TRANSPORT
2008
23(2): 129–134

DEVELOPMENT OF PLANT FOR TREATMENT OF WORKING LIQUIDS USED FOR PROCESS PURPOSES

Igor Trofimov[1], Alexander Zubchenko[2], Aleksey Suliman[3], Sergey Maxymov[4]

[1,2,3] National Aviation University, Chair of Process Equipment, Komarov av., 1, 03680 Kiev, Ukraine
E-mails: [1]troffi@ukr.net; [3]san.ttoa@mail.ru
[4] National Aviation University, Chair of General Physics, Komarov av., 1, 03680 Kiev, Ukraine

Received 10 October 2007; accepted 1 February 2008

Abstract. The questions of working liquids treatment using different methods are considered in this paper. Improved electric separator and hydraulic cyclone are developed for cleaning the liquids from mechanical impurities; the mobile unit is designed for cleaning the working liquids using the force fields. The results of experimental research of the aforementioned unit are represented.

Keywords: working liquids, movable setting, mechanical admixtures, filtration, electric-separator, hydrocyclone, power fields.

1. Introduction

World experience of aircraft operation has accumulated significant amount of statistical data concerning the airborne systems faults due to high level of the working liquids contamination. General experience in national and foreign aircraft fuel systems service reliability shows that almost 30 % of all accidents and disasters, up to 50 % of air- engine failures, 20 to 40 % of hydraulic systems and almost 10 % of fuel systems faults occur due to working liquids contamination; and life time of the pumps and other units decreases in this regard by 6–7 times (Лозицкий, Ветров 1992; Матвеева *et al.* 2005). Similar data can be found in works by G. A. Nikitin (Никитин, Чирков 1996), P. N. Belyanin and other authors (Wilson 1992).

Contaminants in working liquids lead to blockage of nozzles and orifices, to seizure of spool-and-sleeves and fuel-control units; contribute to premature deterioration of pumps and driven assemblies, to an increase of leakage through the moving connection gaps.

The working liquids purity depends not only on the working places and shopfloors atmosphere cleanness, purity of cleaning and process fluids, efficiency of purification, washing and monitoring the cleanness quality of working units and piping. Significant portion of contamination consists of foreign material remaining after the product making. These are remains from thermal treatment and machining, alignment and lapping, remainder of abrasive pastes after these operations.

Permanent attention to the problem of ensuring the liquids industrial purity is determined by many factors. High level of the working liquids purity contributes to flight safety, reliability, increase of system units' useful operating life. All these benefits fully prove costs of achieving and maintaining the necessary level of the working liquids purity. The most essential are the questions of systematization and improvement of methods and practice of industrial purity achievement with possibly minimum efforts and control of purity level during the entire production cycle. Problems of ensuring the working liquids purity are connected with material resources saving, environment protection, improvement of labour health conditions and fire safety of production processes.

2. Analysis of research and publications

The main rejection criteria for petroleum products used for process purposes during cleaning the units and systems of machines are the contents of contamination admixtures and water. Inadmissibility of contaminants and water presence in fuels, oils, hydraulic liquids is the major reason of their replacement in the process equipment. Protection and treatment of petroleum products allows to prolong their life time and, respectively, to ensure the significant economy. The working liquids can be treated using various ways which conditionally can be divided into three groups: filtration, treatment by means of force fields, and treatment using the physical and

ISSN 1648-4142 print / ISSN 1648-3480 online
www.transport.vgtu.lt
DOI: 10.3846/1648-4142.2008.23.129–134

chemical properties of contamination and working liquids (Никонов, Карабцов 1990; Kravets *et al.* 2006).

