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# MICROPROCESSOR CONTROLLED OIL/WATER SEPARATOR

An oily water separator combining chemical destabilization, coalescence in bed, and adsorption has been presented. The separator of a capacity rate of 2.0 $m^3/h$ can be applied to industrial oily water treatment as well as to any processing streams containing finely dispersed oil and grease. Introduction of a novel method of coalescer bed regeneration by a hydrocarbon diluent injection and metering of minute amount of polyelectrolyte enables the purification of wastewater contaminated by highly viscous oils and emulsified oils at ambient temperature. Adsorption of the dissolved hydrocarbons and solvents may result in complete removal of oil from the wastewater. According to the wastewater properties and required effluent quality, the optimal mode of operation is selected and controlled by the separator microprocessing unit.

## 1. INTRODUCTION

Current state-of-the-art of the technology of water deoling enables the design and construction of efficient sewage treatment plants, the effluent from which meets the requirements of the class of purity of the receiver, or is even free from substances termed "oils". Industrial plants producing large streams of wastes and having properly designed and operated sewage treatment plants do not constitute an oil hazard to rivers, lakes or coastal sea waters. The technological lines of such plants usually employ gravity separation, flotation connected with chemical destabilization of oily waters and, finally, biological treatment [1]–[3].

In the case of sources of oil-contaminated waters of small volume flow rate, produced most often in small industrial plants, departments of big plants or floating vessels, the content of "oil" in the purified wastewaters much more often does not meet the requirements [4]. Installations and systems containing coalescence beds are particularly recommended there. Maintenance care available for effluent purification installations is inferior with respect to large treatment plants. Automatical mode of operation is therefore highly desired for such wastewater deoiling.

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The present paper is aimed at discussing the selected large scale tests which preceded the construction of a multi-stage oily water separator as well as at presenting the unit itself which is fitted out with a microprocessor for controlling the deoiling process.

## 2. APPLICATION OF COALESCERS IN WASTEWATER DEOILING

Gradual sharpening of the requirements concerning the content of contaminants discharged with wastewater to receivers refers also to oil separators. In the oldest devices gravitational and centrifugal forces were utilized; they were capable of removal of freely floating oil. Further improvements of gravity separators with labirynth flow and a system of parallel plates enabled a separation of the coarsely dispersed oil. The investigations on wastewaters containing mechanical emulsions from various sources have shown that emulsified oil usually does not exceed 300 mg/dm$^3$. Application of plate separators can reduce this value to 100 mg/dm$^3$, whereas the separators with coalescence beds guarantee the removal range within 15–50 mg/dm$^3$ on average [5]–[7].

Application of coalescent filters for deoiling of wastewaters containing even relatively stable oil emulsions became possible after introduction of preliminary chemical destabilization by means of polyelectrolytes. The content of oil in the effluents falls below 5 mg/dm$^3$. Dissolved oils, if any, require application of adsorption beds.

## 3. CHARACTERISTICS OF OIL-CONTAMINATED WASTEWATERS

Petroleum products are very often the main contaminants of the small streams of oily waters, therefore their removal is usually connected with abrupt improvement of other parameters, e.g., COD, turbidity or suspended matter. The oily phase consists mainly of crude oil and products of its distillation but also contains edible fats, technical greases, and coal tar oils. Oils occur in wastewaters in a few forms, viz.:

floating oils,
dispersed oils (coarse and fine),
oil agglomerates with suspended solids,
dissolved oils.

Regular routine analyses, taking into account division of oil into the above mentioned four groups, might highly facilitate the proper choice of wastewater treatment technology. Table 1 lists the physico-chemical characteristics of oil-contaminated wastewaters in which oil products do not exceed 250 m$^3$/day. The data listed in tab. 1 are average or extreme values, depending on the manner of carrying out the investigations and presentation of the results. It follows from the tab. 1 that the total content of oil does not exceed 1%.

