, it should be noted that during its settling, the suspension may form agglomerations. The size of suspended solids agglomerates depends on solids nature, content, depth of sedimentation layer and on fluid mechanics in the facilities used. That is why correction factors are introduced into the known design formulae for mechanical wastewater treatment facilities and apparatus.

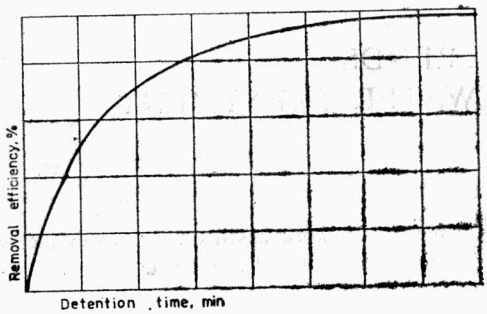

Fig. 1. Kinetics of wastewater sedimentation
Rys. 1. Kinetyka sedymentacji ścieków

Hence, the investigation of interaction between suspended particles during separation process, taking into account their nature and hydrodynamic conditions in the facilities, may give promising results.

Such an approach should allow us to improve the reliability of design relations and to reduce the number of experiments required presently in selection of treatment method for insufficiently elucidated wastewaters.

Of the same importance is the investigation of fluid hydrodynamics in mechanical treatment facilities.

It suffices to say that the useful volume of settling tanks amounts to 40–50%, and to 25–30% in flotation units, the remaining part being occupied by circulation zones and not involved in the separation process.

Thus, in practice, each facility has some reserves owing to which its capacity and treatment efficiency can be increased. So, the design solutions, in which these reserves are utilized, will permit us to increase the efficiency of the existing plants without construction of additional units.

Multi-tier thin-layer settlers (figs. 2, 3 and 4) belong to perspective mechanical treatment facilities which in the near future will find wide application in wastewater treatment.

Multi-tier settler is a basin, working volume of which is divided by inclined plates into the separate settling zones (tiers). In each tier separation of wastewater suspensions proceeds independently. Due to the reduction in sedimentation depth, the time of separation process is reduced. Moreover, the introduction of parallel plates into actual cross-section of a settler promotes a complete utilization of facility volume, since at the inlet of the settler the distribution of working stream remains uniform during its movement. In thin-layer settler the effect of density and convection flows causing turbulent mixing is practically absent.

At present three flow diagrams of reciprocal water and sludge movements (transversal, direct flow, counter-current ones; figs. 2, 3 and 4) are used. Theoretical analysis and experimental testing have shown that counter-current scheme is the most efficient. However, it should be noted that when this scheme is used, some difficulties are encountered in providing a uniform water distribution through cross-section of thin-layer block.

The VODGEO Institute designed a water distribution device, ensuring up to 80–86% utilization of thin-layered volume.

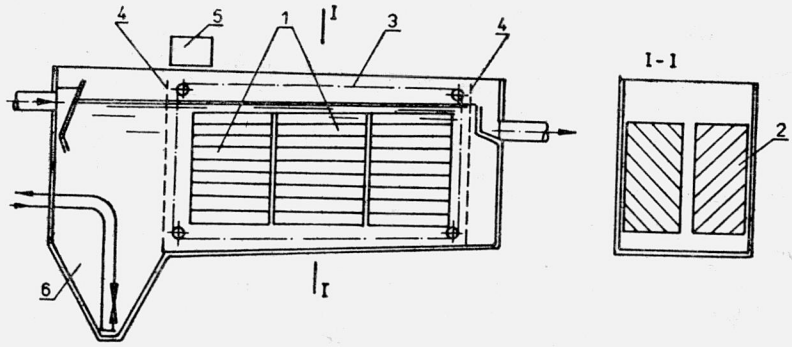

Fig. 2. Multi-tier settlers operating in transversal mode

1 — blocks of parallel plates, *2* — tier, *3* — scrapers, *4* — distribution device, *5* — drive, *6* — sludge pit