As it is well known the filtration occurs during passing the working liquid through the porous partitions of the coarse-mesh and fine filters. Power units operation is based on the effect of interaction between the contamination particles and the force field: gravitational, centrifugal, magnetic, electrostatic, electromagnetic, and the force fields generated by ultrasonic oscillations. Physicochemical treatment and dehydration of working liquids is carried out using silica gel and zeolite, mass exchanged drying, free and emulsion water. Each of these methods has its advantages and disadvantages, however, they all have one common imperfection - extracted from the liquid contaminants concentrate accumulates and remains inside the cleaning device being under the liquid flow hydrodynamic thrust influence. It decreases the throughput capacity and increases hydrodynamic resistance. Additionally, action of flow and pressure pulses cause wash-out and generation of contamination by the cleaning device itself. All these factors affect the treatment reliability and effectiveness and make it necessary to carry out the cleaning devices regular regeneration or filtering elements replacement. Separators are free of such imperfections.

3. Task definition

Tasks of the work: on the base of scientific and experimental works, to develop a more perfect electric separator, hydraulic cyclone for removal of mechanical additives from liquids, and to design a portable device for working liquids treatment using the force fields.

According to specifications and properties of liquids exposed to treatment an electric separator, hydraulic cyclone for removal of mechanical additives from liquids, and a portable device for working liquids treatment were designed.

Electric separator divides the liquid jet into two flows by means of the non-uniform electric field: one flow with the high content of contaminants, and the second flow – with relatively low content. For providing the effective separation of liquid flows with different concentration of contaminants, the working cell structure (Fig. 1) was suggested the operation of which was studied in the laboratory.

The electric separator operating cell consists of body 1 with located inside it operating electrodes 2 and 3 surrounded by the clean liquid collector 4 with openings 5. Cleaning liquid input tube 6, clean liquid output tube 7 and contaminants output tube 8 locate on the electric separator body.

During the electric separator operation non-uniform electric field is created between the electrodes connected to DC high voltage power supply via the potential sign change automatic device. The highest potential of electric field is applied to central part where distance between the electrodes is the smallest. While displacing from the axis in radial direction the electric field intensity decreases. Liquid to be treated flows through the input tube 6 to the area with the electric field maximal intensity.

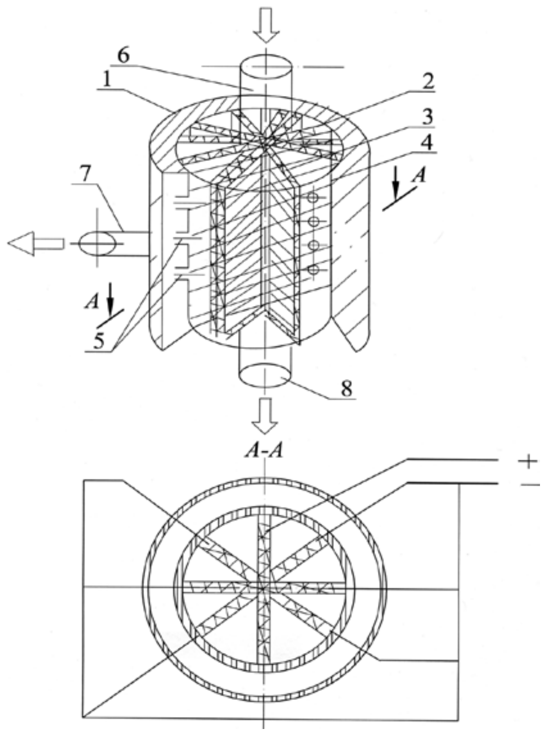

Fig. 1. Elementary diagram of the electric separator operating cell

Liquid in the separator body is divided into two flows: one flow is directed along the separator axis, and the second flow – perpendicular to axis. Contamination particles located in the area with the maximal electric field intensity move through separator together with liquids under the hydrodynamic thrust influence and are taken out via the contaminants output tube.

For further distribution and treatment of liquid we proposed to direct the cleaned in separator liquid to the electric cleaning unit, and to return the contaminated liquid to the cleaning tank (hydraulic cyclone) which has the upgraded structure developed by a composite author and has been patented in Ukraine (Зубченко *et al.* 2006).

