DOI 10.31489/2019Ch3/102-106

UDC628.16. 066.7

B.B. Orazbayev[1], L.T. Kurmangaziyeva[2], G.K. Shambilova[2], A.A. Muratbekova[3]

[1]*L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan;*
[2]*Kh. Dosmukhamedov Atyrau State University, Kazakhstan;*
[3]*Ye.A. Buketov Karaganda State University, Kazakhstan*
(E-mail: shambilova_gulba@mail.ru)

The optimization of device parameters for the separation of oily mixtures by sedimentation

Theoretical studies of optimal sizes of sedimentation equipment for water treatment polluted with oil residues and industrial effluents were carried out, and design and operation experience were analyzed. Thus, it was determined that wastewater treatment issues in cities and towns characterized by high productivity were mainly investigated. Oily water formed during the liquidation of emergency oil and petroleum spills is treated at local treatment facilities with low cleaning capacity and specific design and operation features. The effective solution approach to treat oily mixture by sedimentation was proposed. Algorithm was developed to optimize parameters of sedimentation equipment for oily mixture treatment which determines optimal sizes of sedimentation equipment providing the most effective oily mixture treatment at minimum cost of material for equipment fabrication. The proposed algorithm for calculation of sedimentation equipment parameters is based on search and selection of optimal equipment capacity and can be used to calculate rectangular equipment size. Thus, due to the above theoretical studies, a method for calculation of sedimentation equipment optimal size was proposed to be used in optimal equipment design for oil mixture treatment.

Keywords: water treatment, oily mixture, sedimentation, sedimentation equipment, optimization, oily mixture treatment by sedimentation, equipment optimal size.

Introduction

Experience relating to the design and use of sedimentation devices for the separation of water from industrial sources is described in many research works, for example in [1–4]. Most of this experience relates to facilities for the separation of waste water from cities and other populations centres, which are characterized by high productivity.

The separation of water which contains oil, which has resulted in the process of sedimentation accidental spills of oil and oil products, is carried out using local waste water treatment facilities, which have a low through-put, and the design and operation of which have their own peculiarities. For example, treatment facilities may be floating [5] or vehicular platforms.

An approach to the optimization of device parameters for the treatment of oily mixtures by sedimentation has been proposed. The algorithm proposed for the calculation of sedimentation device parameters can be used for the calculation of dimensions of rectangular cross-section devices.

Materials and Methods

The process of separation by sedimentation is based on the separation of the oil and oil product particles from the rest of the water being purificated, under the action of the force of gravity — G_m and the Archimedes force — A. The force resulting from these 2 forces, the force F, which is equal to the vectoral sum of these forces, determines the movement of the impurity particles. In addition to the force F acting on the moving particles, there is also another force, S, water resistance, which is constant for the particles in the process under investigation [6]:

$$S(t) = -k_1 \nu(t),$$

where k_1 is the coefficient of proportionality.

The main parameter describing the process of separation of the particles from the water being purified is the velocity of movement of the foreign particles ν. This velocity can be determined by analysis or experimentation.

The following formulae for determining the velocity of movement of the foreign particles are identified, resulting from analysis of the equations of motion of these particles [3, 6]:

$$m\frac{d\nu}{dt} = -k\nu + \frac{\pi d^3}{6} g\Delta\rho,$$

where m is the mass of the oil product particles; v is their speed; $k = 3\pi d\eta$ is the coefficient of proportionality; η is the medium viscosity (i.e. of water); d is the size of the oil product particles; $\Delta\rho$ is the difference in density between the water and the oil products.

Analysis of the equations of motion shows that, independent of the initial velocity v_0, the movement of the particles very quickly becomes steady with a uniform velocity of v_{pr}:

$$\nu_{pr} = \frac{C}{\alpha} = \frac{g(\Delta\rho)d^2}{18\eta}.$$

Taking into account the direction of flow of the purified water, the velocity $\overline{v}_h$ of the movement of the oil product particles shall equal $\overline{v}_h = \overline{v}_{pr} + \overline{v}_v$, where $\overline{v}_v$ is the velocity of flow of the purified water.