Table 1

Some properties of oily waters

| Origin of oily water | Content of oil products mg/dm$^3$ | Mean size of oil droplets in wastewater μm | Source of information |
|---|---|---|---|
| Oily water, generally | 1000 | – | [12] |
| Oily water, generally | 15–25* | 15 | [11] |
| Oily water, generally | 44–355* | 50 | [8] |
| Water from washing of oil tanks on tankers | 236–1653 | 5–20 | [9] |
| Bilge water | 280 | – | [10] |
| Bilge water | 110–3600 | 3–50 | own works |
| Bilge water | 80–4500 | 12 | [8] |

* After pretreatment in plate separators.

## 4. EXPERIMENTAL

### 4.1. LARGE SCALE TESTS

Selected results of water deoiling in multi-stage experimental installation equipped with coalescent cartridges, chemical destabilization facilities and adsorbing bed are presented.

The flow rate of model emulsion was equal to 2–4 m$^3$/h. The cartridges with granular polyethylene and active carbon were formed by pouring the packing into cylinders, 50 cm high, made of perforated metal sheets. The thickness of the layer of polyethylene granules was equal to 0.07 m, and the layer of active carbon grains, to 0.15 m. Fiber cartridges were obtained by winding a polypropylene–polyester nonwoven mats around a perforated cylinder, until the thickness of the layer reached 0.07 m under the predetermined packing density.

The schematic diagram of the installation is presented in fig. 1. Three separate units, differing in operation, are distinguished in the diagram, namely the model emulsion preparation unit, chemical reagents proportioning unit, and the separation unit. The subsequent stages in the separation unit were assembled in a sequence most probable in a regular system.

The properties of the model emulsion and the oils involved are listed in tab. 2, and the specification of the materials applied is given in tab. 3. The volume of the separated oil and the pressure drop were measured in each separating stage, and a sample of emulsion was taken for analysis. The content of oil in the emulsion was determined by IR analysis of the $CCl_4$ extract. Subsequent runs lasted from 20 to 30 h of continuous operation of the installation.

