TRANSPORT PROBLEMS 2018 Volume 13 Issue 4
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2018.13.4.2

**Keywords:** compressed air, compressor, rolling stock, drying, purification

**Tatiana RIPOL-SARAGOSI, Leonid RIPOL-SARAGOSI*, Igor SMYCHOK**
Rostov State Transport University
Narodnogo Opolcheniya Sq., 2, 344008, Rostov-on-Don, Russia
**Corresponding author*: E-mail: ripol-saragosi@mail.ru

# COMPRESSED AIR QUALITY INCREASE FOR ROLLING STOCK PNEUMATIC SYSTEMS BASED ON ENERGY EFFICIENCY

**Summary.** The energy efficiency increase problem for railway rolling stock pneumatic systems compressed air preparation is directly connected with its purification and drying technology choice. In the presented materials in the article, the authors find a solution to the problem based on realization analysis of different factors that affect compressed air quality, purification and drying technology choice, as well as based on energy efficiency analysis. To realize the energy-saving events at railway rolling stock compressed air preparation, the authors suggest performing factor analysis influencing on compressed air purification method choice to consider pneumatic system as a module scheme and to employ the modernized construction of the locomotive main tanks.

## 1. INTRODUCTION

The issues of energy saving in the transport sector in light of annual growth of energy consumption, negative environmental effects, and the amount of harmful substances are becoming increasingly important. The transport system of Russia unites not only rail, road, air, sea, and river transport but also main gas and oil pipelines. However, the Russian Railways holding (for instance) is the largest system-forming element of the Russian economy, accounting for more than 45% of cargo turnover and 25% of the country's passenger turnover.

The need to manage the consumption of energy resources and ensure the effective operation of any railway economy in the field of energy conservation is a prerequisite for the development of an energy strategy. Such strategy defines the goals and objectives for medium- and long-term development periods, priorities, guidelines and mechanisms at particular stages of its implementation.

One of the main tasks, the solution of which will allow the operator to maintain leading position in the field of energy efficiency of rail freight and passenger transportation among the world's transport companies, is to increase the transport rate of energy efficiency of the main technological processes that ensure full and reliable energy supply of the transportation process [1].

Thus, carrying out measures to improve the energy efficiency of the transportation process will be an incentive for the introduction of energy-saving technologies in the management of train traffic and ensuring its safety.

## 2. COMPRESSED AIR QUALITY RATES AT ROLLING STOCK PNEUMATIC SYSTEMS

One of the most important technological energy carriers used in the pneumatic systems of the rolling stock is compressed air, the quality of which affects the safety of the transportation process.

The quality of compressed air [2, 3] in pneumatic systems of rolling stock is determined by the three main types of pollutants that can interact with each other:

- solid particles,
- water, and
- oil.

Each of these compressed air pollutants of the main pneumatic lines of rolling stock has its own signatures [4], which in the greatest degree determine the reliability of equipment functioning of pressure, braking, and in cases of industrial transport rolling stock operation – unloading lines. Such signatures include the following:

- for solid particles, maximum size and concentration;
- for water, the number of vapors determining the temperature of the dew point at a given temperature, pressure and relative humidity of the outside air; and
- for oil, concentration.

It is the quantitative characteristics of the aforementioned listed signatures that determine the grade of compressed air purity (table 1).

