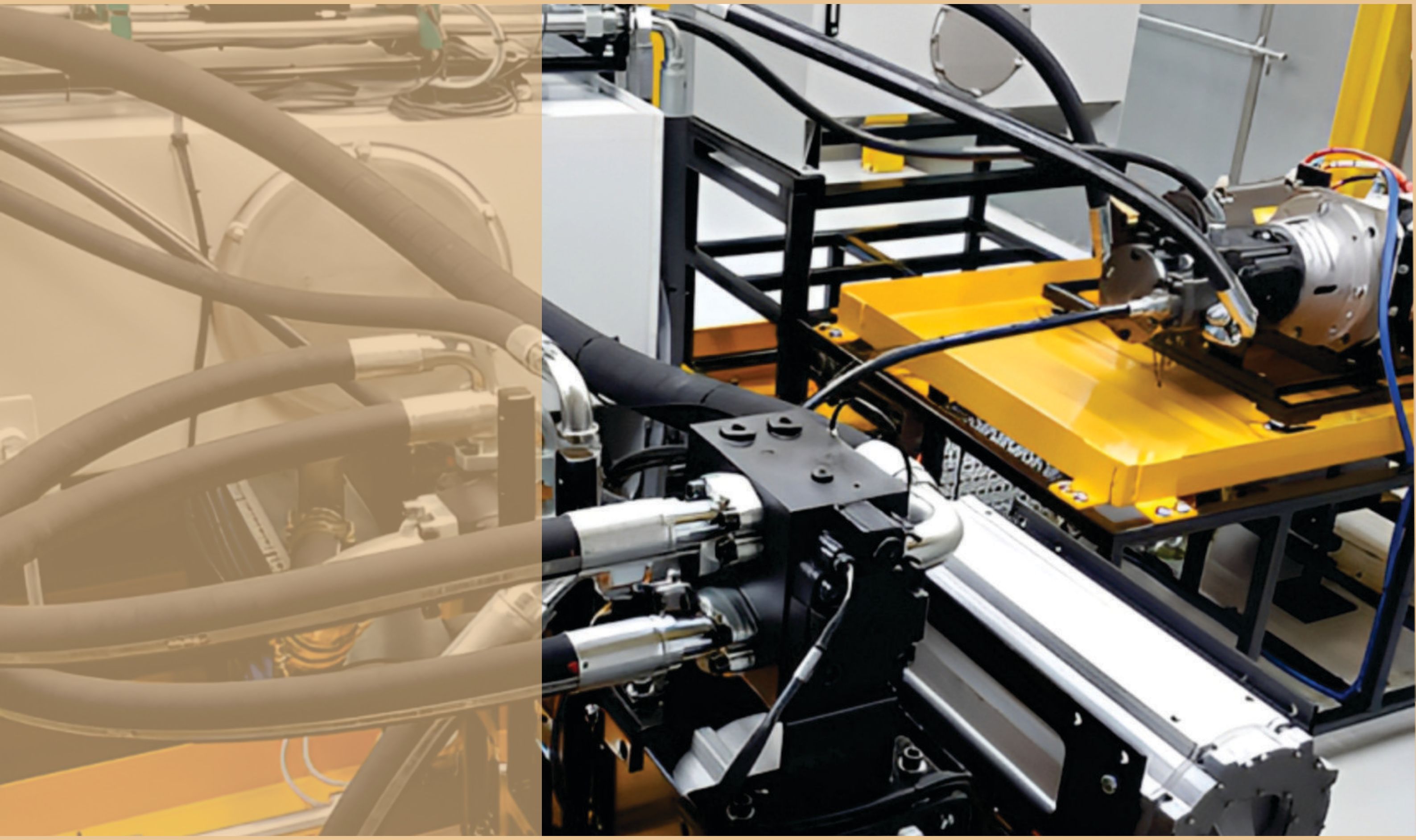
HIDRAULICA

HYDRAULICS-PNEUMATICS-TRIBOLOGY-ECOLOGY-SENSORICS-MECHATRONICS

2023
September
No. 3



ISSN 1453 - 7303
ISSN-L 1453 - 7303

https://hidraulica.fluidas.ro

CONTENTS

Published by:
Hydraulics and Pneumatics Research Institute, Bucharest-Romania
Address: 14 Cuţitul de Argint, district 4, Bucharest, 040558, Romania
Phone: +40 21 336 39 91; Fax: +40 21 337 30 40; e-Mail: ihp@fluidas.ro; Web: www.ihp.ro
with support from:
National Professional Association of Hydraulics and Pneumatics in Romania - FLUIDAS
e-Mail: fluidas@fluidas.ro; Web: www.fluidas.ro

HIDRAULICA Magazine is indexed by international databases

ISSN 1453 – 7303; ISSN – L 1453 – 7303

EDITORIAL

Despre Inteligența Artificială

Dr. Ing. Petrin DRUMEA
DIRECTOR PUBLICAȚIE

În ultima vreme au apărut foarte multe discuții despre Inteligența Artificială, care, întâmplător, ne implică și pe noi, cei care se ocupăm de hidraulică, întrucât este în mare vogă dezvoltarea Hidraulicii Inteligente.

Pentru cei care nu lucrează în domeniu, dacă tot etalează valențe de salvatori ai omenirii, ar fi simplu să fie rugați să oprească războaiele, care sunt cauzate și pornite de lipsa de inteligență, să oprească tendințele criminale la tineret sau să blocheze ideile ciudate ale diverșilor propagandiști de tot felul. Toate aceste necazuri care au năpădit și năpădesc lumea nu au fost aduse de Inteligența Artificială.

Trebuie făcută precizarea că se discută doar despre informatizarea care se aplică în domeniile tehnice de activitate și se decide că totul este rău. Țin să menționez că AI include mai multe domenii, că nici unul nu este rău, ci doar poate fi folosit de oameni cu răutate. Pentru persoanele avizate nu este nevoie de sfaturi, deoarece ele știu că munca lor este constructivă, nu distructivă. Probabil că ar trebui blocată și fizica nucleară, și chimia pulberilor, și chimia substanțelor toxice, și mecanica, electronica și electrica construcțiilor de mașini în general, și, în special, construcția mașinilor de transport.

Să fim serioși, să rugăm Inteligențele Naturale să fie active pozitiv și să nu mai folosim tehnologiile moderne în scopuri de distrugere. Lipsa de cunoștințe de specialitate, lipsa de responsabilitate ori răutatea nu sunt activate de știință și tehnologie. Nu sunt de vină mecanica, electrica, electronica, senzorica, informatica și nici măcar hidraulica că în funcții de conducere, de decizie sau de informare există oameni fără o pregătire corespunzătoare sau lipsiți de echilibru și de rațiune. Inteligența Artificială este un element de progres la îndemâna omenirii, nu un element distructiv, cu condiția ca omenii să fie normali și conduși de sentimente umane.

EDITORIAL

On Artificial Intelligence

Ph.D.Eng. Petrin DRUMEA
MANAGING EDITOR

Lately there have been a lot of discussions about Artificial Intelligence, which, incidentally, also involves us, those who deal with hydraulics, as the development of Intelligent Hydraulics is very popular.

For those who do not work in the field, since they are showing valences as saviours of humanity, it would be simple to be asked to stop wars, which are caused and started by lack of intelligence, to stop criminal tendencies in the youth, or to block the strange ideas of all kinds of propagandists. All these troubles that plagued and are plaguing the world were not brought about by Artificial Intelligence.