For horizontal single-flow sedimentation devices, in which the flow of purified water moves horizontally, the velocity v_h of movement of the impure oil product particles can be calculated using the formula:

$$\nu_h = \sqrt{\nu_{pr}^2 + \nu_v^2}.$$

For vertical single-flow sedimentation devices, in which the flow is downwards (upwards), the velocity v_h is determined by the formula:

$$\nu_h = v_{pr} - v_v \; (v_h = v_{pr} + v_v).$$

The well-known principles [4, 7] are fundamental to calculations for the sedimentation devices for local water treatment facilities, in connection with which the required volume V of the device is determined by the conditions

$$\Delta t = t_v - t_h \ge 0,$$

where t_v is the time that the water being purified is inside the sedimentation device; t_h is the time that it takes for the oil product particles to rise to the upper part of the sedimentation device, that is to separate from the purified water.

For cylindrical forms of sedimentation devices of a vertical nature with a diameter D and height H

$$t_v = \frac{\pi D^2 H}{4Q}.$$

For horizontal sedimentation devices with a rectangular cross-section

$$t_v = \frac{abh}{Q}.$$

The time of movement of the oil product particles for cylindrical and rectangular cross-section sedimentation devices accordingly equals

$$t_h = \frac{H}{\nu_\eta} \text{ and } t_h = \frac{h}{\nu_h}.$$

Results

As a result of the research which has been carried out, the following sequence of calculations is proposed for the calculation of the dimensions of sedimentation devices, for example for devices having a cylindrical form.

Using the known relationship $t_\theta = t_h$ or $\frac{V}{Q} = \frac{H}{\nu_h}$ it becomes possible to propose a formula for the determination of the volume V of the sedimentation device:

$$V = \frac{QH}{v_h}.$$

The required volume V of various containers can be achieved with various relationships between the dimensions [6, 8]. Taking into account the fact that the existing methods for calculating dimensions of sedimentation devices do not give sufficiently sound recommendations for the determination of their optimal dimensions [4, 9–11], we can use the above mentioned characteristic of geometric shapes to determine the optimal ratio of dimensions for sedimentation devices.

The results of the calculation show that the surface area S of the device for various ratios of dimensions of the device without variation in its volume V will have varying values.

For this calculation, in this paper we are proposing an algorithm consisting of the following basic steps:

1. The diameter of the sedimentation device D is given;

2. Using the formula $H = \frac{4V}{\pi D^2}$ the height H of the sedimentation device is calculated;

3. Using the value of D which is given and the height H of the sedimentation device which is derived in point 2, the surface area S of the device is determined: $S = 2\left(\frac{\pi D^2}{4}\right) + \pi DH$;

4. For different diameters D of the sedimentation device, points 2 and 3 are repeated and a range of values for S are calculated for various values of D and H.

Discussion

Figure 1 shows the results of calculations for the surface area S for cylindrical sedimentation devices within the limits of a volume V from 0.25 to 2.0 m^3 [12]. An analysis of the results shows the occurrence of minimal values for surface area S in the size range under consideration. The minimal value of the surface area S corresponds to minimal cost of materials.

However, a more objective indicator of the cost of materials for the production of sedimentation devices is the volume of materials B. Taking into account the thickness of the device walls, and also the presence of rigidity or other such factors in construction, it is possible to calculate the volume B of materials required for various values of D and H.

Results for the calculations of the volume B of materials used in production, taking into account the thickness of the materials and the presence of elements of rigidity are shown in Figure 2. Calculations of the value of B were carried out for devices with a volume V ranging from 1.0; 2.0 and 4.0 m^3. Analysis of the results of the calculations shows the occurrence of minimal values of the volume of material used in production. It is evident that the size of the sedimentation devices which results in a minimal value of B should be used.