Table 1

Classes of compressed air purity State Standard 17433-80

<table>
<tr><th rowspan="2">Contamination class</th><th rowspan="2">Size of solid particle, µm, not more than</th><th colspan="3">Impurities content, mg/m^3, no more than</th></tr>
<tr><th>Solid particles</th><th>Water (in liquid state)</th><th>Oil (in liquid state)</th></tr>
<tr><td>0</td><td>0,5</td><td>0,001</td><td colspan="2" rowspan="2">Not allowed</td></tr>
<tr><td>1</td><td rowspan="2">5</td><td rowspan="2">1</td></tr>
<tr><td>2</td><td>500</td><td>Not allowed</td></tr>
<tr><td>3</td><td rowspan="2">10</td><td rowspan="2">2</td><td colspan="2">Not allowed</td></tr>
<tr><td>4</td><td>800</td><td>16</td></tr>
<tr><td>5</td><td rowspan="2">25</td><td rowspan="2">2</td><td colspan="2">Not allowed</td></tr>
<tr><td>6</td><td>800</td><td>16</td></tr>
<tr><td>7</td><td rowspan="2">40</td><td rowspan="2">4</td><td colspan="2">Not allowed</td></tr>
<tr><td>8</td><td>800</td><td>16</td></tr>
<tr><td>9</td><td rowspan="2">80</td><td rowspan="2">4</td><td colspan="2">Not allowed</td></tr>
<tr><td>10</td><td>800</td><td>16</td></tr>
<tr><td>11</td><td rowspan="4">Not regulated</td><td rowspan="2">12,5</td><td colspan="2">Not allowed</td></tr>
<tr><td>12</td><td>3200</td><td>25</td></tr>
<tr><td>13</td><td rowspan="2">25</td><td colspan="2">Not allowed</td></tr>
<tr><td>14</td><td>10000</td><td>100</td></tr>
</table>

Compressed air in pneumatic systems of the main and industrial rolling stock is a technological energy carrier, which in turn requires certain energy consumption for production and improvement of its quality [5, 6]. The purpose of the presented analytical materials is to conduct a factor analysis for choosing a circuit design for the production and preparation of compressed air in pneumatic systems of rolling stock from the standpoint of energy saving.

To select an adequate circuit design for the production and preparation of compressed air of the required quality, under the conditions of minimizing energy costs, the following will be analyzed:

- types of locomotive compressors used,
- quality of air sucked by locomotive compressors,

- technologies for cleaning and drying compressed air, and
- maintainability of installed equipment.

## 3. MODULE INTERPRETATION AT ROLLING STOCK PNEUMATIC SYSTEMS

Any pneumatic system on locomotives of a rolling stock, as a rule, consists of the following modules (Fig. 1):

- Module I: production of compressed air;
- Module II: processing of compressed air with cleaning from moisture, oil and solid particles; and
- Module III: storage and distribution of compressed air.

The industrial rolling stock locomotives are added with pneumatic cylinders for dump-cars overturning.

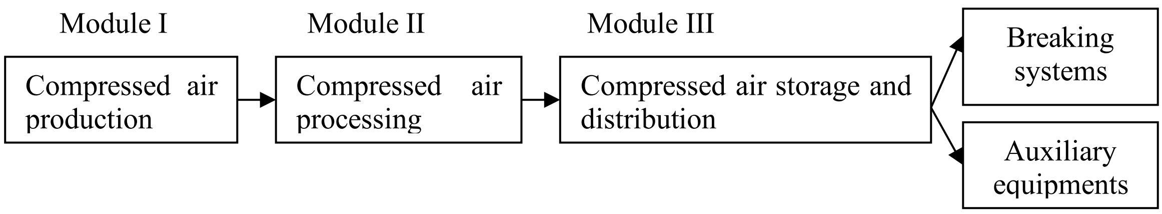


Fig. 1. Rolling stock pneumatic system module system

Certainly the production module and module for compressed air processing and purification are responsible for the preparation quality. Numerous laboratory and industrial tests, and the exploitation results as well, show non-coping with the qualitative and energy-efficient compressed air preparation by the production and processing modules. In this way, the increase in compressed air quality indexes should be done either by additional modules or additional equipment to increase the compressed air quality without additional increase in energy consumption in the technological process.

Compressed air production supply equipment are compressors (normally piston or screw compressors). Compressed air purification apparatus include oil and water separators, main and auxiliary tanks, breaking cylinders, pipes of pressure, feed and breaking cylinders, pipes of pressure, feed and breaking mains [7, 8].

## 4. FACTOR ANALYSIS

The first factor for analysis is the locomotive compressor type. It is the apparatus that influences the choice of technology and construction decision of apparatus at purifying module. The main locomotive part of the RF is equipped with piston compressors; despite the disadvantages of high level of oil at compressed air, high level of noise and vibration, and high energy consumption, they have certain advantages:

- high liability,
- maintainability,
- relative inexpensive,
- devices effective work of compressor at suction under performance decreasing of 15-20% of maximum.