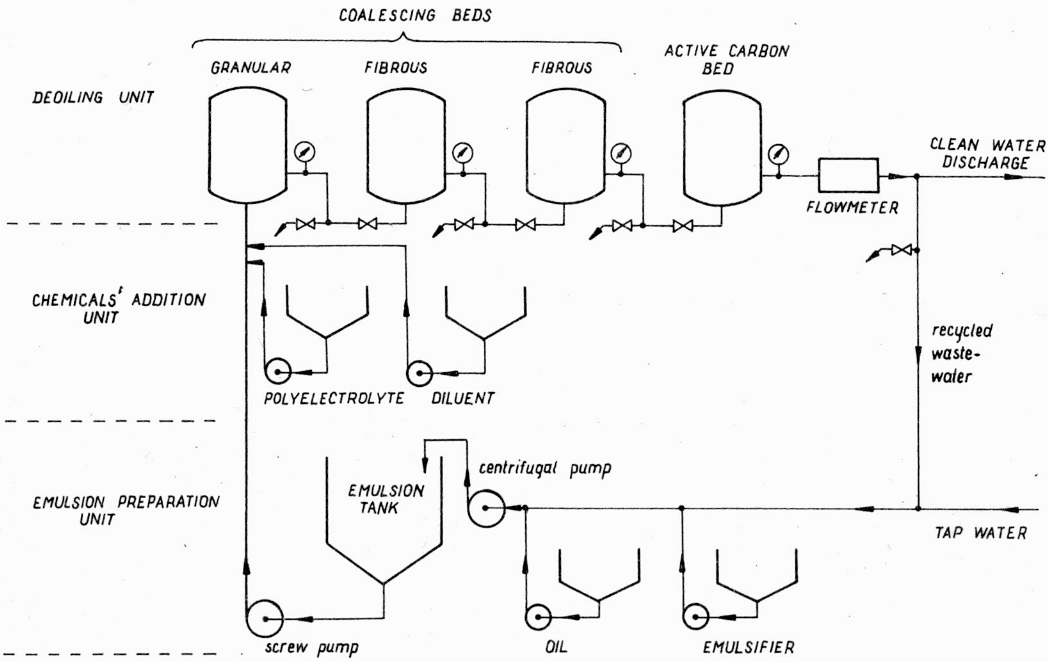


Fig. 1. Large scale test schematic flow chart

Table 2

Characteristics of model oil–water emulsion

| WATER PROPERTICS | | OIL PROPERTIES at 20°C | |
|---|---|---|---|
| Conductivity (Ω/cm) | $2.64 \times 10^{-4}$ | Density (kg/m$^3$) | 890 |
| Hardness (mval/dm$^3$) | 4.2 | Viscosity (mPa·s) | 280 |
| pH | 6.5 | | |

EMULSION PROPERTIES

| Characteristics | Amount of stabilizing agent, wt % | | |
|---|---|---|---|
| | A | B | C |
| | 0 | 0.001 | 0.01 |
| Oil concentration (mg/dm$^3$) | 500±50<br>3000±200 | 500±50<br>3000±200 | 500±50<br>3000±200 |
| Mean drop diameter (μm) | 3.2 | 2.4 | 2.1 |
| O/W interfacial tension (mNm$^{-1}$) | 26.4 | 19.2 | 18.1 |
| Zeta potential (mV) | −39 | −46 | −47 |
| Sedimentation rate constant (h$^{-1}$) | 0.060 | 0.042 | 0.029 |

Table 3

Specification of materials

| | |
|---|---|
| COALESCENCE BED | |
| **Granular** | |
| Material | polyethylene |
| Mean grain diameter | 1.25 mm |
| Density | 0.94 $g/cm^3$ |
| Molecular weight | 50.000 |
| Bed porosity | 0.40 |
| **Fibrous** | |
| Kind of fibres | polypropylene + polyester |
| Mean filament diameter | 18–30 μm |
| Mean density of both fibers | 1.1 $g/cm^3$ |
| Bed porosity | 0.83 |
| ADSORBING BED | |
| Material | activated carbon |
| Grain size | $2 \times 2$ mm, cylinders |
| Total bed porosity | 0.64 |
| DEMULSIFIER | |
| Type | NALCO polyelectrolyte |
| pH | 6.8 |
| Recommended dosage | 0.5 $mg/dm^3$ |
| DILUENT | |
| Substance | fuel oil |
| Density, 20°C | 0.82 $g/cm^3$ |
| Viscosity, 20°C | 1.2 mPa·s |

## 4.2. RESULTS AND DISCUSSION

The fundamental results of the investigation on coalescence efficiency connected with destabilization of emulsion are listed in tab. 4.

The results for mechanical emulsion are satisfactory even without the application of an adsorption bed for both concentrations ($500 \pm 50$ $mg/dm^3$ and $3000 \pm 200$ $mg/dm^3$) of oil. The final concentration of oil was lower than 10 $mg/dm^3$ after passing the emulsion through one granular and two fiber coalescence beds without chemical aid. Application of polyelectrolytes enables treatment with the omission of the second fiber bed. After adsorption on active carbon the content of oil decreased below 5 $mg/dm^3$. However, the process of separation of stabilized emulsion had a different course. It was not until the preliminary chemical destabilization of emulsion was applied that the expected value of 15 $mg/dm^3$ was