Rys. 2. Wielokondygnacyjne osadniki pracujące w płaszczyźnie poprzecznej

1 — bloki równoległych półek, *2* — kondygnacja, *3* — zgarniaki, *4* — urządzenie rozdzielające, *5* — napęd, *6* — dół

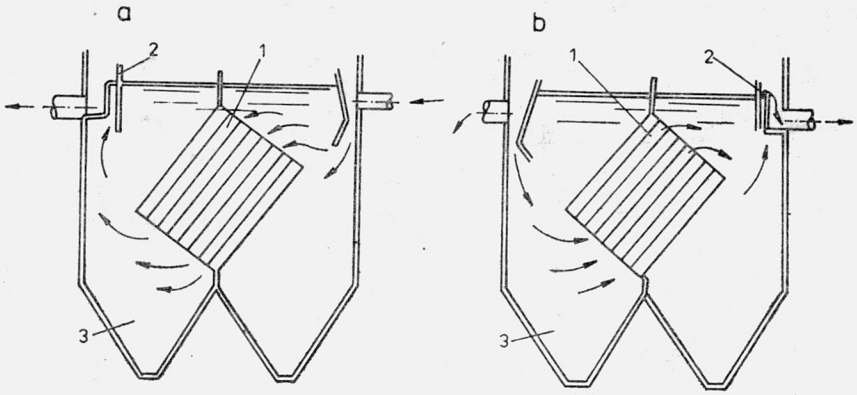

Fig. 3. Multi-tier settler operations

a) direct flow mode; b) countercurrent mode; *1* — block of parrallel plates (tubular block); *2* — half-submerged baffle, *3* — sludge pit

Rys. 3. Praca osadnika wielokondygnacyjnego

a) bezpośredni przepływ, b) przeciwprąd, *1* — blok równoległych półek (blok rurowy), *2* — półzanurzony deflektor, *3* — dół z osadem

As it is evident from the full-scale testing, the advantages of multi-tier settlers make it possible to increase 4–5 times their specific efficiency (i.e. appropriate reduction in volume and area requirements, capital and operating costs) with respect to that of the existing ones.

The use of thin-layer sedimentation can also increase the capacity and water treatment

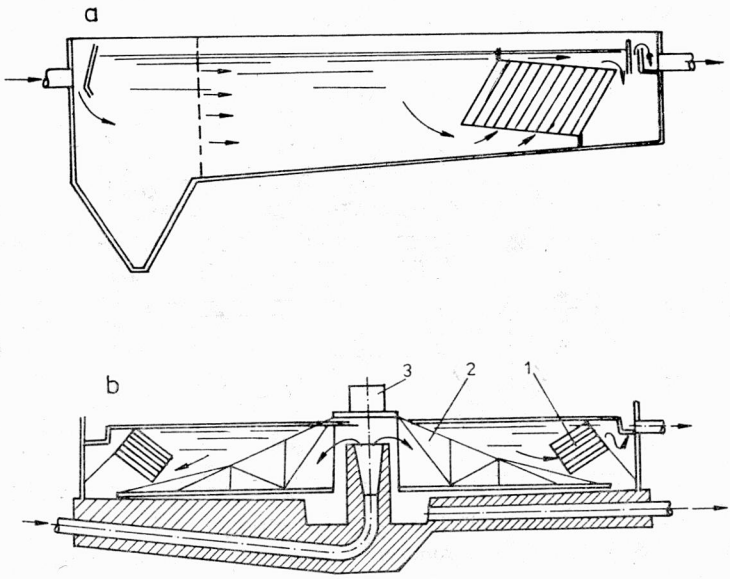

Fig. 4. Flow diagram of the existing settling tanks equipped with blocks of parallel plates

a) horizontal, b) radial

Rys. 4. Schemat przepływu w zbiornikach osadowych wyposażonych w bloki równoległych półek

