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Water recycling automation of car wash with cleaning channel and changeable adsorptive plate holders

***Abstract**. Almaty car service recycling water supply is an important component of environmental safety and of reducing potable water consumption by industry. The article proposes the installation of recycling water supply, the principle of which is based on the purification of oily water effluents in the adsorption changeable cassettes. The pilot installation and algorithm of calculation engineering method allow determining the height and thickness of the adsorbent bed in a removable cassette. Computer experiments and the three-dimensional model confirm calculations and visualize the process of hydrocarbons overflow through the adsorbent bed. This provides automation of water purification process using modern microcontrollers and SCADA-systems.*

***Streszczenie.** Istalacja recyklingu wody w stacji obsługi samochodów miasta Almaty stanowi ważny elementem bezpieczeństwa ekologicznego oraz zmniejszenia zużycia wody pitnej przez przemysł. Artykuł omawia instalację recyrkulacji wody, wykorzystującą wymienne kasety adsorpcyjne. Zastosowany w instalacji pilotażowej algorytm pozwolił na określenie parametrów złoża adsorbentu w wymiennych kasetach. Z kolei parametry przepełniania złoża adsorbentu określają przeprowadzone badania symulacyjne z trójwymiarowym modelem. Przedstawione rozwiązanie zapewnia automatyzację procesu oczyszczania wody z wykorzystaniem mikrokontrolerów i systemów SCADA. (**Automatyzacja uzdatniania wody w myjni samochodowej z kanałem czyszczącym i wymiennymi uchwytami płyt adsorpcyjnych**).*

Keywords: water purification, three-dimensional computer modelling, automated recycling water supply.
Słowa kluczowe: oczyszczanie wody, trójwymiarowe modelowanie komputerowe, automatyczny recykling dostarczania wody.

Introduction

Population and industrial production growth of modern advanced megapolises requires solving the problem of providing drinking water to the cities. Production of high-quality tap water is the priority for the development of urban infrastructure. The whole world, as well as Almaty city is no exception and it is experiencing a lot of difficulties related to water consumption, which may adversely affect the dynamic growth of the city as a financial and economic center of Central Asia and Kazakhstan. An important guideline for reducing the drinking water consumption from the city water supply network is the introducing recycling water supply into industrial, transport and service enterprises. Major water users are the car washes, the number of which is continuously growing. Numerous car washes checks by the city administration regulatory agencies demonstrate the relevance of this problem solution.

Large-scale implementation of water recycling systems at Almaty city car washes is hampered by socio-economic, technical and scientific problems. First, the sharp rise in prices of drinking water can lead to unpredictable social processes. The low price of tap water leads to an increase in its use for technical needs. The optimal solution to this problem, in our opinion, is to create a low-cost, compact and technologically feasible construction of cleaning channel for car wash recycling water supply systems and practicing harsh administrative measures against violators of environmental regulations.

Therefore, research, development and introduction of domestic automated, compact, budget and efficient recycling water supply plants, easily adaptable to the technology of most existing car washes of the city, is an actual scientific-technical and ecological problem [1].

The aim of the work

The aim of the work is to develop compact and feasible automated management system over the city's car washers recycling water supply systems by microcontrollers, allowing reduction of consuming potable tap water of Almaty, raise the level of the enterprise's ecological safety at the expense of reducing hydrocarbon content from transport enterprises' waste water.

To achieve this goal it is necessary to solve the following tasks:

- Studying the design features and specifications of hydraulic structures and hydraulic devices used for water purification by filtration method;
- Analysis and research of mechanisms of water treatment from salt ions and organic impurities using a variety of natural sorbents, minerals in north –east of Kazakhstan;
- Creation of the experimental apparatus, modelling hydraulic processes in a filtration bed of natural sorbents;
- Development of semi-empirical models of processes in filtration cartridges, filled with natural sorbents; carrying out numerical calculations to assess the effectiveness of water treatment cost;
- Computer modelling of filtration processes in the hydraulic channel with removable adsorbent cartridges;
- Elaboration of recommendations on the design and creation of automated compact hydraulic channel with removable adsorbent cartridges.