Table 4

Efficiency of oil removal from model wastewater

| Emulsion stability and initial oil concentration mg/dm³ | 0.5 mg/dm³ addition of demulsifier | Residual oil concentration, mg/dm³ | | | |
|---|---|---|---|---|---|
| | | Granular coalescence bed | Fibrous coalescence bed | Second fibrous coalescence bed | Active carbon adsorption |
| A 500 | no | 210 | 110 | 10 | 5 |
| A 500 | yes | 80 | 10 | 5 | 5 |
| B 500 | no | 440 | 380 | 330 | 180 |
| B 500 | yes | 230 | 160 | 15 | 5 |
| A 3000 | no | 800 | 380 | 10 | 5 |
| A 3000 | yes | 200 | 15 | 5 | 5 |
| B 3000 | no | 1200 | 1600 | 900 | 220 |
| B 3000 | yes | 1300 | 620 | 110 | 15 |
| C 500 | yes | 400 | 310 | 140 | 15 |
| C 3000 | yes | 2140 | 1460 | 420 | 50 |

achieved. In the case of B500 emulsion the 15 mg oil concentration/dm$^3$ was obtained when one granular and two fiber coalescence beds were used and simultaneously destabilization of the emulsion was performed. For B3000 emulsion the goal was achieved not earlier than after adsorption.

For emulsions of type C, the 15 mg content of oil/dm$^3$ in the effluent was achieved only for initial oil concentration lower than 500 mg/dm$^3$. Addition of polyelectrolyte in the concentration of 0.5 mg/dm$^3$ did not increase significantly the rate of coalescence of oil droplets, provided the emulsion remained in quiescent conditions or was gently agitated. It was the coalescence in the bed of destabilized oil droplets that dramatically reduced the oil content.

It also should be pointed out that a high degree of separation was achieved despite the application of common coalescing materials.

The effect of regeneration of the bed can be observed in fig. 2. It shows the dependence of pressure drop across the bed and the oil content in the effluent on the time of bed operation. As elsewhere discussed, the liberation of the bed from the excess of viscous oil was achieved only for granular beds [13] and no attempt was made during the presented investigation to inject a solvent to a fibrous bed. Favourable effect of a diluent on extension of the lifetime of the cartridge with granular polyethylene is beyond any doubt. Field experiments also indicated that up to 90% of suspended matter previously accumulated in the polyethylene bed may be liberated together with oil.

The disturbance of the quasi-equilibrium in the coalescence bed due to

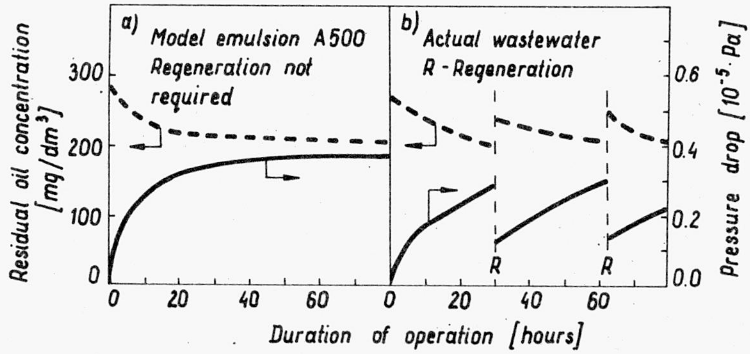


Fig. 2. Effect of granular bed regeneration by diluent injection

proportioning of a solvent results in a temporary increase of oil content in the effluent owing to the liberation of fine droplets from the bed. These droplets and the suspension are not retained in the gravitational chamber of the separator and can be transported to the fibrous bed. In order to avoid clogging of the fibrous cartridge, the effluent from the first stage should be directed to the preliminary storage tank.

In the discussed experimental setup, adsorption bed was the final stage in the system. Oil phase, if present, was highly dispersed – average droplet size below 2 μm. Dissolved hydrocarbons, in the amount requiring their removal, were not present in the model wastewater. The application of the active carbon bed resulted usually in lowering the content of oil in water of the value lower than 5 mg/dm$^3$. The sorption capacity of the activated carbon determined at $20 \pm 1\,^\circ C$ equalled 0.35 g/g.