The energy-efficiency integral rate for each of the two abovementioned compressor types to determine is not to be done, as their comparable work conditions analysis is hard to be realized [9].

It goes out from the said above, the rolling-stock and industrial locomotives are basically equipped with piston compressors. The compressed air may contain significant amount of oil that inevitably influences on scheme solutions for preparation, purifying and drying choice.

The significant effect on the choice of a technology and a constructive decision for the compressed air purification equipment affects maintainability after being set on a locomotive. For instance, the shunting locomotives, industrial traction locomotives, maintainability sharply goes down after adsorber being set.

The second factor to take decision on compressed air purifying system technological scheme design should be the quality of atmospheric air sucked by locomotive compressors. On realizing the compressed air purification system design, the following factors are to be analyzed before:

- the incoming air quality at the rolling-stock motion zones, analyzing soot, dust, and non-burned hydrocarbons;
- heat and humidity atmospheric air parameters (temperature and relative air humidity) influence on moisture quantity leaking into rolling-stock pneumatic system and consequently dew point; and
- compressed air consumption average rates at particular areas depending on compressor switching frequency.

Normally atmospheric air sucked by locomotive compressors contains wide pollutants range worsening its quality and negatively influencing on pneumatic system functioning modes [10]. The Fig. 2 shows the diagram illustrating types and measures of the solid parts at the atmospheric air.