Hydraulic cyclone for extraction of mechanical impurities from the liquids (Fig. 2) consists of cylindrical body 1 with lower cone part 2, perforated cone body-divider 3 installed inside the body and dividing the hydraulic cyclone body into two parts: internal and external relatively to body-divider, intake sleeve with wire-mesh wall 4 located inside the cone body-divider, intake tube 5 connected to intake sleeve and taking out the treated liquid, sludge drainage tube 6 connected to lower cone part of body, valve 7 connected to sludge drainage tube, tangential tube for the liquid input 8 located in the body lower part, float 9 fitted on the top of intake sleeve with the wire-mesh wall. The perforated cone body-divider divides the body internal housing into two parts: internal and external relatively to the cone body-divider.

Operating principle of the hydraulic cyclone for extraction of mechanical impurities from the liquids is the following. Pressurized liquid is supplied via the tangential tube into body. Due to centrifugal forces action

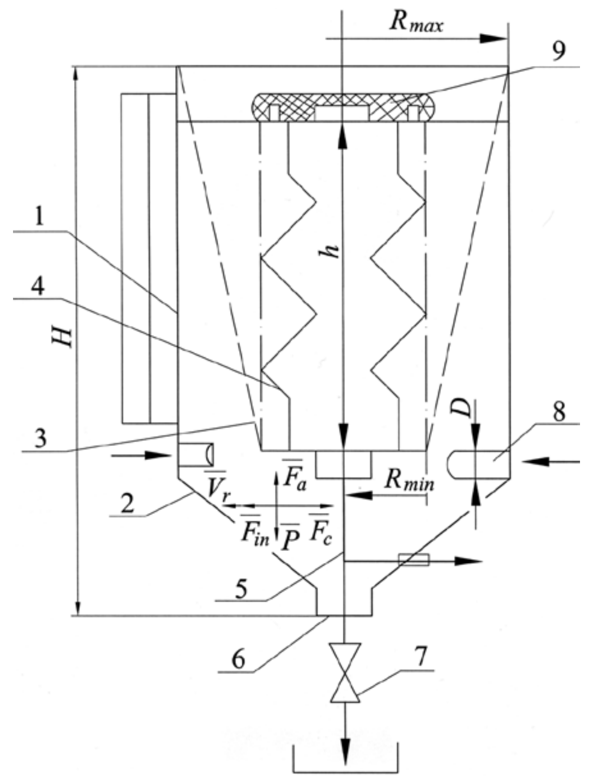

Fig. 2. Hydraulic cyclone for cleaning liquids from mechanical impurities and diagram of forces acting on contamination particle: 1 – hydraulic cyclone body; 2 – lower cone part; 3 – perforated cone body-divider; 4 – intake sleeve with wire-mesh wall; 5 – intake tube; 6 – sludge drainage tube; 7 – drain valve; 8 – liquid input tangential tube; 9 – float; *H* – hydraulic body height; *D* – liquid input tangential tube diameter; *h* – intake sleeve with wire-mesh wall height; R_{max} – maximal radius of perforated cone body-divider upper part; R_{min} – minimal radius of perforated cone body-divider lower part

the liquid with containing in it contaminants begins to perform rotary motion, and the contaminants are displaced to hydraulic cyclone walls, and cleaning liquid concentrates in the body center. Separated cleaning liquid moves up inside the hydraulic cyclone concentrating more around the cone body-divider.

Due to perforated cone body-divider in the internal housing the liquid movement is absent ($v_1 = 0$), i.e. the pressure has the maximum value ($P_1 = \max$); outside the cone body-divider velocity v_2 achieves maximum value ($v_2 = \max$) due to centrifugal field existing, thus the pressure tends to minimum value ($P_2 = \min$). It results in pressure difference ($P_1 >> P_2$) which is directed from the cone body-divider interior that allows preventing the mechanical impurities penetration from the external part into internal one. In the internal part of the cone body-divider the cleaned liquid flows to intake sleeve with wire-mesh wall and to the tank for cleaned liquid (not shown in Fig. 2) via intake tube. Fine-dispersed particles of contamination settle in the lower cone part of body and then move to sludge drainage tube and are taken out of the hydraulic cyclone at the valve opening.