It must be clarified that only the computerization that is applied in the technical fields of activity is discussed, and it is decided that everything is bad. I would like to point out that AI includes many areas, none of which are bad, just can be used by people maliciously. For wise persons concerned there is no need for advice, because they know that their work is constructive, not destructive. Nuclear physics, and powder chemistry, and the chemistry of toxic substances, and mechanics, electronics and electrical engineering of machine building in general, and the construction of transport machines in particular, all should probably be blocked as well.

Let's be serious, let's ask the Natural Intelligences to be positively active and stop using modern technologies for destructive purposes. Lack of expertise, irresponsibility or malice are not enabled by science and technology. It is not the fault of mechanics, electricity, electronics, sensors, informatics or even hydraulics that there are people in leadership, decision-making or monitoring positions without proper training or lacking balance and sound judgement. Artificial Intelligence is an element of progress within the reach of mankind, not a destructive element, provided that people are normal and driven by human feelings.

Natural Zeolite-Based Filter for the Treatment of Well Water

Dr. **Marin ȘENILĂ**[1,*], Dr. **Oana CADAR**[1], Dr. **Maria-Alexandra RESZ**[1], Dr. **Dorina SIMEDRU**[1], PhD. Stud. **Eniko KOVACS**[1], Dr. **Marius ROMAN**[1], Dr. **Cecilia ROMAN**[1], Dr. **Adriana Mariana BORȘ**[2]

[1] INCDO-INOE 2000, Research Institute for Analytical Instrumentation ICIA Cluj-Napoca

[2] National Institute of Research & Development for Optoelectronics/INOE 2000, Subsidiary Hydraulics and Pneumatics Research Institute/IHP

* marin.senila@icia.ro

Abstract: *In many cases, the quality of the well water intended for human consumption does not meet the standards to be directly consumed by humans. Well water can be affected in the underground both by the interaction with minerals from aquifers and by contamination caused by anthropogenic activities. The objective of the study was to produce and test a filter containing an efficient and cost-effective filtering material based on thermally activated clinoptilolite-type natural zeolites from Romania to remove dissolved ammonium ion and metallic cations from water. The XRD patterns of the zeolitic materials displayed the presence of clinoptilolite as the main phase. The best results for the removal efficiency of contaminants were obtained when the natural zeolite with the particle size of 0.5 – 1.25 mm thermally activated at 300 C was used, but in general, all types of materials were efficient to decrease the concentrations of contaminants below the maximum admitted concentrations established by the EU Drinking Water Directive.*

Keywords: *Natural zeolite, drinking water, water treatment, clinoptilolite, heavy metals, ammonium*

1. Introduction

Groundwater is one of the most important sources of drinking water, and in many regions worldwide it represents the sole source of drinking water. Because of the interactions between groundwater and aquifers, as well as due to contamination from anthropogenic sources, some chemical parameters can be affected, making the quality of water inadequate for drinking [1-4]. In particular, the contamination with ammonium due to agricultural practices and domestic activities [5], or with metals and metalloids coming both from the mineral matrix of aquifers or from industrial activities are of high concern [6,7].
The human right to safe drinking water is recognized as part of the international law by the UN General Assembly and the Human Rights Council in 2010 [8,9]. According to the World Health Organization (WHO), the "Safe drinking water" represents the water which does not pose any substantial health risk due to its consumption [10]. It is estimated that around 2.3 billion people worldwide are at risk of diseases caused by contaminated drinking water due to the lack of adequate water treatment and the absence of a proper distribution system [10].
In order to protect human health, the EU Drinking Water Directive demand the control of public water systems to ensure that the water produced for human consumption can be safely consumed, but a scarce water supply is a foremost challenge in rural areas, where domestic wells are the key drinking water sources [11]. The estimated amount of necessary drinking water is at least 20 litres of water per person per day, up to 1 km radius of the user's home [12]. On the other hand, it is appraised that, in rural areas of Romania, almost 50% of households have their own wells as a primary source of drinking water [12]. In general, it is recognized that many groundwaters in Romania are contaminated by ammonia and metals, mainly Fe and Mn [5,13].
Accordingly, there is a high demand to develop methodologies to treat well water to meet the required quality standards for drinkability. The proposed solutions should consider both the costs of treatment and the efficiency in producing safe drinking water, by the removal of as many as possible contaminants using a single filtering material.
Porous materials can be used as cost-efficient and sustainable adsorbents to remove cations for water treatment. In this class, natural zeolites are ecologically and economically adequate materials. They are aluminosilicate materials with extraordinary ion-exchange and adsorptive

properties. Their unique properties are conferred by the tree-dimensional porous structure with a negative charge on the surface, resulting from the isomorphic replacement of Si by Al in the framework structure. Many studies have confirmed their outstanding performance in removing cations from waters [13-16].
The work aims to develop and test a filter for water treatment based on clinoptilolite type natural zeolite from Chilioara, NW of Romania, as an adsorbent material. The zeolitic tuff was characterized from structural and physico-chemical point of view. Four materials were produced (two different particle sizes, 0.5 – 1.25 mm and 1.25 – 3.00 mm), each of them thermally activated at two temperatures: 200 °C and, respectively 300 °C, and were tested in order to evaluate their adsorption properties for ammonia and metals removal from aqueous solutions.

2. Materials and Methods

Natural zeolite (NZ) material was obtained from a quarry located in Chilioara, Salaj County, Romania. Two fractions with particle sizes of 0.50 – 1.25 mm (NZ1) and 1.25 – 3.00 mm (NZ2) were produced by crushing and granulometric separation. Then, both NZ1 and NZ2 fractions were subjected to activation at two temperatures: 200 °C and, respectively 300 °C, to obtain the samples NZ1-200, NZ1-300, and NZ2-200, NZ2-300, respectively.
Major elements (Al, Ca, Mg, K, Na, Fe, Mn) in zeolite samples were measured by inductively coupled plasma optical emission spectrometer Optima 5300DV (Perkin Elmer, Norwalk, CT, USA) after microwave assisted acid digestion USING an Xpert system (Berghof, Eningen, Germany). 0.5 g of the sample was digested with a mixture of HNO_3 65% : HCl 37% : HF 40% (3:9:2, *v:v:v*). The cation exchange capacity (CEC) was obtained by the measurement of the major cations (K, Na, Ca, and Mg) extracted in ammonium acetate solution 1 M using ICP-OES. Three parallel measurements were carried out for each sample analysis.
The X-ray diffraction (XRD) patterns were recorded at room temperature using a D8 Advance (Bruker, Karlsruhe, Germany) diffractometer with CuKα radiation (λ = 1.54060 Å), operating at 40 kV and 40 mA, at room temperature. The morphology of NZ1 200 was observed using a scanning electron microscope (SEM VEGAS 3 SBU, Tescan, Brno-Kohoutovice, Czech Republic) with an EDX detector.