The pilot installation of the hydraulic channel with replaceable adsorptive cassettes. For the construction of automated quality management system of oily wastewater treatment, let's consider the existing algorithms for flow parameters calculation upon hydrocarbons adsorption in the hydraulic channel with the cassettes installed therein with different sorbent composition. Photography allows fixing the dynamics of the spatial pattern of hydrocarbons front slip motion through the adsorbent bed. The calculations were made to determine the Darcy filtration coefficient for various industrial sorbents [2, 3]. As the bulk filter material there were used: activated carbon BAU-A, vermiculite sorbent "VermiSorb", silica brands KSKG, KSMG.

Let's investigate the processes occurring in hydraulic channel of rectangular cross section, sizes 1,5×1,5 m. The full-scale model of the device [1] is made of organic glass in a scale of 1:10.

In engineering calculations under the "actual speed" of the water motion in the pores of the load is referred to as the average value:

$$u' = \frac{Q}{w_{пор}} \quad (1)$$

where: Q – flow of water in the channel, $w_{пор}$ – actual speed of water motion in pores.

The rate of filtration is fictitious (imaginary) speed, supposing, that the water travels not only through the pores, but as well through the open area of the load's particles, at that, the water flow rate is equal to the fixed rate:

$$u = \frac{Q}{w_{геом}} = \frac{Q}{w_{пор} + w_{част}} , \quad (2)$$

where $w_{геом}$ – is the flow speed through the cross section of loading particles.

Dependence between the actual speed and the filtering rate can be found from the Darcy formula, expressing the fundamental law of laminar filtration:

$$u = k \cdot J , \quad (3)$$

where u – filtering rate in the given point of filtration flow; J – virtual-slope in the same point; k – proportionality constant, called filtration coefficient.

Filtration coefficient, having dimension of velocity (as J in formula (3) is nondimensional quantity), represents the filtration rate upon slope J = 1.

It was experimentally established that for the water with a predetermined temperature, the value k depends on the properties of the charged material. Theoretically, k depends as well on the viscosity of water, filtered through water adsorbent, since the viscosity of water depends on the temperature. Equation (3) shows that the filtration rate u, is directly proportional to the value of J in the first degree.

To construct the algorithms of calculation and oil-containing wastewater management it is necessary to take into account the existence of three different methods of determining the filtration coefficient in the Darcy formula:

- laboratory method: k is determined in the laboratory on a special device, where the sample of the load we are interested in is put in (with intact or broken structure);
- calculation method: k is determined by calculation, using special empirical formulas depending upon the load particle diameter value;
- field method: k is determined at the construction site of cleaning channel, bailing out water from behind filtration cartridges.

All three approaches should be used for the design and verification of automated control system. At low water consumption, and small quantities of hydrocarbons in the stream it is allowed to use bulk filtering sorbents [4, 5]. Replaceable cassette is designed so that the flow regime is pressureless. Fig. 1 shows a filtering process flow diagram.

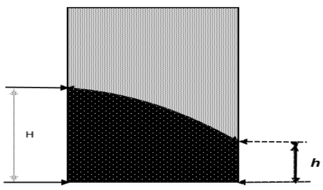

Fig. 1. Scheme of free flow filtering cassette

That is, the height of the car wash wastewater stream is lower than the height of the adsorbent bed. In this case an engineering method of calculation will be made for reasons of turbulent (quadratic) filtration in free flow filtration stream with free surface, contacting with the air in filter interlayer.

Water depth before free flow filtering cassette is defined (considering that channel bottom slope is practically small and does not influence at filtration rate) according to the formula.

Table 1. Value of turbulent filtration factor k in cm/sec

Average diameter of sorbent particles, adduced to the ball [mm]	Coefficient k for solid particles			Average diameter of sorbent particles, adduced to the ball [cm]	Coefficient k for solid particles		
	rolled	mongrel	torn sharp-cornered		rolled	mongrel	torn sharp-cornered
5	0,15	0,17	0,19	25	0,39	0,44	0,49
10	0,23	0,26	0,29	30	0,43	0,50	0,53
15	0,30	0,33	0,37	40	0,50	0,56	0,62
20	0,35	0,39	0,43	50	0,56	0,63	0,70

The best case is, if the figures are of the same width as the column – 8 cm. The letters in the figures should be not smaller than 2 mm. Figure 1 presents an example of a graph:

$$H = \sqrt[3]{\frac{Q^2 l}{b^2 k^2} + h_{\sigma}^3} , \quad (4)$$

where: $h_{б}$ – depth of purified water behind the filtering cassette, l – adsorbent charging length, b – adsorbent charging height, k – filtration factor.