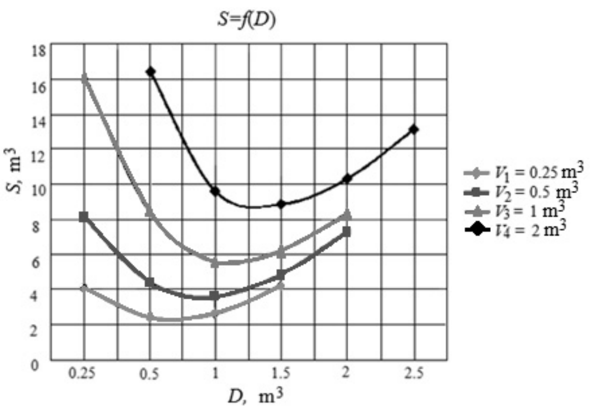

Figure 1. Changes in the surface area of sedimentation devices

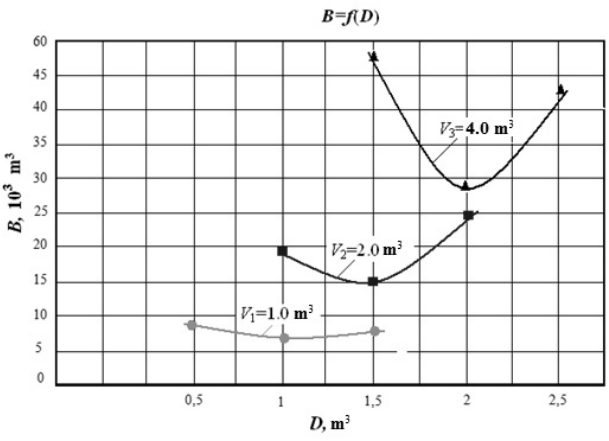

Figure 2. Changes in the volume of materials used in the production of sedimentation devices

The optimal dimensions can be determined as follows: Using the relationship $B = f(D)$, constructed for the required volume V, the value of the diameter D, can be determined for which B will have a minimum value. Using the value for diameter D which has been thus determined and the formula shown above (point 2 of the algorithm) to calculate the height H a new value can be calculated.

Calculations show that the relationship D/H for the range of dimensions under consideration, can have a value from 0.79 to 1.57. For values of $D/H < 1$ a horizontal sedimentation device with a cylindrical form is recommended, and for values of $D/H > 1$ a cylindrical sedimentation device should be used vertically.

Conclusion

As a result of the theoretical research, which is laid out in this paper, we have been able to propose an algorithm and calculation methods for the computation of optimal dimensions for sedimentation devices, which can then be used in their design.

In this way, according to the research results, this paper has proposed a method for the optimisation of device parameters for sedimentation devices, which allows for the determination of the optimal dimensions of sedimentation devices, ensuring the most effective working regime for the treatment process while minimising expenditure on the materials used to produce the device.

References

1 Жуков А.И. Методы очистки производственных сточных вод / А.И. Жуков, И.Л. Монгайт, И.Д. Родзиллер. — М.: Стройиздат, 1987. — 204 с.

2 Кульский Л.А. Справочник по свойствам, методам анализа и очистке воды / Л.А. Кульский, Н.Т. Гороновский, А.М. Когановский, М.А. Шевченко. — Киев: Наук. думка, 1980. — 126 с.

3 Стахов Е.А. Очистка нефтесодержащих сточных вод / Е.А. Стахов. — Л.: Недра, 1983. — 363 с.

4 Яковлев С.В. Канализация / С.В. Яковлев, Я.А. Карелин, А.И. Жуков. — М.: Стройиздат, 1995. — 632 с.

5 Жигульский В.А. Плавучий комплекс для переработки нефтеводяной смеси / В.А. Жигульский, В.И. Решняк // Судостроение. — 2006. — № 5. — С. 47–48.

6 Зельдович Я.Б. Высшая математика для начинающих физиков и инженеров / Я.Б. Зельдович, И.М. Яглом. — М.: Наука, 1982. — 512 с.

7 Иванов В.М. Экспериментальное исследование поведения частиц жидкого топлива и топливно-водяной эмульсии в окислительной и нейтральной среде / В.М. Иванов, П.И. Нефедов, Б.В. Канторович // Отчеты ИГИ АН СССР, 1960. — 59 с.

8 Решняк В.П. Оптимизация размеров устройств при проектировании природоохранных технических средств: сб. науч. тр. / В.П. Решняк, В.А. Жигульский, Н.Е. Пестерева. — СПб.: СПбГУВК, 2006. — С. 173–178.

9 Яковлев С.В. Очистка производственных сточных вод / С.В. Яковлев. — М.: Стройиздат, 1979. — 35 с.