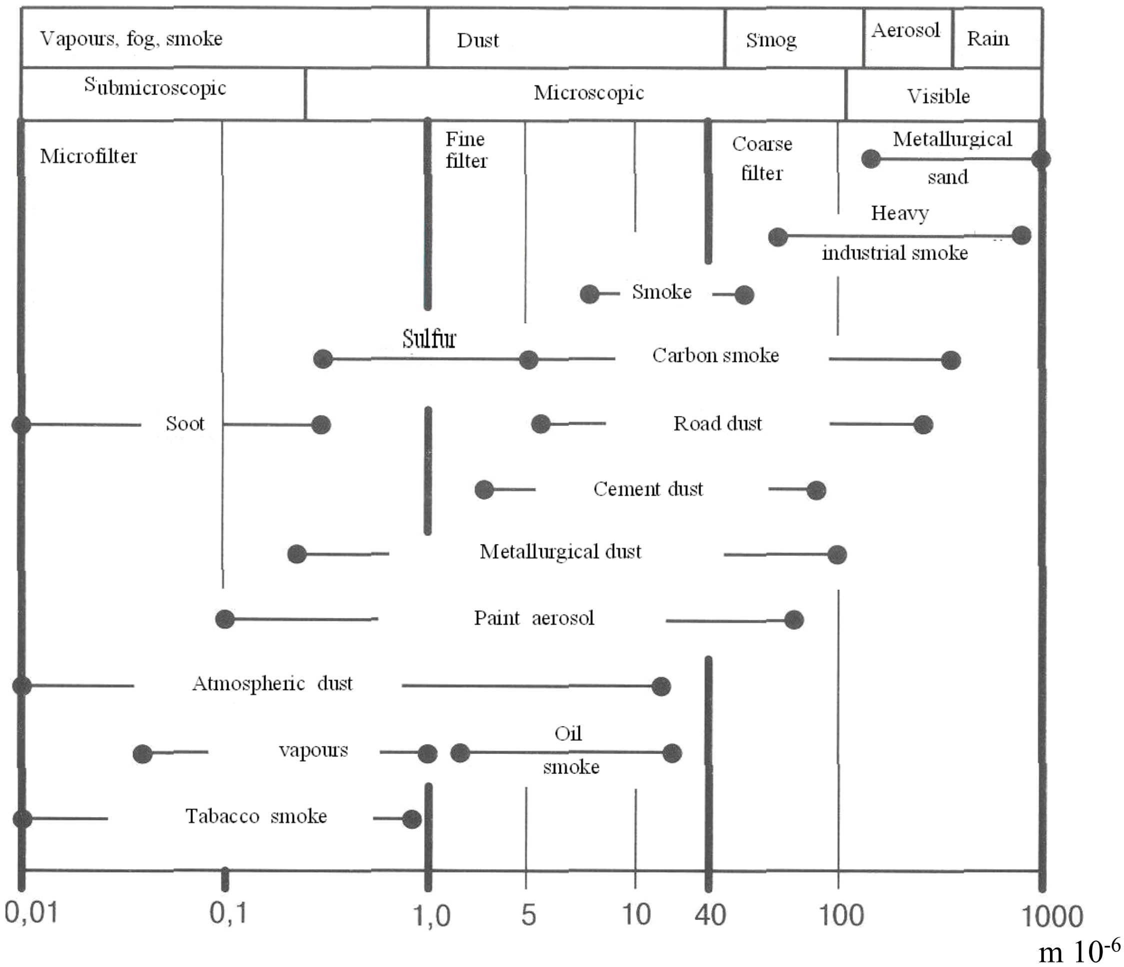


Fig. 2. Types and measures of solid parts in the air, m $10^{-6}$

Atmospheric air compression (0.1 MPa) up to 0,9 MPa increases pollutant content proportionally. Atmospheric air at metallurgical and engineering plants localization normally contains about 140 million solid parts per 1 cubic meter; moreover, 80% are less 5 mcm. This concentration presents a real threat to breaking apparatus functioning.

In this way compressed air pretreatment module should be set at suction line and consist of at least two stages: coarse and fine purification. Taking into consideration the atmospheric air variability, the ability to hold visible microscopic and submicroscopic part is evident.

Atmospheric air relative humidity influences incoming moisture quantity with compressed air into pneumatic system.

The low atmospheric air relative humidity (up to 40%), even nine fold moisture increasing at 1 cubic meter of the compressed air, allows to have a dew point reserve. In case of the atmospheric air relative humidity increase (80% and over), a significant moisture quantity incomes into pneumatic system, and cooling should condense. To define the beginning condensation site, the Shukhov's formule might be used:

$$\frac{T_{(x+\Delta x)} - T_{out}}{T_{(x)} - T_{out}} \approx e^{\left(-\frac{K\cdot\pi\cdot D\cdot\Delta x}{C_p\cdot m_{(x\ldots x+\Delta x)}}\right)}, \quad (1)$$

where: $T_{out}$ and $T_{(x)}$, $T_{(x+\Delta x)}$ – temperatures of outer air and compressed air at pipeline sections «X» and «X+ΔX» respectively, K; D – inner pipe diameter, m; m – compressed air average discharge at «X» and «X+ΔX» sections at i-moment of time, $m^3/s$; $C_p$ – air heat capacity at constant pressure, J/(kg·K); U – heat transfer coefficient, $W/(m^2\cdot K)$.

Approximation sign at (1) is conditioned on the assumption of compressed air discharge consistently at «X» and «X+ΔX» and equality of its average length at the lots knowing dew point temperature of atmospheric air (it might be determined by temperature of atmospheric air and relative humidity) and its compression. The moisture quantity determines at 1 $m^3$ compressed air easily, the dew point temperature as well.

Calculation results with enough degree of accuracy allow to determine site for compressed air drying apparatus at module 2.

Incoming moisture quantity will depend on compressed air discharge [11,12], determined by compressors switching frequency (SF). Hence, influencing on heat and humidity functioning mode of the rolling-stock the compressor's will influence on distributing temperature characteristic at pneumatic main condensation, start point and, as a result, purification modules necessity.

The third factor to analyze is the compressed air purification and drying method for rolling stock to choose.

It is meant that the purification should be divided in two stages – pre-purification (with apparatus installation at module 0 before compressor) and final purification (with apparatus installation at module II).

In this way, based on the made analysis, the following conclusions might be made:

- compressed air purification system design might be done based on main factors' impact and expenditures-benefits principle;
- basic impact factors on technology and equipment choice for compressed air purification should be suction air, solid parts, heat and humidity characteristics, compressed air discharge (SF), compressor type (screw or piston), and maintainability after compressed air purification equipment being set.