At the initial stage of filtration the value thereof is neglected in calculations.

$$H = \sqrt[3]{\frac{Q^2 l}{b^2 k^2}} . \quad (5)$$

If the water depth is predetermined, the width of filtering cassette b is taken as designed.

For previous example data there is calculated the water depth before the cassette. Taking b = 20 cm, we have:

$$H = \sqrt[3]{\frac{2^2 \cdot 30}{0.2^2 \cdot 0.39^2}} , \quad (6)$$

which shows, you really can not pass the designed flow without pressure through the layer of 1 m height. The height of filter cartridge shall be more than H = 1,25 m.

Computer modelling of physical-chemical processes of oily water in the hydraulic channel with replaceable filtration cartridges

As it is known that upon adsorption from solutions there takes place absorption of pollution and medium molecules [6]. Purification of aqueous solutions is characterized by competition between the two types of intermolecular interactions: hydration of adsorptive molecules, i.e., their interaction with the water molecules in solution and the interaction of molecules of the adsorbate with adsorbent.

The energy difference between two processes thereof is the energy with which the extracted from the solution substance is kept by particles of adsorbent immersed into the solution. If the adsorbent surface has electrically charged centers, the strongest adsorption interaction is observed in cases when the molecules structure has multiple bonds, formed with participation of π - electrons. Therefore, aromatic compounds on sorbents are adsorbed better than aliphatic ones.

On the other hand, the presence of an electric charge, orienting around itself the water dipoles deteriorates the adsorption, therefore adsorbate's hydrated ions are adsorbed significantly worse than the undissociated molecules of the same substance. Adsorption is also degraded with an increase of hydroxyl groups number with high hydration energy in adsorptive molecules. Figure 2 shows the competition of hydration and adsorption processes associated with the differentiation of the sorbents for the removal of organic and inorganic substances.

For the sorption of organic substances there used porous carbon materials – activated carbons, crushed various organic materials as coal, coke, fuel, slag, sorbents based on cellulose and rubber, synthetic polymers.

The polar hydrophilic materials – resins, clay, silica, alumina gel, zeolites, oxides and hydroxides for the adsorption of organic substances are of little use, since the energy of their interaction with water molecules is equal to sorption energy of organic pollution molecules or exceeds it. Hydrophilic materials thereof are used to remove water from the inorganic compounds present in it, usually in ionic form).

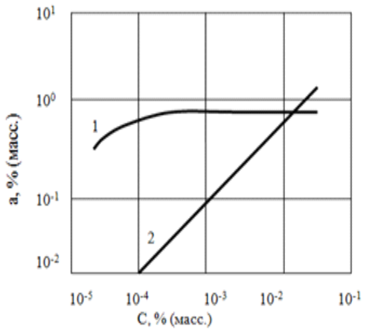

Fig. 2. An Absorptive power of active carbon (1) and extractant – Buthylacetate (2) as per phenol, extracted from aqueous medium, where a – adsorbent adsorption capacity, C – hydrocarbons percentage content