## 5. CONSTRUCTION AND PRINCIPLE OF OPERATION

The separator, which has been constructed on the basis of our previously presented investigation, guarantees several stages of purification (see fig. 3). In order to eliminate large particles from entering the pump, a strainer basket, 0.15 m diameter and 0.30 m high, is installed on the suction side. Free and roughly disperged oil undergoes separation in a gravitational separator provided with a stack of corrugated plates. It was found advisable not to fit any gravitational separator at the suction side of the pump because of the possibility of air getting into it easily. Coalescence, followed by adsorption of the oil, takes place in two consecutive tanks in which there are three cylindrical coalescent cartridges and an active carbon bed. Duplex gauges on the inlet and outlet sides of the strainer and the beds are used to determine the pressure drop on each of them. The separator is provided with 5 solenoid and 3 pneumatic valves for discharging the oil.

The principle of operation is described below. Engagement of the separator for work makes the pump P1 start and the valves to be set so that wastewater flows

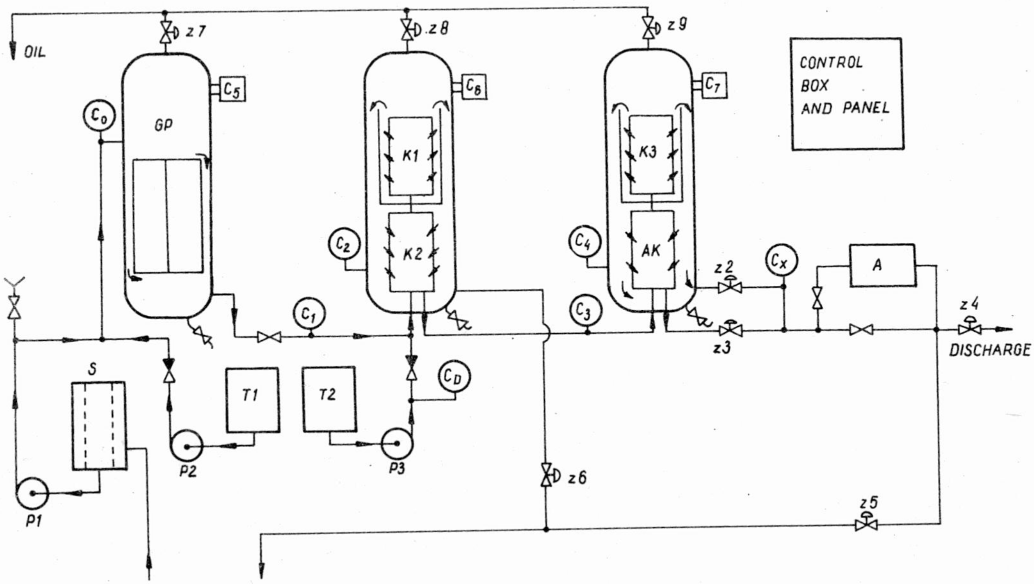


Fig. 3. Simplified schematic diagram of the separator; capacity rate 2 m³/h

A – oil content analyser, AK – active carbon bed, C – sensors, GP – gravity plate separator, K1 – granular bed, K2, K3 – fibrous bed, P1 – screw pump, P2, P3 – metering pumps, T1 – demulsifier tank, T2 – diluent tank

through three coalescence beds, and by-passing the adsorption bed returns to the storage tank. If a correct level of oil is indicated by the analyzer after 30 min of operation, the water is discharged to the receiver. If the oil content is higher than permissible, the pump P2 begins dosing a polyelectrolyte solution as demulsifier.

The quality of wastewater is expected to be improved after approximately 15 min. If it still is insufficient, the flow of wastewater will be directed to the bed with activated carbon. If the required deoiling effect is not attained even with the application of activated carbon, which is highly improbable and may occur for a 15 mg/dm$^3$ level only, then the concentration of polyelectrolyte is increased in the solution that is being dosed into the wastewater or the adsorption bed can be replaced. If the predetermined pressure drop over the K1 bed is exceeded, the pump P3 becomes engaged with dosing the diluent, the valve z6 opens, and the valves z2 and z3 close. Regeneration takes place for a present period of time, e.g., 15 min, after which the pump is stopped, but the position of the valves does not change for another 15 min. If the flow resistance does not become lower, regeneration will be repeated once more. On completion of the regeneration process the automatically controlled system comes back to its preregeneration state.