a) poziomy, b) promieniowy

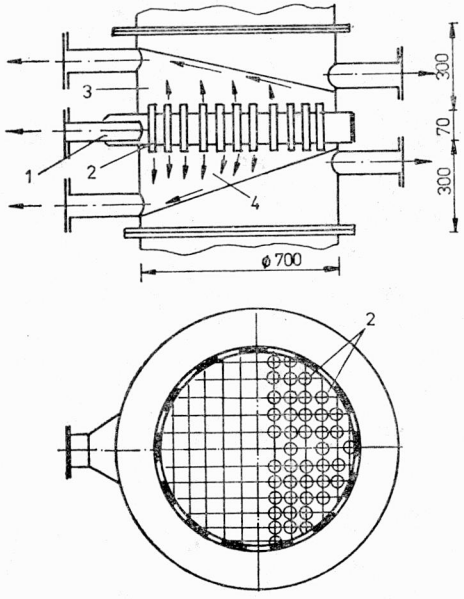

Fig. 5. Block of multicyclones of diameter of 15 m

1 — distribution chamber, *2* — hydrocyclones, *3* — clarified water tank, *4* — sludge chamber

Rys. 5. Blok multicyklonu o średnicy 15 m

1 — komora rozdziału, *2* — hydrocyklony, *3* — zbiornik sklarowanej wody, *4* — komora osadowa

efficiency of the existing settling tanks, due to the attached blocks of parallel plates (figs. 5 and 6).

Plates of the inclination of 60° have been recommended by many investigators studying multi-tier settler operation. As experiments show, this parameter depends on characteristics of sludge produced and in each particular case should be determined individually. Otherwise, with significantly increasing angle of inclination, the velocity of sludge slipping down increases, and at the water flow and sludge boundary, friction forces result in turbulent flows, causing resuspension of sludge solids and secondary pollution of water stream.

In order to design adequately thin-layer settlers, it is necessary to determine the relationships between the properties of generated sludges, surface area of plate material and angle of inclination, required for sludge slipping down.

The height of the tier, where the process takes place, also depends on characteristics of mechanical impurities. So far this relationship has not been investigated thoroughly.

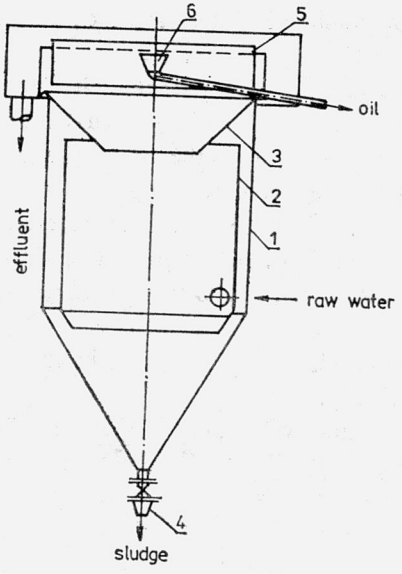

Fig. 6. Open hydrocyclone

1 — case, *2* — inner cylinder, *3* — cone diaphragm, *4* — spare slime nozzle, *5* — petroleum-oil retaining baffle, *6* — oil-petroleum receiving funnel

Rys. 6. Otwarty hydrocyklon

1 — obudowa, *2* — cylinder wewnętrzny, *3* — kryza stożkowa, *4* — zapasowa dysza szlamu, *5* — deflektor zatrzymujący olej i ropę naftową, *6* — lej zbierający olej i ropę naftową