Thus, treatment of liquids containing contaminants in a form of mechanical impurities with size of 20 μm and more is carried out. Treatment process performed by means of proposed hydraulic cyclone has high effectiveness and consumes minimal energy only to support the liquid supply to hydraulic cyclone.

Calculation of geometrical dimensions of hydraulic cyclone for mechanical impurities extraction from liquids and time of precipitation of mechanical impurities with size of 20 μm and more is shown below.

The following forces act on the contamination particle: inertia centrifugal force F_{in}, Stocks' resistance force F_c, gravity force P, Archimedean force F_a and Coriolis force of inertia (not shown in Fig. 2 as it is perpendicular to drawing plane). As to P and F_a forces, they virtually counterbalance each other, and Coriolis force of inertia can be ignored due to relatively small velocity of contamination particles (Никонов, Карабцов 1990).

In this case differential equation of contamination particles motion can be written in the following form:

$$m = \frac{dv_r}{dt} = F_{\text{з}n} - F_c, \tag{1}$$

where: m is contamination particle mass; $v_r = \frac{dr}{dt}$ is relative velocity.

As it is known (Никонов, Карабцов 1990) the centrifugal force of inertia equals:

$$F_{in} = m\frac{v_E^2}{r}, \tag{2}$$

where v_E is transport velocity,

$$F_c = 3\pi d\mu v_\tau, \tag{3}$$

where: d is the particle conditional diameter; μ is the liquid dynamic viscosity coefficient.

Transport velocity v_E can be determined using flow rate Q and the liquid input into tube cross-section area:

$$v_E = \frac{4Q}{\pi D^2}, \tag{4}$$

where D is this tube diameter.

As for the contamination particle mass m, assuming conditionally the sphere shape of particle with diameter d and density ρ, it can be determined as:

$$m = \frac{\pi d^3}{6}\rho. \tag{5}$$

After using all specified quantities in equation (1) and additional mathematical operations, this equation can be written in the following form:

$$\frac{d^2r}{dt} + 18\frac{\mu}{d^2\rho dt}\frac{dr}{dt} - \left(\frac{4Q}{\pi d^2}\right)\frac{1}{r} = 0; \tag{6}$$

where: $\frac{dr}{dt} = \mathrm{v}_r; \frac{d^2r}{dt} = \frac{d\mathrm{v}_r}{dt}$.

Equation (6) is nonlinear homogeneous second-order differential equation the solution of which has some difficulties. However the solution can be carried out by determining quantity r in a form of its Maclaurin series expansion, i.e. in the following form:

$$r = r_{(0)} + r_0 t + \frac{r_{(0)}}{2!}t^2 + \frac{r_{(0)}}{3!}t^3 + \frac{r_{(0)}}{4!}t^4. \quad (7)$$

To determine the initial values of 3-order and higher derivatives containing in Maclaurin series it is possible to differentiate successively with respect to time index the differential equation of contamination particles motion, i.e. rising its order by 1 at a time.

After solution of each equation from the obtained in such a way relatively high order, general determinations (as function of time index) of 3-order and higher derivatives are obtained which can be solved. General determinations for the second-order derivative can be obtained directly from the motion differential equation. Using the initial conditions, i.e. $t = 0$, $r_{(o)} = r_o$, $r_{(o)} = 0$ in determined in such a way derivatives it is easily possible to get expressions for all coefficients in Maclaurin series in the function of known initial conditions and the motion differential equation coefficients.

As an example, let us consider the cyclone having the following parameters: $r_o = 2.5$ cm; $R = 25$ cm; $Q = 10^3$ cm^3/s; $D = 1$ cm; $R \geq r \geq r_o$.