Based on the reference analysis and tests (both natural and laboratory), it is considered that for the rolling stock locomotives working at – 20 $^0$C up to +5 $^0$C and relative humidity ≤75% under SF ≤35% and piston compressors with no free space and dusty air, compressed air preparation system can be divided in two modules:

- module "0". Pre-purification – should contain two-stage purification filter, gas and liquid separator "Kolibri" for instance (Fig. 3), where cyclone type separator is the first and the filter up to 3 mcm parts to catch is the second.

Vortex gas and liquid separator "Kolibri" is designed for deep purification of gas flow from drop, microfine, aerosol moisture and mechanical impurity. Under binary mix separation (gas-liquid), the process of liquid phase degasification is simultaneously realized.

The device functioning principle is as follows. Gas and liquid mix incomes through the introduction pipe (2), placed at upper part (Fig. 3). Its position allows to solve the task of centrifugal effect saving values of gas and liquid mix while incoming, practically keeping reliability separators casing. Deflector (3) prevents gas passing to axis zone of separation packet (4) without gas suspension preliminary division. Application of the deflector with changing section allows to remove gas and liquid flow horizontally at deflector's outcome from separation flow (4) slots and vertically disperse evenly and "pin down" at the same time liquid phase to inner separator's surface. At the space between casing (1) and plates (5), the main liquid mass allocates. Liquid drops are thrown by centrifugal forces to casing surface of the device, and under gravitational forces along gas flow, they downward spiral transport through annular gap (6) to power nozzle (7).

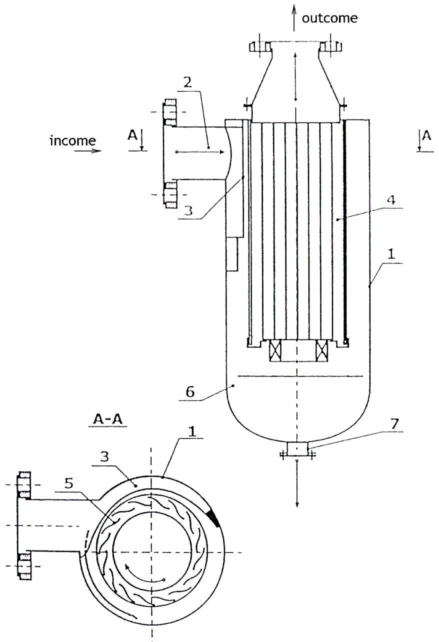


Fig. 3. Gas and liquid separator "Kolibri"

Gas and fluid separator "Kolibri" removes part of liquid and oil at liquid state.

The effectiveness by condensated water and oil is high enough (over 94%).

The compressed air drying technology choice is the most crucial moment of the complex analysis preceding scheme solutions design for compressed air quality based on energy efficiency to increase. At the present time in the Russian Federation two compressed air drying technologies for rolling-stock are used: the thermodynamic (mechanical) and chemical (adsorption).

Despite the undeniable advantages of the adsorption compressed air method drying, it has a number of disadvantages:

- significant consumption of the already dried compressed air for adsorbent regeneration (15 – 20%);
- long time period for estimated quality compressed air drying mode;
- strict compliance of the drying and regeneration cycles duration necessity;
- significant measures and weight set characteristics;
- a big amount of isolation valves leading to compressed air pressure losses at pneumatic systems;
- automation nodes failures;
- the extra stuff training necessity;
- adsorbent supply presence and its storing at specially equipped rooms.

The aforementioned disadvantages of the compressed air drying adsorption method combined with high material-capacity and obvious energy consumption at the process including negative impact of the oil on adsorbent moisture-consumption ability edge its implement at compressed air drying schemes equipped with piston compressor [13].