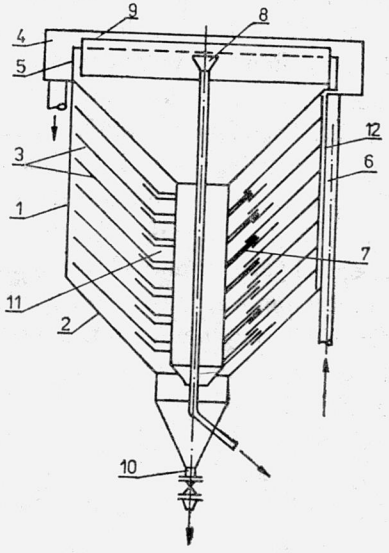

Fig. 7. Multi-tier hydrocyclone

1 — cylindrical part, *2* — cone part, *3* — cone diaphragms *4* — water collecting tray, *5* — weir, *6* — distributing forebay, *7* — outlets, *8* — oil-receiving funnel, *9* — oil-retaining ring, *10* — sludge disposal pipe, *11* — slime separation baffle, *12* — slot for disposal

Rys. 7. Wielokondygnacyjny hydrocyklon

1 — część cylindryczna, *2* — część stożkowa, *3* — kryza stożkowa, *4* — korytko zbierające wodę, *5* — przelew, *6* — wstępna komora rozdzielająca, *7* — wyloty, *8* — lej zbierający olej, *9* — pierścień zatrzymujący olej, *10* — rura usuwająca osad, *11* — przegroda rozdzielająca szlam, 12 — szczelina odprowadzająca

Removal of mechanical impurities from wastewaters may be intensified by application of centrifugal field. In centrifugal apparatus, the forces causing separation of suspensions exceed that of gravity by dozens, hundreds and thousands times. Therefore, the volumes of centrifugal units, being lower than those of gravitational ones, determine costs of construction, assembling and operation.

Centrifugal apparatus, used in wastewater treatment, includes pressure and open hydrocyclones and centrifuges. As it is evident from studies, hydrocyclones can be successfully used for removal of structurized suspensions from wastewaters, being very efficient in local treatment of industrial wastes. It has been found that the removal efficiency of settling tanks will be higher if wastewaters are pretreated in pressure hydrocyclones. Moreover, the operation of settlers is then simple, the bulk of impurities being preliminary removed in hydrocyclones. Efficiency of wastewater separation increases with the decreasing diameter of hydrocyclone.

The hydrocyclones of smaller diameters (15–20 mm) can remove small particles (0.1 mm/s hydraulic grain size). In order to reduce the amount of such particles by sedimentation, a large area is required. Hydrocyclones of smaller diameters are recommended to be united in blocks, thus to reduce significantly the piping (fig. 7).

Investigations show that pressure hydrocyclones, in spite of apparent high efficiency of centrifugal forces, have low efficiency, as separations of suspensions occurs near the side walls. Therefore, the objective of further research is to improve the hydrocyclone efficiency by utilizing its entire volume and reducing the turbulence.

Open cyclones can remove the pollutants both heavier and lighter than water. Furthermore, they are capable of removing coagulated suspensions. Although specific capacity of an open hydrocyclone is lower than that of the pressure one, but its larger volume makes the processing capacity high.

Open hydrocyclones with inner cylinder and cone diaphragm and multi-tier hydrocyclones (figs. 6 and 7) are of great interest for industry.

Removal of impurities in open hydrocyclones occurs by the action of gravity force. Rotation promotes only the agglomeration of suspended solids and utilization of entire facility volume.

In multi-tier hydrocyclones the time of separation process is shortened due to the reduction of layer depth which is achieved by dividing the facility volume into separate tiers by easily removable cone diaphragms.

In this country open hydrocyclones are widely employed for treatment of industrial wastewaters from metallurgical, engineering, asbestos-cement and motor transport works.

Technical and economic evaluation of multi-tier hydrocyclones operation at one of the plants shows that capital costs are approximately 3 times and operating costs are 20% lower than those of horizontal settling tanks. Thereby, the area occupied by hydrocyclone is 5 times smaller than that required for settling tanks.

So far, however, the laws of rotation movement during separation of wastewater suspensions have not been thoroughly studied, that is why a harmonious system of open hydrocyclones could not be developed and its design optimized.