For contamination particles with size of $d = 0.002$ cm.

$$r = 2.5 + 2.5 \cdot 10^3 t^2 - 12.75 \cdot 10^7 t^3 +$$

$$8.0 \cdot 10^{11} t^4 + ... + \frac{r_{(0)}}{n!}t^n. \quad (8)$$

Assuming $r = R - r_o = 22.5$ cm it is possible from expression to find motion time of such a particle which approximately equals $t = 0.26$ s. For larger contamination particles this time will have the smaller value.

Let us compare this time t value with time τ of location in the device. The τ value can be determined using the device for known volume which equals:

$$V = rR^2 h + \frac{2}{3}\tau r R^2 (H - h). \quad (9)$$

From formula $V = Q\tau$ we determine:

$$\tau = \frac{\pi R^2 h + \frac{2}{3}\pi R^2 (H - h)}{Q}. \quad (10)$$

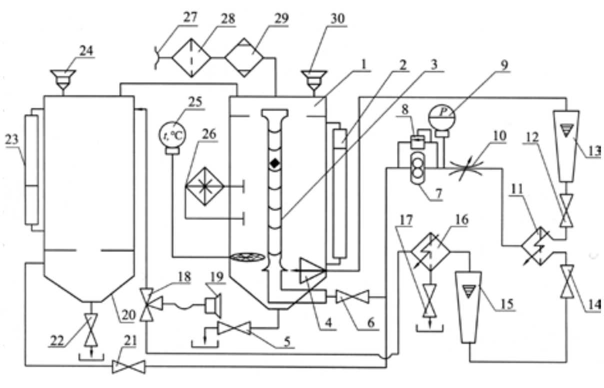

Fig. 3. Hydraulic circuit of mobile unit for cleaning the working liquids

Additionally, the composite author has developed, tested and patented in Ukraine (Трофімов *et al.* 2006) the mobile unit for working liquids treatment. Hydraulic circuit of portable device for cleaning the contaminated working liquid is shown in Fig. 3, ant its operation principle and components description are represented below.

Portable device for cleaning the contaminated working liquid consists of gravitational cleaning tank 1 containing sight glass 2, floating intake sleeve with wire-mesh wall 3, contaminated liquid input tube 4 located tangentially to tank wall in its lower part, and the contaminants drainage valve 5 fitted in the lower part of tank. The floating intake sleeve with wire-mesh wall 3, as far as exiting the gravitational cleaning tank, transforms into tube, after which valve 6 and gear pump 7 are installed downstream the piping. To prevent the overpressure after the pump the safety valve are installed, and then downstream the piping manometer 9, flow rate governor 10 and electric separator 11 are mounted. On one branch of piping after electric separator, the contaminated liquid valve 12 and rotameter 13 are installed after which the liquid in the piping flows to input tube for contaminated liquid. On the second branch of piping after electric separator, the clean liquid valve 14 and the clean liquid rotameter 15 and electric cleaning device 16 are installed for removal of mechanical impurities. Valve 17 for contaminants drainage is installed at the bottom of this device. After the electric cleaning device for removal of mechanical impurities, the three-way valve 18 is installed to which the output nipple 19 connected to tank 20 for treated liquid is attached. The tank for treated liquid is additionally connected to gear pump via the valve 21. The tank for treated liquid contains the treated liquid drain valve 22, sight glass 23, and filler neck 24 located in the tank upper part. Thermometer 25 and heat exchanger 26 are attached to the gravitational cleaning tank via the nipple joint, and the air intake 27 is installed on top of the tank. Between the air intake and the tank, the air filter 28 and attached to it the air dryer 29 are mounted in series, and the filler neck 30 is installed on top of the tank.