10 Егорова Е.Н. Методические основы оценки экономического ущерба, возникающего в результате аварийных разливов на морских акваториях / Е.Н. Егорова // Исследование в России. — 2004. — С. 955–971.

11 СНиП 12. 04.03–85 «Проектирование сооружений для очистки сточных вод». — М.: Стройиздат, 1990. — 136 с.

12 Жигульский В.А. Геоэкологические технологии переработки нефтеводяной смеси при ликвидации аварийных разливов: автореф. дис. … канд. техн. наук: спец. 25.00.36 — «Геоэкология» / В.А. Жигульский. — СПб., 2009. — 18 с.

Б.Б. Оразбаев, Л.Т. Курмангазиева, Г.К. Шамбилова, А.А. Муратбекова

Седиментациялау арқылы мұнайсу қоспасын тазалауға арналған құрылғылар көрсеткіштерін оңтайландыру

Мұнай қалдықтары мен өндірістік ағындарымен ластанған сулардың тазалауға арналған седиментациялық құрылғылар өлшемдерінің оңтайлы мәндеріне теориялық зерттеулер жүргізілген. Суды тазалау үшін седиментациялық құрылғаларды жобалау мен пайдалану тәжірибесі талданып, негізінен, үлкен өнімділікпен сипатталатын қалалар мен тұрғын жайлардын ағатын суды тазарту сұрақтары зерттелгені анықталған. Мұнай мен мұнай өнімдерінің апаттық төгілісін жоюда пайда болатын мұнай құрамды суларды тазалау, өздерінің ерекшеліктері бар, өнімі кішігірім локалды тазарту құрылғыларында жүзеге асырылады. Мақалада седиментациялау арқылы мұнайлы су қоспасын тазалау сұрақтарын тиімді шешу тәсілдемесі ұсынылған. Мұнайлы суды тазалайтын седиментациялық құрылғылардың оңтайлы көлемдерін анықтауға мүмкіндік беретін және ондай құрылғыларды дайындауға қажетті минималды материалдар шығынын, тиімді тазалау процесін қамтамасыз ететін седиментациялық құрылғылардың көрсеткіштерін оңтайландыру алгоритмі жасақталып, сипатталған. Седиментациялық құрылғылардың параметрлерін есептеуге, алгоритм құрылғының оңтайлы көлемін іздеуге және таңдап алуға негізделген және тікбұрыш формалы құрылғылар көлемдерін есептеуде қолданылуы мүмкін. Сонымен, теориялық зерттеулер нәтижесінде авторлар мұнайлы су қоспасын тазалау құрылғыларын оңтайлы жобалау кезінде қолдануға болатын, седиментациялық құрылғылар көлемдерінің оңтайлы мәндерін есептеу тәсілін ұсынған.

Кілт сөздер: суды тазалау, мұнайлы су қоспасы, седиментациялау, седиментациялық құрылғы, оңтайландыру, седиментациялау арқылы мұнайлы су қоспасын тазалау, құрылғының оңтайлы өлшемдері.

Б.Б. Оразбаев, Л.Т. Курмангазиева, Г.К. Шамбилова, А.А. Муратбекова

Оптимизация параметров устройств для очистки нефтеводяной смеси седиментацией

Проведены теоретические исследования оптимальных значений размеров седиментационных устройств, предназначенных для очистки воды, загрязненной нефтяными остатками, и промышленных стоков. Проанализирован опыт проектирования и эксплуатации седиментационных устройств для очистки воды, определено, что, в основном исследованы вопросы очистки сточной воды городов и населенных пунктов, которые характеризуются большой производительностью. Очистка нефтесодержащей воды, образующейся при ликвидации аварийных разливов нефти и нефтепродуктов, осуществляется на локальных очистных сооружениях с небольшой производительностью очистки, проектирование и эксплуатация которых имеет свои специфические особенности. В статье предложен подход к эффективному решению вопросов очистки нефтеводяной смеси седиментацией. Разработан и описан алгоритм оптимизации параметров седиментационных устройств для очистки нефтеводяной смеси, который позволяет определить оптимальные размеры седиментационных устройств, обеспечивающих наиболее эффективный режим процесса очистки нефтеводяной смеси при минимальных затратах на материал для изготовления устройств. Предложенный алгоритм расчета параметров седиментационных устройств основан на поиске и подборе оптимального объема устройства и может быть использован для расчета размеров устройств прямоугольной формы. Таким образом, в результате теоретических исследований в настоящей работе предложен метод расчета оптимальных значений размеров седиментационных устройств, который может быть применен при оптимальном проектировании устройств для очистки нефтеводяной смеси.