Another promising facility is the centrifugal unit. Centrifuges are especially efficient in local treatment of industrial wastewaters, containing the sludge which can be reused in industry. Thus, the centrifuges perform a double role being used for water treatment and sludge handling. From the studies conducted by the VODGEO Institute, it is evident that majority of wastewaters should be treated in low-speed centrifuges having separation factor $F_2 = 150–300$. Hence, by applying low-speed machines with rotors of large volume, the number of operating machines can be reduced. However, such centrifuges have not been designed yet.

Filtration is employed when high level of treatment is required.

Of the filters those with sand medium are the most widely used and numerous papers are dealing with them. Sand medium has, however, a number of significant disadvantages, of which the using up during operation and insufficient adhesion capacity to some pollutants are the main ones. Furthermore, borrow pits containing sand used as a medium are limited.

For these reasons new materials for filter medium had to be found. The application of synthetic materials: polystyrene and expanded polyurethane, as a filter medium, seems to be of the greatest interest. The performed investigations have revealed that polystyrene granulate of 2.5–4 mm in size, applied in rolling shops to wastewater treatment, preliminary settled at filtration rates of 45–55 m/h, yielded 10 mg/dm^3 removal of suspended solids and petroleum products.

Filters with expanded polyurethane have also been found to operate at high (25–35 m/h) filtration rates and to provide high removal efficiency of petroleum products (up to 4.5 mg/dm^3). As follows from the studies, specific flow rates required for regeneration of synthetic media are significantly lower (10–15 times) than those required for backwashing of sand filters. The application of any material as filter medium depends, among others, on its regeneration ability. Regeneration of a filter medium is a process which practically cannot be performed in filter columns, usually used in tests of wastewater filtration, since the accumulation of residual contaminants in filter body is found only during long-term operation.

The studies have revealed that in practice the sand filters employed in water and wastewater treatment cannot be regenerated completely by recommended backwashing methods. Investigations carried out by the VODGEO Institute have revealed that recurrent superimposition of ultrasonic field is one of the rapid methods that may be used for regeneration of sand media. The VODGEO Institute has designed a filter with ultrasonic washing. Studies on methods and facilities for mechanical treatment and investigations of characteristics of wastewaters, generated by various industries, lead to the conclusion that there is no universal method and apparatus for mechanical treatment. The choice of method in each particular case must be based on technological and economical comparisons of several variants and their evaluations.

Another way of designing the facilities and apparatus for mechanical treatment is to develop computer-aided programmes, based on characteristics of wastewater pollutants, their quantities and local conditions of cities and industrial enterprises in order to select appropriate treatment methods.

TRENDY BADAWCZE W MECHANICZNYM OCZYSZCZANIU ŚCIEKÓW

Przedstawiono cele i główne kierunki badań w mechanicznej obróbce ścieków, wynikające z aktualnego stanu wiedzy oraz doświadczeń zgromadzonych podczas montażu i eksploatacji urządzeń, a także podczas stosowania różnych metod oczyszczenia.

DIE TENDENZEN IN DER MECHANISCHEN ABWASSERREINIGUNG

Der Beitrag präsentiert Ziele und Vorstellungen der mechanischen Abwasserreinigung. Diese gehen aus dem aktuellen Stand der Wissenschaft und Technik, aus den Erkenntnissen und Untersuchungen die bei Montage und beim Betrieb von Anlagen, sowie bei der Anwendung verschiedener Verfahren gesammelt wurden hervor.

ИССЛЕДОВАТЕЛЬСКИЕ ТРЕНДЫ В ОБЛАСТИ МЕХАНИЧЕСКОЙ ОЧИСТКИ СТОЧНЫХ ВОД

Указаны цели и главные направления исследований по механической обработке сточных вод, следующие из актуального состояния знаний, а также опыта, накопленного при сборке и эксплуатации установок, а также при применении различных методов очистки.