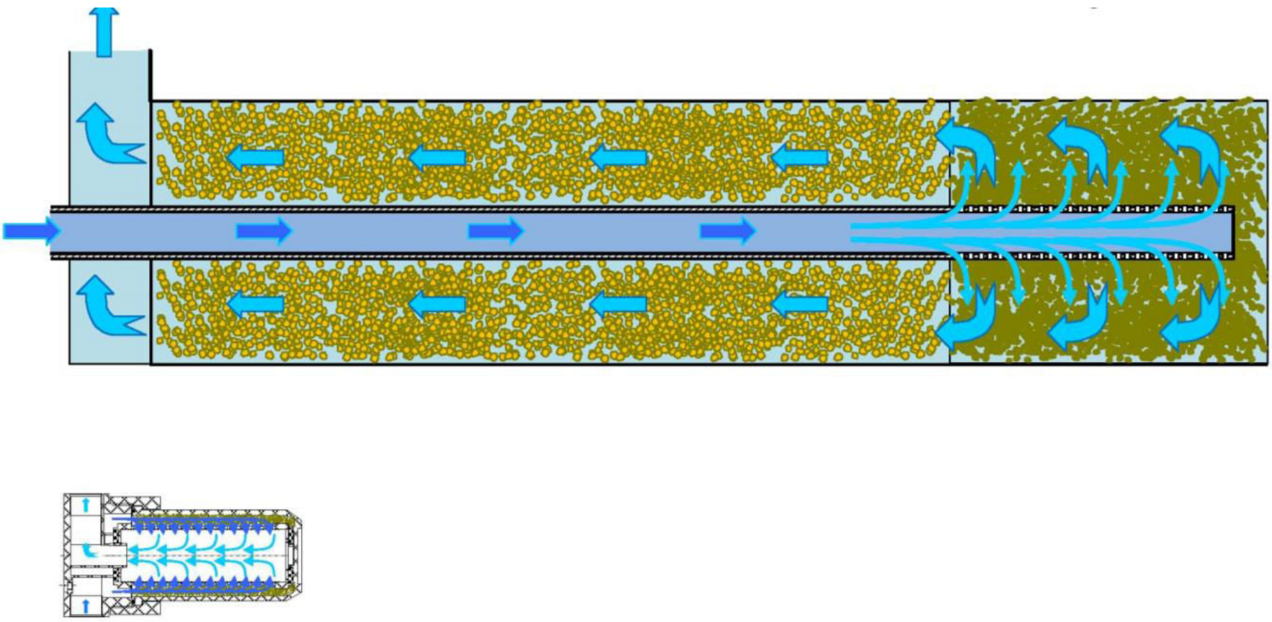


Fig. 1. Design of the natural zeolites-based filter for water filtration

A natural zeolites-based filter, presented in Figure 1, was designed and built at the appropriate dimensions for domestic use, and to assure a maximum efficiency of the filtration process.

The flow direction of the fluid is parallel to the permeable porous medium, the liquid "sweeping" through the flow, the surface of the filter. Tangential filtration is a dynamic process; the fluid flow is parallel to the surface of the filter element, thus preventing the formation of a layer of impurities above the filter surface through agglomeration. Hence, the filter's functionality is maintained by reducing the jamming effect. The pressure drop and fluid flow remain constant over time. With tangential filtration, recirculation filtration can be performed in a closed circuit, an important advantage for specific energy consumption.
For each batch experiment, 50 L of distilled water was contaminated with known quantities of contaminants: ammonium, Al, Cd, Cr, Cu, Mn, Ni, Fe, Mn, Na and Zn. The solutions were filtered in four different experiments using the four zeolitic materials (NZ1-200, NZ1-300, and NZ2-200, NZ2-300). The concentrations of metals in the resulted solutions were measured by ICP-OES, while the ammonium concentration was measured using a Lamda-25 Perkin Elmer UV-Vis spectrophotometer.

3. Results and discussion

3.1 Characteristics of the natural zeolites

The chemical composition in terms of the major oxides and total CEC of the thermally activated natural zeolites with different particle size zeolites is presented in Table 1.

Table 1: Chemical composition (wt. %) and CEC of the thermally activated natural zeolites

Zeolite	SiO_2	Al_2O_3	Na_2O	K_2O	CaO	MgO	Fe_2O_3	MnO	CEC
	%								mEq $100g^{-1}$
NZ1-200	65.2	12.3	0.27	2.46	1.64	1.09	1.23	0.04	120
NZ1-300	66.9	12.4	0.25	2.51	1.48	1.17	1.31	0.04	107
NZ2-200	64.8	12.2	0.28	2.33	1.63	1.21	1.22	0.03	126
NZ2-300	65.1	11.9	0.29	2.24	1.55	1.08	1.17	0.04	112

According to the SiO_2/Al_2O_3 ratio, the natural zeolite from Chilioara belongs to the group of super silicic materials. The grain sizes and the activation temperature do not significantly influence the chemical composition of the materials.

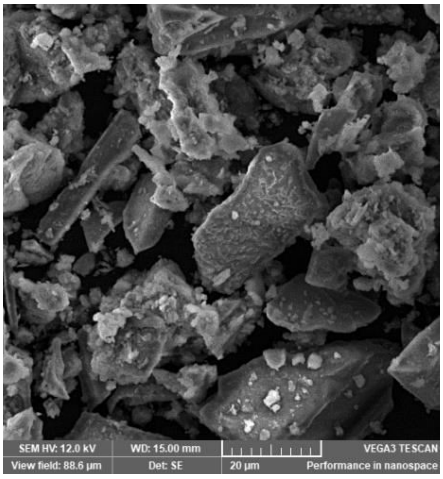


Fig. 2. SEM images of the NZ1 200 zeolite sample

The Scanning Electron Microscopy (SEM) image of the NZ1 200 zeolite is shown in Figure 2. The rough surfaces were favourable for the adsorption of metals.

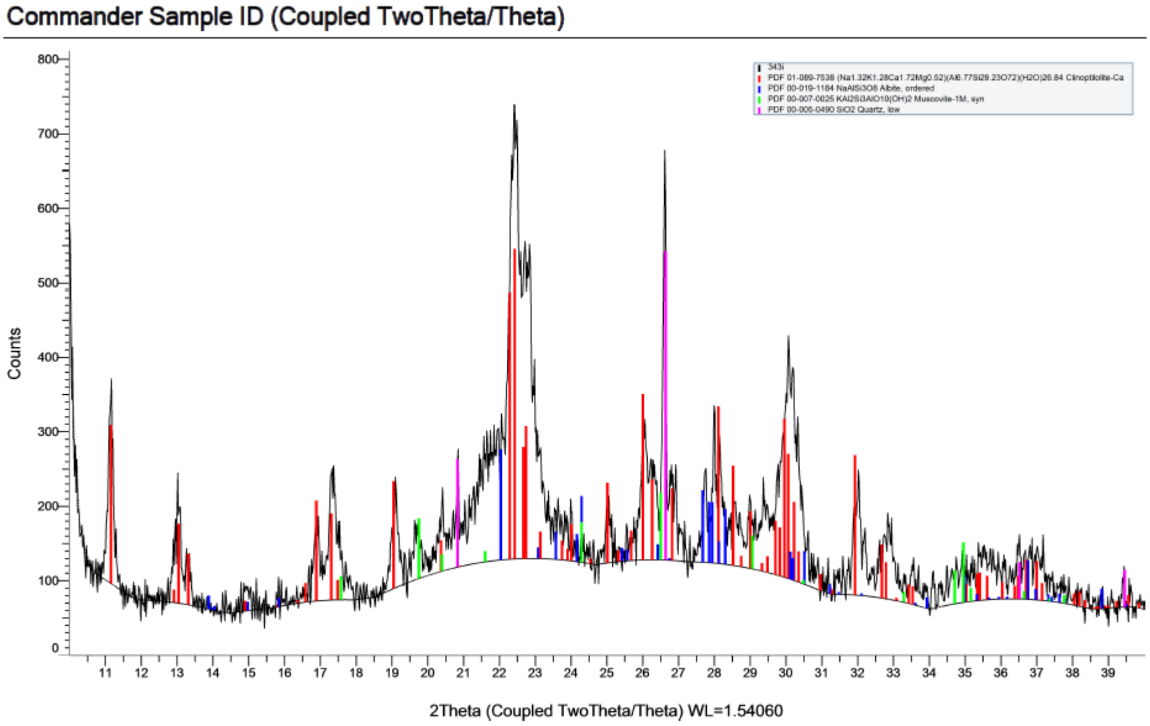


Fig. 3. XRD pattern of the NZ1 200 sample

The XRD patterns of the zeolitic tuffs presented in Figure 3 display the presence of clinoptilolite as the main phase, joined by muscovite, albite, orthoclase, quartz, and montmorillonite. The RIR (Reference Intensity Ratio) method, employed for the quantitative phase analysis, indicates a clinoptilolite content of about 65%.