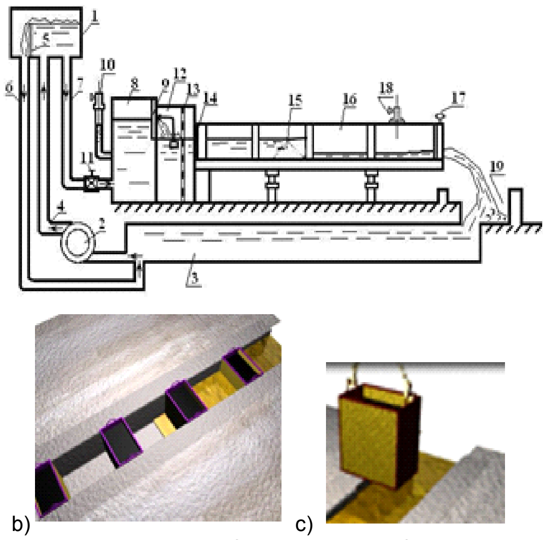

Fig. 3. A schematic diagram of the pilot setup of the car wash (a), hydraulic channel and its three–dimensional model (b) and construction of a cassette for adsorbent (c): 1 – pressure tank, 2 – pressure (feed) pump, 3 – pond, 4 – pressure pump pipe, 5 – pressure pump drain, 6 – pipe of the pressure pump return, 7 – surge tank piping, 8 – surge tank, 9 – valve of water level tank in the tray, 10 – surge tank level gage, 11 – surge tank valve, 12 – automatic regulator, 13 – measuring stick, 14 – first adsorption cassette, 15 – water between the second and third cassettes, 16 – tray, 17 – tray valve, 18 – sliding measuring stick of water level in the tray, 19 – water removing from the tray [8]

Out of these physical and chemical prerequisites there is performed the selection of the porous material as a filler for filter cartridges of cleaning hydraulic channel. Also taken into account that the given structural element of water recycling system is the most expensive and the responsible unit of the proposed facility. Optimization of design and economic parameters of the channel have an impact at the cost of the entire installation [7].

The most important feature of the small slope hydraulic channel is the ability to combine gravity and filtration methods of purifying waste water from impurities. This allows using in the process of car wash wastewater cleaning from petroleum products the coagulators, dosing of which in practice are established experimentally.

Analysis of industrial adsorbents and coagulators properties shows that the Kazakhstan market is the most appropriate to use as coagulator – polyacrylamide and zeolite as adsorbent. Potential suppliers of polyacrylamide H-600 might be LLP "Astak trade" and of zeolite A-4M – Russian company KNT group. Cost of reagents will not exceed $ 10 for one cycle of purification. To automate the process of spraying these reagents there is available Russian automatic feeders such as Alpha DLT easily embedded in PCS systems.

It is known that analytical methods for solving filtration differential equations through a porous medium are considered in the fundamental course of mathematical physics. In the stationary state the distribution function of hydrocarbons concentration *U(x, y)* per unit volume of the porous medium is described by Laplace elliptic equation, which has the form of:

(7) $$div(grad(U)) = 0$$

where: J – current density, r – distance, A, B, C – coefficients.

In Cartesian coordinates system for rectangular adsorbent layer in cross-section having a thickness – d (m), the geometric meaning of the problem and the Dirichletian boundary conditions are shown on Figure 4.

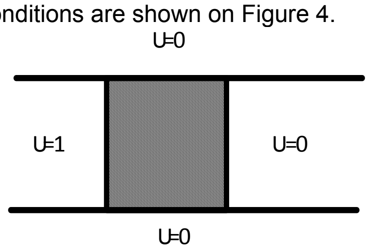

Fig. 4. Filtration task and Dirichletian boundary conditions, where U-flow

To solve the set problem in relation to the automation system using a SCADA system, calculations were carried out in PDE toolbox Matlab 6.5 [9]. Visualization algorithm of filtering estimated pattern and definition of hydrocarbons overflow line through the absorbent layer requires the following configuration of Matlab 6.5 medium tools

Thus: Step 1: Type *pde tool* command in the Matlab command window;

Step 2: In PDE toolbox window use the *Draw menu* tools and draw a rectangle;

Step 3: Through the menu *Boundary* by double-clicking the left mouse button on the left border of integration region reconfigure the window *Boundary Condition*, and enter value 1 into the r area;

Step 4: Enter *PDE Specification* sub-menu and set the type of elliptic equation, and set the value 1 in Q window;

Step 5: With the Mesh menu icons we achieve optimal triangulation of the integration domain for future finite element solution of Laplace equation under the given boundary conditions. The resulting picture of the integration computational domain is shown on Figure 5.

As far as hydrocarbons slip concentration wave passes through total adsorbent layer replaceable cartridges are discharged from the channel. Pictures of animated three-dimensional model of the replacement algorithm of spent cassettes with an adsorbent have been designed with 3dsMax [10] and presented in Figure 6.