Ключевые слова: очистка воды, нефтеводяная смесь, седиментация, седиментационное устройство, оптимизация, очистка нефтеводяной смеси седиментацией, оптимальные размеры устройства.

References

1 Zhukov, A.I., Mongait I.L., & Rodziller, I.D. (1977). *Metody ochistki proizvodstvennykh stochnykh vod [Methods of sedimentation of production sewage]*. Moscow: Stroiizdat [in Russian].

2 Kulskiy, L.A., Goronovskiy, N.T., Koganovskiy, A.M., & Shevshenko, M.A. (1980). *Spravochnik po svoistvam, metodam analiza i ochistke vody [Reference guide for the properties analysis methods and treatment of water]*. Kiev: Naukova dumka [in Russian].

3 Stakhov, E.A. (1983). *Ochistka neftesoderzhaschikh stochnykh vod [Treatment of oil containing water sources]*. Leningrad: Nedra [in Russian].

4 Yakovlev, S.V., Kareliv, Y.A., & Zhukov, A.I. (1995). *Kanalizatsiia [Sewage Systems]*. Moscow: Stroiizdat [in Russian].

5 Zhigulskiy, V.S., & Reshnyak, V.I. (2006). Plavuchii complex dlia pererabotki neftevodianoi smesi [Floating complexes for the treatment of oily mixtures]. *Sudostroenie — Shipbuilding, 5*, 47–48 [in Russian].

6 Zeldovich, Ya.B., & Yaglom, I.M. (1982). Vyshaia matematika dlia nachinayushchikh fizikov i inzhenerov [Higher mathematics for elementary physicists and engineers]. Moscow: Nauka [in Russian].

7 Ivanov, V.M., Nefedov, P.I., & Kantorovich, B.V. (1960). Eksperimentalnoe issledovanie povedeniia chastits zhidkoho topliva i toplivno-vodianoi emulsii v okislitelnoi i neitralnoi srede [Experimental research into the behaviour of liquid fuel particles and fuel-water emulsions in acidic and neutral environments]. *Otchety IGI AN SSSR — Reports of IGI of the Academy of Science of the USSR, 59* [in Russian].

8 Reshnyak, V.I., Zhigulskii, V.A., & Pestereva, N.E. (2006). *Optimizatsiia razmerov ustroistv pri proektirovanii prirodookhrannykh tekhnicheskikh sredstv [The optimisation of device dimensions for the design of environmental protection equipment]*. Saint Petersburg: SPBGUVK, 173–178 [in Russian].

9 Yakovlev, S.V. (1979). *Ochistka proizvodstvennykh stochnykh vod [The treatment of industrial water sources]*. Moscow: Stroiizdat [in Russian].

10 Egorova, E.N. (2004). Metodicheskie osnovy otsenki economicheskoho ushcherba, voznikaiuschcheho v rezultate avariinykh razlivov na morskikh akvatoriiakh [A methodological basis for an evaluation of environmental damage, resulting from accidnetal spills into marine basins]. *Issledovanie v Rossii — Research in Russia*, 955–971 [in Russian].

11 *SNiP 12. 04.03–85 Proektirovanie sooruzhenii dlia ochistki stochnykh vod [Construction Norms and Standards 12. 04.03–85 Equipment design for waste water treatment]*. (1990). Moscow: Stroiizdat [in Russian].

12 Zhigulskiy, V.A. (2009). Heoekolohicheskie tehnolohii pererabotki neftevodianoi smesi pri likvidatsii avariynykh razlivov [Geological technology for the treatment of oily mixtures in the clean up of accidental spills]. *Extended abstract of candidate's thesis*. Saint-Petersburg [in Russian].