3.2 Adsorptive characteristics of the filter filled with the four types adsorbent materials

In Table 2 are presented the concentrations of cations of metals and ammonium before and after the filtration of the contaminated solutions using the filtering material NZ1-200.

Table 2: Concentrations of pollutants before and after the filtration of contaminated solutions using the filtering material NZ1-200

Parameter	MAC*	Initial concentrations	Concentrations after filtration
Al	200 μg/l	400 μg/l	150 μg/l
Cd	5.0 μg/l	10 μg/l	3.5 μg/l
Cr	50 μg/l	100 μg/l	36 μg/l
Cu	0.1 mg/l	0.2 mg/l	0.05 mg/l
Ni	20 μg/l	40 μg/l	13 μg/l
NH_4^+	0.50 mg/l	1 mg/l	0.33 mg/l
Fe	200 μg/l	400 μg/l	110 μg/l
Mn	50 μg/l	100 μg/l	28 μg/l
Na	200 mg/l	400 mg/l	132 mg/l
Zn	5 mg/l	10 mg/l	8.2 mg/l

MAC* maximum admitted concentrations according to Drinking Water Directive [17]

In Table 3 are presented the concentrations of contaminants in the contaminated solutions before and after the filtrations using the filtering material NZ1-300.

Table 3: Concentrations of pollutants before and after the filtration of contaminated solutions using the filtering material NZ1-300

Parameter	MAC*	Initial concentrations	Concentrations after filtration
Al	200 µg/l	400 µg/l	42 µg/l
Cd	5.0 µg/l	10 µg/l	0.9 µg/l
Cr	50 µg/l	100 µg/l	22 µg/l
Cu	0.1 mg/l	0.2 mg/l	0.03 mg/l
Ni	20 µg/l	40 µg/l	7 µg/l
NH_4^+	0.50 mg/l	1 mg/l	0.12 mg/l
Fe	200 µg/l	400 µg/l	50 µg/l
Mn	50 µg/l	100 µg/l	12 µg/l
Na	200 mg/l	400 mg/l	44 mg/l
Zn	5 mg/l	10 mg/l	4.6 mg/l

In Table 4 are presented the concentrations of contaminants in the contaminated solutions before and after the filtrations using the filtering material NZ2-200.

Table 4: Concentrations of pollutants before and after the filtration of contaminated solutions using the filtering material NZ2-200

Parameter	MAC*	Initial concentrations	Concentrations after filtration
Al	200 µg/l	400 µg/l	175 µg/l
Cd	5.0 µg/l	10 µg/l	4.7 µg/l
Cr	50 µg/l	100 µg/l	44 µg/l
Cu	0.1 mg/l	0.2 mg/l	0.1 mg/l
Ni	20 µg/l	40 µg/l	19 µg/l
NH_4^+	0.50 mg/l	1 mg/l	0.41 mg/l
Fe	200 µg/l	400 µg/l	175 µg/l
Mn	50 µg/l	100 µg/l	50 µg/l
Na	200 mg/l	400 mg/l	175 mg/l
Zn	5 mg/l	10 mg/l	7.9 mg/l

In Table 5 are presented the concentrations of contaminants in the contaminated solutions before and after the filtrations using the filtering material NZ2-200.

Table 5: Concentrations of pollutants before and after the filtration of contaminated solutions using the filtering material NZ2-300

Parameter	MAC*	Initial concentrations	Concentrations after filtration
Al	200 µg/l	400 µg/l	180 µg/l
Cd	5.0 µg/l	10 µg/l	4.6 µg/l
Cr	50 µg/l	100 µg/l	50 µg/l
Cu	0.1 mg/l	0.2 mg/l	0.09 mg/l
Ni	20 µg/l	40 µg/l	19 µg/l
NH_4^+	0.50 mg/l	1 mg/l	0.4 mg/l
Fe	200 µg/l	400 µg/l	180 µg/l
Mn	50 µg/l	100 µg/l	48 µg/l

Parameter	MAC*	Initial concentrations	Concentrations after filtration
Na	200 mg/l	400 mg/l	184 mg/l
Zn	5 mg/l	10 mg/l	8.2 mg/l

According to the data presented in Tables 2-5, the best results for the removal of contaminants from water were obtained when the natural zeolite with the grain size of 0.5 – 1.25 mm thermally activated at 300 °C was used for the filtration. Generally, the use of all types of natural zeolites was proved to be efficient since the concentrations of contaminants in water decreased below the maximum admitted concentrations established by the EU Drinking Water Directive.

4. Conclusions

This paper investigated the simultaneous removal of ammonium ion and metal cations using natural zeolite form Chilioara as filtering material. The XRD patterns of the zeolitic materials showed the presence of clinoptilolite as the main phase in a content of about 65%, which explains the excellent adsorbtive and ion-exchage properties of the material. The rough surface of the thermally activated natural zeolite, as shown by the SEM images, favors the adsorption of contaminants. The best results for the removal efficiency of contaminants were obtained when the natural zeolite with a grain size of 0.5 – 1.25 mm thermally activated at 300 °C was used, but in general, all types of materials were efficient to decrease the concentrations of contaminants below the maximum admitted concentrations established by the EU Drinking Water Directive. The obtained results demonstrate the possibility of using activated natural zeolite from Chilioara querry to simultaneously remove cations from aqueous solutions, including producing drinking water from contaminated wells.

Acknowledgments

This research was funded by the Ministry of Research, Innovation and Digitization through the Core Program within the National Research Development and Innovation Plan 2022–2027, carried out with the support of MCID, project no. PN 23 05. The research received funding also by a project funded by MCID through Programme 1 – Development of the national research & development system, Sub-programme 1.2– Institutional performance–Projects financing the R&D&I excellence, Financial Agreement no. 18PFE/30.12.2021.

References

[1] Whyte, Colin J., Avner Vengosh, Nathaniel R. Warner, Robert B. Jackson, Karlis Muehlenbachs, Franklin W. Schwartz, and Thomas H. Darrah. “Geochemical evidence for fugitive gas contamination and associated water quality changes in drinking-water wells from Parker County, Texas.” *Science of The Total Environment* 780 (2021): 146555.
[2] Debnath, P., M.M. Abdullah Al Mamun, Shyamal Karmakar, Mohammed Salim Uddin, and Tapan Kumar Nath. “Drinking water quality of Chattogram city in Bangladesh: An analytical and residents' perception study.” *Heliyon* 8 (2022): e12247.
[3] Sun, Y., Zhengfu Guo, Wenbin Zhao, Jujing Li, Lin Ma, Xiaocheng Zhou, and Fengxia Sun. “Geochemical characteristics and water quality assessment in the Mt. Changbai volcanic field, Northeastern China.” *Applied Geochemistry* 150 (2023): 105583.
[4] Galoie, Majid, Artemis Motamedi, Jihui Fan, and Mahdi Moudi. “Prediction of water quality under the impacts of fine dust and sand storm events using an experimental model and multivariate regression analysis.” *Environmental Pollution* 336 (2023): 122462.
[5] Resz, Maria Alexandra, Cecilia Roman, Marin Senila, Iulia Török, and Eniko Kovacs. “A Comprehensive Approach to the Chemistry, Pollution Impact and Risk Assessment of Drinking Water Sources in a Former Industrialized Area of Romania.” *Water* 15 (2023): 1180.
[6] Senila, Marin, Erika Levei, Oana Cadar, Lacrimioara Ramona Senila, Marius Roman, Ferenc Puskas, and Mihaela Sima. “Assessment of Availability and Human Health Risk Posed by Arsenic Contaminated Well Waters from Timis-Bega Area, Romania.” *Journal of Analytical Methods in Chemistry* 2017 (2017): 3037651.
[7] Butaciu, Sinziana, Marin Senila, Costel Sarbu, Michaela Ponta, Claudiu Tanaselia, Oana Cadar, Marius Roman, Emil Radu, Mihaela Sima, and Tiberiu Frentiu. “Chemical modeling of groundwater in the Banat