Numerous published studies have proved the condensation beginning process at the first main tank of the compressed air under the pointed heat and moisture functioning modes at the rolling-stock pneumatic system. Hence, being equipped with piston compressor and cluttered space at the locomotive, the "module II" (compressed air purification) is to be combined with the "module III" (storage and distribution of the compressed air). It is to choose the thermodynamic technology for the compressed air purification with the jalousie separators at the locomotive main tanks [14] (Fig. 4).

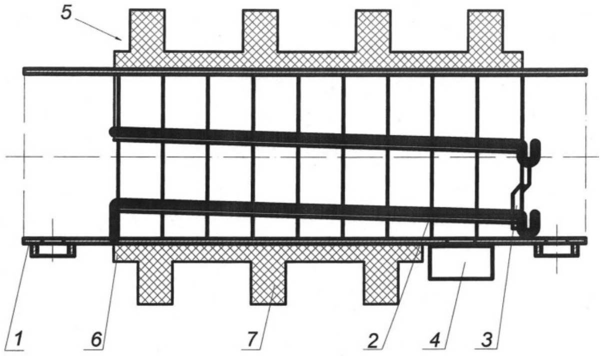


Fig. 4. Main tank with jalousie separator. 1 – hull; 2 – vertical goffered row of plates with drainage holes; 3 – drainage tube; 4 – automatic purge valve; 5 – heat transfer paste lay; 6 – recess; 7– edge

The quantity of the jalousie separators needed to be set might be defined with the suggested methodology.

The final rolling stock pneumatic system module scheme might be as follows:

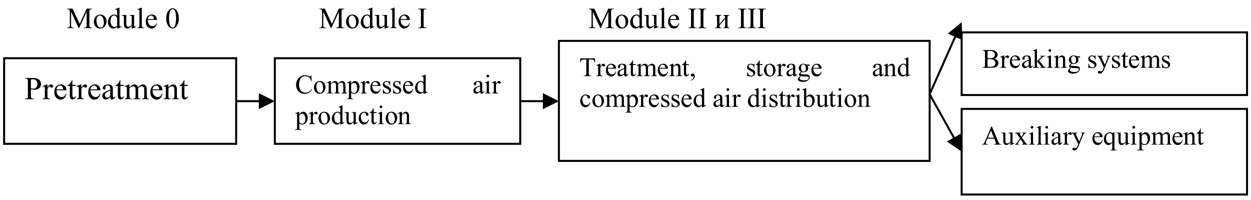


Fig. 5. Rolling stock pneumatic system module scheme with pretreatment

As the scheme shows (Fig. 5), despite the addition the extra module "Pretreatment", the quantity of modules at the pneumatic scheme has remained due to the compressed air storage and drying combination at one module [15]. Herewith is not necessary additional compressed air consumption (as in case of adsorption drying) that allows to increase compressed air preparation process energy-efficiency at the rolling-stock pneumatic systems without maintainability decrease.

## 5. CONCLUSION

Despite the significant number of construction solutions and the compressed air preparation methods available today, experts still differ in opinions about the optimal way. Now technologists and constructors significantly have advanced at apparatus creation for dew point management. To achieve the best result, in authors' opinion, it is necessary to analyze several factors influencing compressed air quality before choosing the apparatus part of the pneumatic system. Among them are the following:

- atmospheric air content;
- compressors type and the existing equipment;
- exploitation conditions; and
- compressed air quality – the main (necessary and enough).

The factor analyses, realized by the authors, have allowed making conclusions about quality of compressed air coming into railway rolling-stock pneumatic systems without preparation devices. Based on it and normative documents as well, the authors suggest a module scheme of the compressed air at pneumatic system preparation stages and its distribution.

As technological solutions, which in authors' opinion may lead to significant increase of the compressed air quality at the railway rolling-stock pneumatic systems, it is suggested to employ the compressed air purification mechanical method with cyclone-type filter (for instance gas and liquid separator "Kolibri") at the module "Pretreatment". The compressed air drying purification degree is to increase by placing jalousie separators at the main tanks of locomotives.

The aforementioned activities realization allows significantly increase energy efficiency of the railway rolling-stock pneumatic systems and the compressed air quality as well.

Thus, based on the realized analysis, the following conclusions might be made:

– compressed air drying and purifying system design should be based on main impact factors and energy efficiency principles.