Mobile unit for cleaning the working liquids operates in the following manner. The liquid to be treated is supplied to gravitational cleaning tank via the filler neck. The liquid level and its volume in the tank are monitored through the sight glass. In the tank the liquid is cleaned preliminary from the large contamination particles under the action of gravitational forces. From the tank the liquid with the help of gear pump through the piping flows for further cleaning to electric separator; in case of overpressure the safety valve triggers, thus regulating the system pressure measured by pressure gauge. Adjustment of liquid supply to electric separator is carried out by means of flow rate governor. Electric separator provides dividing the cleaned liquid flow into flows with low and high contamination level in comparison with output liquid. After electric separator the liquid with high contamination level returns to tank for settling and post-treatment under the influence of centrifugal forces as the liquid enters into tank tangentially to tank wall in its lower part by means of tube and due to this fact the liquid performs rotary motion. After electric separator the treated liquid (with low contamination level) flows to electric cleaning device for finer cleaning and then to the tank for clean liquid. The cleaned flow rate is measured by means of rotameters and is adjusted by the contaminated and clean liquid valves. Liquid is supplied to electric separator by means of floating intake sleeve with the wire-mesh wall from the liquid upper layer. The viscous cleaning liquid heating is performed by means of heat exchanger, and the cleaning liquid temperature is monitored by thermometer. Treated liquid quantity in tank is determined with the help of sight glass. Filler neck is designed for preventing vacuum or overpressure in tank as well as for filling the tank with clean liquid for storage or post-treatment. In case of valve 21 opening and valves 6 and 12 closing it is possible to clean liquid by means of electric separator or electric cleaning device only. Using three-way valve and the output nipple it is possible, if necessary, to pump the cleaned liquid to external vessel connected unit with the help of nipple. In the tank upper part the filler neck, air filter, air dryer are located, designed for supply of clean and dry air to the tank to prevent penetrating of foreign objects to the tank and creating vacuum and overpressure inside it. Contaminants accumulating in the gravitational cleaning tank final settlement chamber are removed from it by opening the sludge drain valve. For treated liquid drainage from the tank the treated liquid drain valve opens. The contaminants drainage from the electric cleaning device is carried out by opening the sludge drain valve of electric cleaning device.

Apart from the described above the mobile unit for contaminated working liquid treatment additionally allows pumping liquid from the clean liquid tank to gravitational cleaning tank while opening the valves 21 and 12 and closing the valves 14 and 6; cleaning the contaminated liquid only in the gravitational cleaning tank while closing the valves 21 and 14 and opening the valves 6 and 12; performing pumping and cleaning the contaminated liquid supplied from the external vessel.

As the investigation results have shown in case of using TS-1 jet fuel with contamination initial level up to 12 g/l, after treatment, fuel was obtained complying with the purity of 2-nd class according to GOSt 17216-71. The investigation results are shown in Figs. 4 and 5.

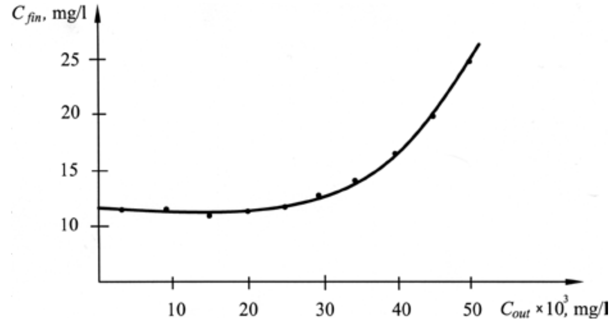

Fig. 4. Dependence of TS-1 fuel treatment results upon the contamination initial level

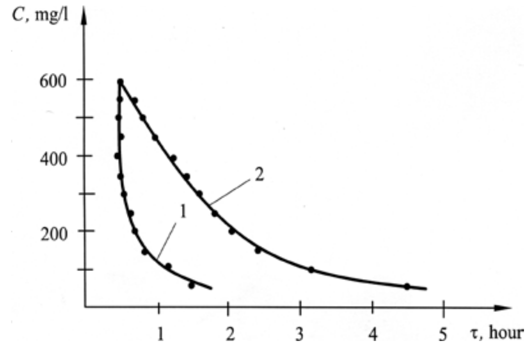

Fig. 5. Influence of separation time τ on the oil products treatment degree: 1 – TS-1 fuel; 2 –AMG-10 oil