The lack of polyelectrolyte or diluent in the T1 and T2 tanks (such state being alarmed earlier) interrupts the work of the unit in order to supplement chemicals, avoiding in such a case the necessity of replacing the coalescent cartridges or the activated carbon bed.

The carried-out tests as well as the knowledge of the properties of oily water indicate that replacement of the activated carbon bed is expected not oftener than once every few thousand m$^3$ of purified water or once every several months. Blocked fibrous cartridges are also the subject of replacement.

## CONTROL

The separator is provided with two control systems, i.e., one automatic and one emergency. In its regular mode of operation the unit is controlled by means of a microprocessor which engages only the indispensable stages of purification.

In order to optimize the deoiling process the microprocessor has been programmed in compliance with the logical diagram given in fig. 4. Higher contamination of

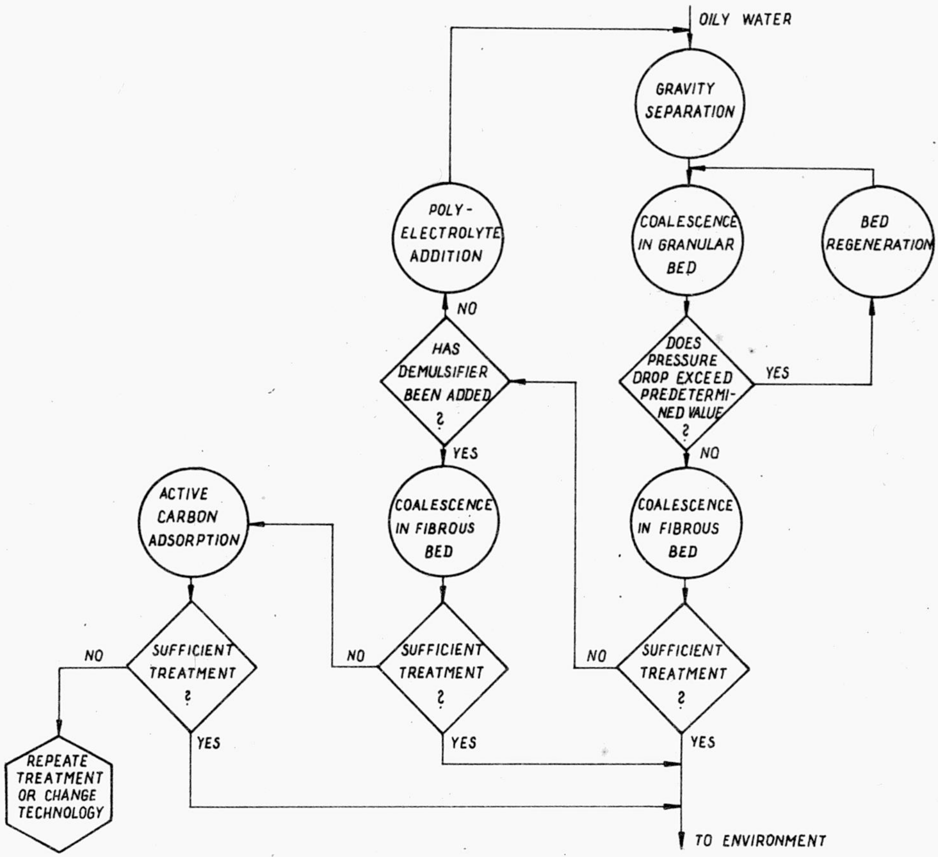


Fig. 4. Logic diagram for oily water treatment

the oily water, characterized by higher concentration of oil, increasing stability of the emulsion or increasing viscosity of the oil, is met by a more complex treatment of the wastewater. Nevertheless, such extended treatment lasts only for an absolutely required period of time and is given up as soon as its cause is eliminated. Reliable control of the unit has been made possible by the installation of 11 sensors which give their monitoring signals directly to the microprocessor. The following sensors have been applied:

2 level indicators (at the demulsifier and diluent tanks),
2 pressure controls,
3 differential pressure controls,
3 oil level sensors,
1 oil content analyzer.