– basic factors of the impact on technology and equipment choice for compressed air drying might be the following: sucked air quality by presence of the solid particles, its heat and moisture characteristics, compressed air consumption (compressor's SF), locomotive compressor type (screw or piston), and maintainability after compressed air drying sets installation.

## References

1. Ferrero, D. & Gamba, M. & Lanzini, A. & Santarelli, M. et al. Energy Procedia Power-to-Gas Hydrogen: techno-economic assessment of processes towards a multi-purpose energy carrier. In: *Proceedings of 71st Conference of the Italian Thermal Machines Engineering Association*. Turin: ATI2016. 14-16 September 2016. P. 50-57.
2. White Jr., D. Compressed Air and Gas Purification and Fractionation for High Purity Applications by Improved PSA Processes. *Separation Science and Technology.* 2008. Vol. 43. No. 9-100. P. 2298-2306.
3. Iwainsky, H. & Beeck, U. & Ivan, J. Redundant Compressed Air Supply for Trams and Railcars. *Fahrzeuge rolling-stock.* 2016. Vol. 140. P. 75-79.
4. Ruppelt, E. & Bahr, M. Efficient compressed air drying. 2015. *Kaiser kompressoren. Technical Press article.* Available at: http://en.kaeser.co.th/m/Advisor/Technical_articles/articles/hybitec.asp
5. *Cost Saving Air Dryer Technology.* Available at: https://www.bryair.com/news-and-events/articles/cost-saving-air-dryer-technology.
6. *Drying Compressed Air 2011*. Lancaster: Parker Hannifin Corporation. 2011. Bulletin M261K. Available at: http://www.parker.com/Literature/Gas%20Separation%20and%20Filtration%20Division/PDF%20 Files/DryingCompressedAirGuide.pdf.
7. Curtin, K. Clean Air is Crucial for Optimal Pneumatics. *Design World Staff.* 2011. Vol. 1. P. 35-41.
8. Chris, E. *Improving Compressed Air Quality.* Available at: http://www.izsystems.com/articles/detail/improving-compressed-air-quality-by-eliminating-mo
9. *Cleveland compressed air services. Aug 24, 2016.* The benefits of different types of compressed air dryers. Available at: https://clevelandcompressors.com.au/the-benefits-of-different-types-of-compressed-air-dryers/.
10. Goodarzia, G. & Dehghani, S. & Akbarzadeh, A. & Date, A. Energy saving opportunities in air drying process in high-pressure compressors. In: *Proceedings of 1st International Conference on Energy and Power, ICEP2016.* Melbourne: RMIT University. 14-16 December 2016. P. 428-433.
11. Kairouz, K. & Jazdzyk, D. & Al Musawi, S. Energy efficiency with compressed air. *Processing*. 2016. Vol. 4. P. 111-115.
12. *Energy savings through proper use of pneumatics* – Fluid Power Journal. Available at: https://www.festo.com/rep/en-us_us/assets/pdf/US_Articles_FluidPowerJournal_March2014.pdf.
13. Yan, F., Rinoshika, A. An experimental study on a horizontal energy-saving pneumatic conveying system. In: *Proceedings of the 7th World Congress on Particle Technology (WCPT7).* Jiangsu University of Science and Technology, School of Mechanical Engineering, Department of Mechanical Systems Engineering. 2016. P. 75-86.

14. Патент № 2514871. Риполь-Сарагоси, Т.Л. & Риполь-Сарагоси, Л.Ф. *Резервуар для осаждения и удаления влаги из сжатых газов*. [In Russian: Patent No. 2514871. Ripol-Saragosi, T.L. & Ripol-Saragosi, L.F. *Tank for condensation and removal from compressed gases*].
15. ГОСТ Р 53977-2010 *Сжатый воздух пневматических систем железнодорожного подвижного состава. Требования к качеству*, 7 с. [In Russian: *Compressed air of railway rolling stock pneumatic systems. Requirements for quality*, 7 p.].

Received 10.02.2017; accepted in revised form 26.11.2018