Plain, southwestern Romania, with elevated As content and co-occurring species by combining diagrams and unsupervised multivariate statistical approaches." *Chemosphere* 172 (April 2017): 127-137.
[8] Petculescu, Ioan, Paul Hynds, R. Stephen Brown, Kevin McDermott, and Anna Majury. "An assessment of total coliforms and associated thresholds as water quality indicators using a large Ontario private drinking water well dataset." *Science of The Total Environment* 846 (2022): 157478.
[9] United Nations. "The human right to water and sanitation." Media brief. Resolution A/RES/64/292. 2010. https://www.un.org/waterforlifedecade/pdf/human_right_to_water_and_sanitation_media_brief.pdf. Accessed August 29, 2023.
[10] Perveen, Shazia, Amar-Ul-Haque. "Drinking water quality monitoring, assessment and management in Pakistan: A review." *Heliyon* 9 (February 2023): e13872.
[11] Celebi, A., B. Sengorur, and B. Klove. "Human health risk assessment of dissolved metals in groundwater and surface waters in the Melen watershed, Turkey." *Journal of Environmental Science and Health, Part A* 49 (2014): 153–161.
[12] Calin, D. I., and C. Rosu. "Drinking water quality assessment of rural wells from Aiud Area." *AES Bioflux* 3 (2011): 108-122.
[13] Neag, E., A.I. Török, C. Tanaselia, I. Aschilean, and M. Senila. "Kinetics and Equilibrium Studies for the Removal of Mn and Fe from Binary Metal Solution Systems Using a Romanian Thermally Activated Natural Zeolite." *Water* 12 (2020): 1614.
[14] Senila, M., E. Neag, O. Cadar, E.D. Kovacs, I. Aschilean, and M.H. Kovacs. "Simultaneous removal of heavy metals (Cu, Cd, Cr, Ni, Zn and Pb) from aqueous solutions using thermally treated Romanian zeolitic volcanic tuff." *Molecules* 27 (2022): 3938.
[15] Senila, L., E. Neag, O. Cadar, A. Becze, D.A. Scurtu, C.H. Tomoiag, and M. Senila. "Removal of methylene blue on thermally treated natural zeolites." *Analytical Letters* 55 (2022): 226-236.
[16] Șenilă, M., E. Neag, C. Tănăselia, and L. Șenilă. "Removal of cesium and strontium ions from aqueous solutions by thermally treated natural zeolite." *Materials* 16 (2023): 2965.
[17] European Union. "Drinking Water Directive." https://environment.ec.europa.eu/topics/water/drinking-water_en. Accessed August 30, 2023.

Case Study on Reducing Potable Water in Residential Buildings by Implementing Rainwater Storage Systems

Assoc. Prof. PhD. Eng. **Adriana TOKAR**[1,*], R. A. PhD. student Eng. **Daniel MUNTEAN**[1], Assist. Prof. PhD. Eng. **Dănuț TOKAR**[1]

[1] University Politehnica Timisoara, Romania

* adriana.tokar@upt.ro

Abstract: *Given that water is an indispensable and valuable resource, the water shortage faced by some areas of the globe has recently attracted the attention of the European Environment Agency (EEA). For this reason, the paper deals with aspects regarding the possibility of using water from precipitation, taking into account, for the study, buildings from two rural localities adjacent to Timișoara (Giarmata and Moșnița Nouă). An analysis was carried out regarding the amount of drinking water that can be replaced in indoor sanitary installations with captured and stored water from precipitation. The amount of potable water that can be replaced was considered only for household needs such as: flushing toilets, washing clothes, watering green spaces and gardens and washing impervious spaces (lanes, yards, etc.) on the property. The study considered 5 stages of approach through which the quantity and quality of rainwater that can be collected, the technical solutions that can be implemented and the reduction of the amount of drinking water were evaluated, taking into account two consumption scenarios (reduced and increased). Based on the data obtained, it was concluded that for a low level of consumption, in the two buildings, the amount of water collected from precipitation fully covers the consumption of the household needs taken into account, and for the scenario of increased consumption, only 2 and 3 weeks of consumption remain uncorrelated which are the equivalent of a normal vacation period in which no consumption is recorded. In conclusion, the installation of rainwater storage systems is reliable for residential buildings, especially in rural localities where properties benefit from larger land areas.*

Keywords: *Rainwater storage, residential buildings, reduction of drinking water consumption*

1. Introduction

Water is an indispensable and valuable resource for mankind, but unfortunately, in recent times, there has been a decrease in both water reserves and the depth of groundwater, especially in regions where consumption exceeds the regeneration capacity of groundwater [1]. Regarding Europe, since 2009, the European Environment Agency draws attention to the water shortage faced by the southern areas and which has extended to the northern parts, problems that will probably worsen due to climate change [2]. Although Romania is included among the countries with relatively limited water resources, together with Spain and Turkey, by the EEA [3], Romania still has a fairly sustainable water resource system, except for some areas where problems related to quantities of water can be observed [4].

These problems can become a threat for several areas, among which: public health, food security, ecosystems, etc. On the other hand, the unsustainable use of water resources leads to increased costs in drinking water supply systems (in treatment plants, on distribution networks). Moreover, population growth in urban areas and their adjacent areas in recent years has become a problem of the present and probably a stress for the future in terms of consumption of water resources. The migration of the population towards these localities determined the emergence of densely populated areas, which led to a considerable increase in the consumption of drinking water, which, being also used for green sap maintenance, implicitly led to the overloading of the drinking water supply systems. All these aspects lead to the need to save water by implementing measures to reduce drinking water consumption in buildings. The reduction of potable water consumption for installations in residential buildings, in a percentage of about 30%, is possible through the collection, storage and use of stormwater [5]. For this reason, the paper addresses issues regarding the return on investment in stormwater storage and use systems for residential applications in regions in western Romania, more precisely in the Timiş Plain, where the population density is continuously increasing, resulting in a large number of water consumers. drinking water

[4] (approximately 86.1 inhabitants/km), of which 59% of the population is located in the urban environment, and the remaining 41% in the rural environment [6], with the highest concentration in the rural areas adjacent to Timisoara.
For this reason, two localities from Timiș County, located near the town of Timișoara (Giarmata and Moșnița Nouă), were chosen for the study, where, in the last period, there has been a considerable increase in built space and implicitly in population growth. For these localities, an analysis was carried out regarding the opportunity of investing in rainwater storage systems and its use, both in indoor sanitary installations for washing WC bowls and for washing machines, as well as for irrigating green spaces, watering gardens and for various cleaning activities outside buildings.
Moreover, when designing and dimensioning water supply systems in a centralized system, a water requirement for irrigating green spaces and watering gardens on private properties is not taken into account. So the storage and use of meteoric water for the needs of a household outside the building would satisfy a need that is not provided by the water supply systems and at the same time would ensure the reduction of the pressure placed on the water systems by these unforeseen consumptions in the design and dimensioning. The design standards and regulations in Romania [7,8] establish a specific daily flow of water/person for household needs depending on the type of facility equipment of the buildings. Thus, for the localities of Giarmata and Moșnița Nouă that are equipped with centralized water supply systems and indoor sanitary installations of cold and hot water, sewerage and individual preparation of hot water, the normative NP 133/2023 [7] considers a specific flow of water of 100-120 l/person/day which also includes the flow required for washing WC bowls and for washing machines. Thus, by replacing the water requirement for these facilities with water from precipitation, the water requirement in l/person/day would be reduced.
For this purpose, meteoric water samples were collected for which the water quality was analyzed by determining the physico-chemical and microbiological parameters. Solutions for its use are also proposed, in order to reduce drinking water consumption and implicitly costs.