Emergency control takes place in connection with a possible damage to the microprocessor or a break in its work. In such a case some of microprocessor decisions are taken over by the crew, e.g., the beginning and stopping of the demulsifier metering process or carrying out regeneration of the polyethylene-filled cartridge. The discharge of the recovered oil and the control of the z4 and z5 valves, however, continue to proceed automatically by means of signals coming from the analyzer.

Only four signals are led up to the control console, viz.,

opening of the z4 valve (counting of the duration of the valve's open stage is used for recording the quantity of water discharged to the receiver),

opening of the z5 valve (when processed water is being returned to the storage tank),

emergency alarm signal (an indication of any fault in operation),

indications given by the oil content analyzer.

Preliminary tests of the newly built separator entirely confirmed its expected deoiling capability below 15 mg/dm$^3$ regardless of the kind of wastewater.

## 6. SUMMARY AND CONCLUSIONS

1. The carried out experiments have proved that the proposed technology of deoling (fig. 1) resulted in total removal of oil from nearly all the model emulsions applied regardless of the degree of dispersion of oil and stability of the emulsion.

2. The regeneration effect of the coarse coalescence bed is particulary significant for an actual wastewater stream containing suspended matter. The regeneration diminishes the usual disadvantages of coalescers connected with a short lifetime of cartridges due to the presence of heavy oil and suspended matter in the aqueous and oil phases.

3. Chemical destabilization of oily waters enables application of cartridges packed with common readily available coalescing materials.

4. The carried out research resulted in the development of a logical system for oily water purification used as a basis for programming of the separator microprocessor.

## ACKNOWLEDGMENT

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## STEROWANY MIKROPROCESOROWO SEPARATOR FAZ W EMULSJI TYPU OLEJ/WODA

Zaprezentowano separator faz w emulsji typu O/W, działający na zasadzie koalescencji w złożu, chemicznej destabilizacji emulsji oraz adsorpcji. Separator o nominalnej wydajności 2 $m^3/h$ może być stosowany zarówno do odolejania ścieków przemysłowych, jak również innych wód procesowych, zawierających zdyspergowane oleje. Nowa metoda regeneracji złoża koalescencyjnego, polegająca na dyspersji rozpuszczalnika organicznego w strumieniu emulsji w trakcie trwania procesu oraz dozowaniu polielektrolitów, daje możność oczyszczania ścieków zawierających silnie zemulgowane oleje o dużej lepkości.

W zależności od właściwości emulsji i wymaganego stopnia odolejenia ścieków, optymalny sposób pracy separatora jest wybierany i sterowany działaniem układu mikroprocesorowego, wchodzącego w skład wyposażenia urządzenia.

# МИКРОПРОЦЕССОРНО УПРАВЛЯЕМЫЙ СЕПАРАТОР В ЭМУЛЬСИИ ТИПА МАСЛО/ВОДА

Представлен сепаратор фаз в эмульсии типа масло/вода (М/В), работающий по принципу коалесценции в слое, химической дестабилизации эмульсии и адсорбции. Сепаратор номинальной эффективности 2 м$^3$/ч может применяться для обезмасливания промышленных сточных вод, а также других вод, происходящих из промышленных процессов, содержащих дисперсные масла. Новый метод регенерации коалесценционного слоя, состоящий в дисперсии органического растворителя в струе эмульсии по ходу продолжения процесса, а также в дозировке полиэлектролитов, дает возможность очистки сточных вод, содержащих сильно эмульгированные масла большой вязкости.

В зависимости от свойств эмульсии и требуемой степени обезмасления сточных вод, оптимальный способ работы сепаратора выбирают и управляют им посредством действия микропроцессорной системы, будущей в оборудовании устройства.