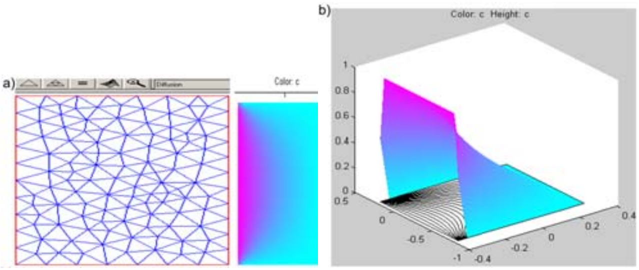

Fig. 5. The PDE modelling: a) integration domain final element grid after triangulation b) calculation of hydrocarbons motion in adsorbent layer

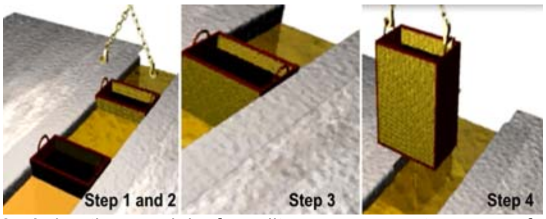

Fig. 6. Animation model of quality management process for car wash waste water cleaning

Their contents - the spent natural adsorbent with hydrocarbons - can be used as fuel oil, after which it can be reused as a sorbent. These arguments make the proposed scientific and technological solutions effective from environmental and financial-economic standpoint.

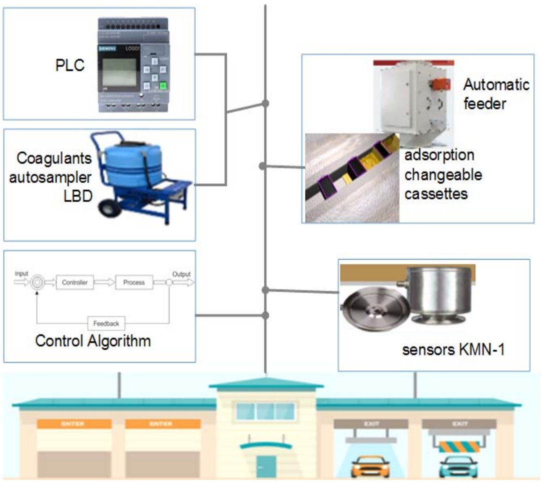

Fig. 7. Functional diagram of the process control system of a car wash with a sensor for defining hydrocarbons content and coagulants automatic dosage meter

It is known that the hydraulic channels with adsorption cassettes can be controlled due to the principle of automatic control. It requires: multiple sensors KMN-1, to measure the content of hydrocarbons in the inlet and outlet of the cartridge, as well as coagulants autosampler alpha LBD and microcontroller LOGO! [11]. Their functionally is adapted to control similar technological processes (as presented in the Figure 7).

The cost of a mini-PCS will be low, increased functional in the future will allow to create more complex control system with elements of the remote access via the Internet and computer animation technological processes [12].

Thus, the introduction of water recycling supply car washes with a hydraulic channel with replaceable adsorption cartridges and automation of waste water treatment quality control on the basis of microcontrollers can reduce the consumption of tap water for 10-15 times.

Conclusions

1. The patent and literature search showed that the adsorption method for carwashes wastewater purification is not widely used in buildings, structures and devices for cleaning oily waste tankers, oil tank trucks and petroleum storage reservoirs.
2. The adsorption properties of activated carbon, natural sorbents allow cleaning the water surface from oil and organic hydrocarbon stains upon man-made disasters in the seas and rivers.
3. The widespread use of sorption materials at wastewater treatment plants is difficult due to the rapid loss of adsorptive permeability of the filters and need in frequent replacement.
4. The rapid development of motorization leads to a need to equip all carwashes with compact, technologically advanced and environmentally friendly water recycling systems.
5. Developed water recycling equipment have a design flaw related to the lack of technology for utilization of collected hydrocarbons upon cleaning.
6. Proposed in the work the automated system of car washes recycling water supply system, completed with hydraulic channels with interchangeable adsorption cassettes allows, apart from water purification problems solution, is solving the problem of utilization through incinerating the wastes with high hydrocarbons content as a stove fuel. This approach has an innovative novelty.
7. The studied and proposed model, technology of automation and control over the hydraulic channel parameters, hydrocarbon adsorption processes in removable cassettes has scientific novelty and practical value.

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