4. Conclusions

1. Far more perfect electric separator and hydraulic cyclone for removal of mechanical impurities were developed and tested; the mobile unit for working liquids treatment using the force fields was designed.
2. Results of the unit operation experimental research allows making the following conclusions: developed mobile unit for contaminated working liquid treatment allows simplifying the contaminated working liquid treatment process (significantly contaminated petroleum products, used oil, special liquids for hydraulic systems) of removal the contaminants of different origin: ground dust, the pipes and tanks corrosion products, friction parts of wear products, moisture, biological contaminants, as the universal complex facility for treatment allows performing treatment of liquids with contamination level from 12 g/l (fine-dispersed contaminants with diameter of 5 μm and greater) to purity of first and second class according to GOST 17216-71, decreasing the treatment process labour content, increasing operation life of automotive and aircraft dielectric oils and the oil system units respectively.

References

Wilson, P. J. 1992. Solid contaminant profiles, *Fluid Power International* 37(439): 19–22.

Зубченко, О. М.; Трофимов, І. Л.; Бурдюженко, Л. В. Пат. 15975 Україна. МПК Гідроциклон для очистки рідин від механічних домішок [Zubchenko, A. N.; Trofimov, I. L.; Burduzhenko, L. V. Patent 15975 Ukraine IPC (2006) B04C 5/00 Hydraulic cyclone for liquids treatment for mechanical impurities removal] Valid from 17.07.2006 (in Ukrainian).

Кравец, И. А.; Трофімов, И. Л.; Матвеева, Е. Л.; Бурыкин, В. В. 2006. Стабилизация эксплуатационных свойств органических масел для газотурбинных двигателей внешним электромагнитным полем [Kravets, I. A.; Trofimov, I. L.; Matveeva, E. L.; Burykyn, V. V. Stabilization of operating ability of organic oils for turbine engines by means of external electromagnetic field], *Friction and wear problems*. Scientific and technical papers. Kyiv: NAU, 46: 201–209 (in Russian).

Лозицкий, Л. П.; Ветров, А. М. 1992. *Конструкция и прочность авиационных газотурбинных двигателей* [Lozitskiy, L. P., Vetrov, A. M. Construction and strength of the aviation turbine engines]. Москва: Транспорт. 735 с. (in Russian).

Матвээва, О. Л.; Захарчук, П. П.; Захарчук, В. П. 2005. Дослідження забрудненості рідин гідросистем літаків [Matveeva, O. L.; Zaharchuk, V. P.; Zaharchuk, P. P. Research of the airplanes hydraulics liquids contamination], *All-Ukrainian scientific and technical Journal "Industrial Hydraulics and Pneumatics"* 2(8): 36–42 (in Ukrainian).

Никитин, Г. А.; Чирков, С. В. 1996. *Влияние загрязнённости жидкости на надёжность гидросистем летательных аппаратов* [Nykytyn, G. A.; Chyrkov, S. V. Influence of liquid contamination on the aircraft hydraulics reliability]. Москва: Транспорт. 183 p. (in Russian).

Никонов, К. Б.; Карабцов, Г. П. 1990. *Очистка жидкостей в силовых полях* [Nykonov, K. B.; Karabtsov, G. P. Liquid treatment in force fields]. Киiv: КIIСА, 48 p. (in Russian).

Трофімов, І. Л.; Зубченко, О. М.; Матвээва, О. Л.; Захарчук, П. П. Пат. 18337 Україна. МПК (2006) B03C 5/00. Пересувна установка для очистки забрудненої діелектричної рідини [Trofimov, I. L.; Zubchenko, A. N.; Matveeva, O. L.; Zaharchuk, P. P. Patent 18337 Ukraine IPC (2006) B03C 5/00 Nobile unit for contaminated dielectric liquid treatment]. Valid from 15.11.2006 (in Ukrainian).