2. Case study

2.1 Methodology

As Europe risks facing water shortages in many regions, it is necessary that water consumption in buildings is an important factor in the management of water resources and the efficient use of the environment. Therefore, an alternative and viable source of water is water from rainwater, which, however, requires several stages of approach:
- Stage I - evaluation of the amount of water from precipitation that can be collected;
- Stage II – analysis of the quality of the collected water and possibly the establishment of treatment solutions;
- Stage III – analysis of solutions that can be implemented;
- Stage IV – estimation of the volume of water from precipitation that can be collected and, respectively, that can be used at consumption points;
- Stage V – estimation of water consumption reduction.

2.2 Results and discussion

The study was carried out by approaching the three stages, as follows:

Stage I – for this stage, an assessment of the amount of precipitation was carried out for the two localities (Giarmata and Moșnița Nouă) by consulting the data provided by Meteoblue AG [9], for which the amounts of monthly precipitation were determined, according to Fig. 1 and Fig. 2.
It can be seen that location can affect investment as rainfall is unpredictable, fluctuating and seasonal in different regions. However, an estimation of the precipitation leading to the correct sizing of the storage reservoirs is necessary. The study was carried out taking into account the period September 1, 2022 - August 31, 2023, for which the total amount of rainwater was calculated (Q_{tr}) which can be collected for the two localities, based on the data provided by Meteoblue AG [9]. Rainwater values for the period September 1, 2022 - August 31, 2023 are presented in Fig. 1 for the town of Giarmata and in Fig. 2 for the town of Moșnița Nouă.

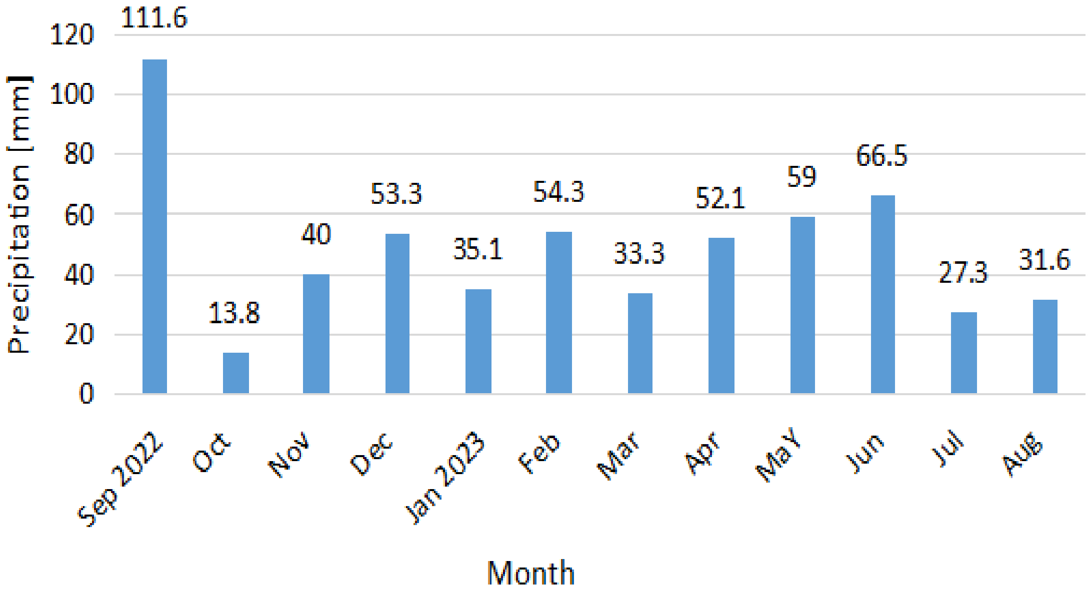


Fig. 1. Monthly rainwater – Giarmata [9]

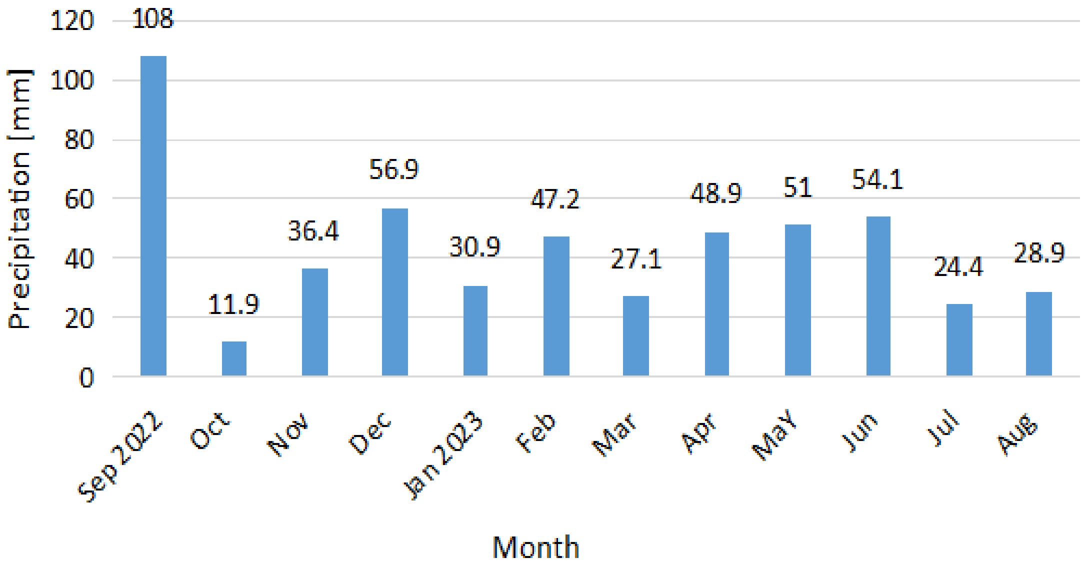


Fig. 2. Monthly rainwater - Moșnița Nouă [9]

For the two localities, the result was:
- for the town of Giarmata, resulted a value of 577.9 mm/year;
- for the town of Moșnița Nouă, resulted a value of 525.7 mm/year.

Stage II – analysis of water quality from precipitation was performed after collection and storage for 15 days in sterile plastic containers. The water was kept at a temperature of about 20°C in the containers in which it was stored and protected from sunlight. Two buildings, from the two localities, were chosen for the collection of meteoric water, which have the same type of covering (tile) and the same collection system (gutters and downspouts made of galvanized sheet). Water collection was done at the base of the downspout, after the water had washed the casing and discharged through gutters and downspouts.
The quality analyzes of the water samples were performed in the laboratory of the ICER Research Institute of the Polytechnic University of Timișoara. Table 1 shows the results obtained for the main water quality indicators in comparison.

Table 1: Results obtained for the main water quality indicators

No.	Analysis executed	Unit	Giramata rainfall water sample	Moșnița Nouă rainfall water sample	Recommended values for drinking water	Test method
1	pH (temperature)	unit. pH (^{0}C)	6.7 (23^{0}C)	5.7 (23^{0}C)	6.5 – 9.5 / la max. 24^{0}C	POL-CM-09, ed.1/rev.0
2	Conductivity (20^{0}C)	µS/cm	40	50	2500 µm/cm (20^{0}C)	POL-CM-42, ed.1/rev. 0
3	Nitrites	mg/L	-	0.08	max. 0.5	POL-CM-17, ed.1/rev.0
4	Nitrates	mg/L	< 10	10	< 50, adults < 10, baby	POL-CM-16, ed.1/rev.0
5	Ammonium	mg/L	bdl	0.04	max. 0.5	POL-CM-18, ed.1/rev.0
6	Content of Ca	mg/L	-	2.0	< 100	POL-CM-14, ed.1/rev. 0
7	Content of Mn	mg/L	-	0.035	max. 0.05	POL-CM-12, ed.1/rev. 0
8	Content of Fe	mg/L	bdl	bdl	max. 0,2	POL-CM-12, ed.1/rev. 0
9	Content of Cd	mg/L	-	bld	-	POL-CM-12, ed.1/rev. 0
10	Content of Ni	mg/L	-	0.2	not normed	POL-CM-14, ed.1/rev. 0
11	Content of Cu	mg/L	-	bdl	-	POL-CM-12, ed.1/rev. 0
12	Content of Zn	mg/L	bdl	bdl	not normed	POL-CM-14, ed.1/rev. 0
13	Total dissolved solids (TDS)	mg/L	2.0	1.0	max. 500	gravimetric analysis

Note: bdl (below the detection limit)

Table 1 shows the slightly acidic nature of the stored meteoric waters, which can be easily corrected with solutions to increase the PH.
From the point of view of electrical conductivity, nitrates, nitrites, ammonium, the content of metals Ca, Mn, Fe, Cd, Ni, Cu, Zn and the total dissolved solids, it can be observed that the stored meteoric water falls within the potability limits.
Based on the results of the analyzes of the water quality indicators, it was concluded that:
- for the Giarmata locality it can be appreciated that the water from precipitation can be used for household needs considered without treatment;
- for the town of Moșnița Nouă, it can be appreciated that the water from the precipitation can be used for the household needs considered with a slight correction in terms of the pH of the water.

Stage III – the analysis of the solutions that can be implemented was carried out by taking into account the following directions of use of meteoric waters:
• use to reduce drinking water consumption;
Meteoric water is collected from roofs, balconies, terraces, or other surfaces with a low degree of pollution, roofs being the preferred surface for their collection. The quality of the collected water depends on the surface with which it comes into contact, as well as the quality of the air, and it will be treated as necessary.

The analysis of the solutions that can be implemented, from the point of view of reuse in order to reduce the consumption of potable water, was carried out by identifying the points of consumption in the indoor sanitary installations where the potable water can be replaced by the collected meteoric water, as well as the identification of the spaces outside the building where meteoric water can be used.

Thus, solutions are proposed that involve changes in the classic design of cold water supply sanitary installations that serve buildings by separating and grouping consumption points that require potable water (drinking, cooking, personal hygiene and washing dishes) and those that can use water from precipitation that has been collected and stored (flushing toilets, washing machines, washing driveways, sidewalks, parking lots and yards).
At this stage, general systems were proposed (Fig. 3) that can be adapted according to the configuration of the indoor water supply plumbing. Also, the type of system is chosen according to the availability of land in each location.

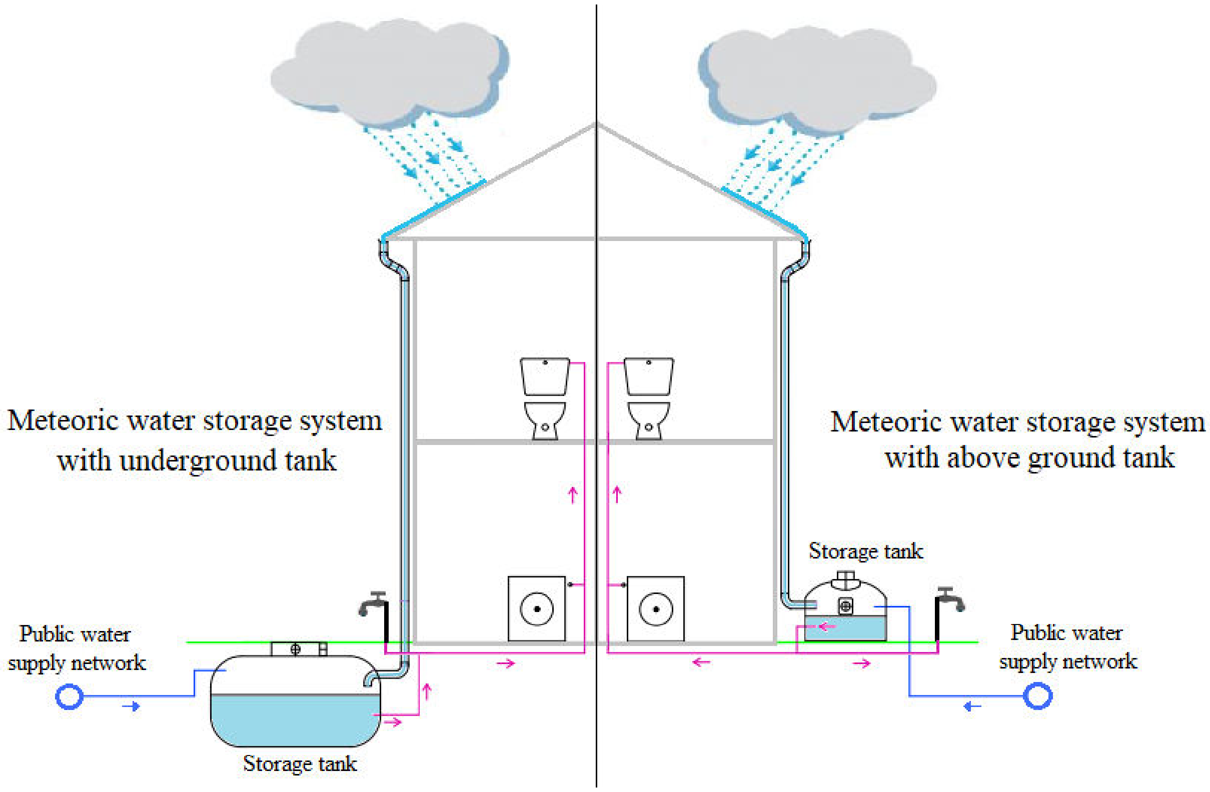


Fig. 3. Meteoric water storage systems

• use for underground water conservation.

From this point of view, it is necessary to make an assessment of the need to enrich the underground water layer in the areas where the collection and storage is done. Thus, to conserve groundwater and protect the environment, stormwater can be collected, stored and used for artificial infiltration into the soil, ensuring both the natural water cycle and for irrigating gardens and green spaces during periods of drought.
From the analysis of the two directions of reuse of the collected and stored meteoric waters, the optimal use solution will result.

Stage IV – involves carrying out a study to estimate the volume of water from precipitation that can be collected and then used in indoor plumbing.

• volume of water that can be collected from precipitation

To evaluate the amount of water from precipitation for the two households in the two localities, the amount of water from precipitation determined in Stage 1, the useful surface of the roof from which it can be collected, was taken into account. The calculation of the volume of water that can be collected was determined with the relation (1) [10]:

$$Q_{mwc} = \frac{S_u \cdot Q_{tr} \cdot k}{1000} \quad (1)$$

where:
Q_{mwc}- meteoric water collected [m^3];
S_u- useful roof surface [m^2];
Q_{tr}- total annual rainfall [m^2];
k - water collection efficiency coefficient [-].

The coefficient k, depending on the material of the roof and the particularities of the construction, can take values between 0.8-0.94 (Table 2) [10]. For the two buildings that have a frame-type roof covered with concrete tiles, the coefficient k = 0.8 was considered.

Table 2: Consumption of potable water for household needs that can use stored meteoric water

Roof type	Coefficient k
Tin roof	1
Fired Clay Tile	0.9
Slate tile, concrete	0.8
Gravel screed	0.6

About 80% of the useful roof surface was considered for the useful roof surface:
- for the town of Giarmata, a water volume of 60,102 liters resulted, which can be collected;
- for the town of Moșnița Nouă, a water volume of 54,673 m3 resulted that can be collected.
• volume of water that can be used at points of consumption in indoor plumbing

Starting from the specific water flow (100-120 l/pers/day) taken into account when designing water supply networks for localities of the type considered for the study (Giarmata and Moșnita Nouă), an estimate of water consumption was made for household needs such as: washing toilets and washing clothes. Two residential buildings in the two mentioned localities, in which 4 people live, were taken into account.
The estimation was carried out considering, for the mentioned household needs, the weekly consumptions from Table 3. For washing machines, two classes of energy efficiency were considered: class A, capacity 7 kg and a water consumption/cycle of 36l and class D, capacity 7 kg and a water consumption/cycle of 44l. For the values in Table 3, a class A washing machine was accepted for the low consumption category, and a class D washing machine was accepted for the high consumption category [11].
For the estimated calculation of the weekly consumption, relation (2) was used:

$$Q_{wtotal} = n_u \cdot q_u \cdot N_p \cdot n_z \text{ [l/week]} \quad (2)$$

where:
n_u - number of uses/day [-];
q_u – consumption/use [l/use];
N_p - number of people [-];
n_z - number of days/week [-];
Q_{wtotal} - total consumption [l/week].

Table 3: Drinking water consumption for household needs that can use the stored meteoric water

Household needs	n_u [-]	q_u [l/ use]	N_p [-]	n_z [-]	Q_{wtotal} [l/week]	Q_{atotal} [l/year]
Low consumption						
Toilet bowl washing	5	6	4	7	840	43,680
Washing clothes	1	36	4	2	72	3,744
Total						47,424
Increased consumption						
Toilet bowl washing	5	9	4	7	1260	65,520
Washing clothes	1	44	4	2	88	4,576
Total						70,096

Considering an average of 4 weeks/month, the monthly consumption was calculated for the two variants of consumption degrees:
- for reduced consumption: Q_{lunar} = 3,648 l/month;
- for increased consumption: Q_{lunar} = 5,392 l/month.

Stage V – for an estimate of water consumption reduction it is necessary to make an annual assessment of the annual amount of water consumed/household and the amount of rainwater collected and stored. As the amount of water from precipitation is seasonally variable, a monthly assessment at this stage is most likely irrelevant. Thus, a number of 52 weeks was considered for a common year.
Thus, for the two consumption categories, an annual amount of water consumed by:
- for reduced consumption: Q_{atotal} = 47,424 l/year;
- for increased consumption: Q_{atotal} = 70,096 l/year.

Comparing the consumption with the amount of water from precipitation that can be collected and stored in the two localities considered for the study (Giarmata: Qstocat = 60,102 l/year and Moșnița Nouă: Qstocat = 54,673 l/year) the amount of water recovered (Qrec by the difference between the two amounts of water, with relation (3):

$$Q_{rec} = Q_{stocat} - Q_{atotal} \text{ [l]} \quad (3)$$

where:
Q_{rec}- the amount of drinking water recovered [l];
Q_{atotal} - the amount of drinking water used [l];
Q_{stocat} - the amount of rainwater stored [l].

Based on the data obtained, the amount of recovered water was calculated for the two buildings in the two localities, and obtained:
- for the town of Giarmata:
  - for reduced consumption: Q_{rec} = 12,678 l/year;
  - for increased consumption: Q_{rec} = -9,994 l/year.
- for the town of Moșnița Nouă:
  - for reduced consumption: Q_{rec} = 7,249 l/year;
  - for increased consumption: Q_{rec} = -15,423 l/year.

3. Conclusion

Based on the data obtained, it can be found that both for Giarmata and Moșnița Nouă localities, in the scenario of reduced consumption, the entire amount of drinking water used for the two categories of household needs (washing WC bowls and washing clothes) is fully covered, even resulting in a surplus that can be used for other needs outside the buildings (watering green spaces, gardens, etc.), respectively 12,678 l/year for Giarmata and 7,249 l/year for Moșnița Nouă.

This quantity may be sufficient during the vegetation period of the plants, but that obviously depends on the type of crops.
Conversely, in the case of the increased consumption scenario, the amount of water required for household needs is not covered for any of the localities, registering a deficit of 9,994 l/year for Giarmata and 15,423 l/year respectively for Moșnița Nouă. These deficits will not cover the considered household needs for approximately 2 weeks for the Giarmata locality and for approximately 3 weeks for the Giarmata locality, obviously related to the increased consumption scenario.
On the other hand, even in the case of increased consumption, for the two localities considered for the study, it can be considered that the entire amount of recovered water can be recovered if it is taken into account that during the holidays (2-3 weeks), no drinking water consumption is recorded in the two buildings.

As future directions, we propose to do a comparative analysis over a period of 3 years in which to include several localities from the Timișului plain.

References

[1] Water Science School. ”Drought and Groundwater Levels”. 06 June 2018. Accessed August 30, 2023. https://www.usgs.gov/special-topics/water-science-school/science/drought-and-groundwater-levels.
[2] European Environment Agency. ”Water resources across Europe – confronting water scarcity and drought". EEA Report, no. 2 (2009): 9-11.
[3] European Environment Agency. ”Water resources across Europe – confronting water scarcity and drought". EEA Report, no. 2 (2009): 15-16.
[4] Mitrică, B., E. Mitrică, P. Enciu, and I. Mocanu. “An approach for forecasting of public water scarcity at the end of the 21st century, in the Timiş Plain of Romania.” *Technological Forecasting & Social Change*, no. 118 (2017): 258–269.
[5] Tokar, A., P. Frăsie, and D. Tokar. “Rainwater Harvesting, a Solution to Reduce Drinking Water Consumption for Buildings.” *Hidraulica Magazine*, no. 2 (2021): 57-63.
[6] Timiș County Council / Consiliul Județean Timiș. ”Prezentarea județului”. Accessed August 30, 2023. https://www.cjtimis.ro/judetul-timis/prezentarea-judetului/.
[7] Romanian Ministry of Development, Public Works and Administration (MDLPA). “Normative regarding the design, execution and operation of the water supply and sewage systems of localities” / “Normativ privind proiectarea, execuția și exploatarea sistemelor de alimentare cu apă și canalizare ale localităților”, reference number NP 133-2022, volume I, The Official Gazette of Romania / Monitorul Oficial al României, Year 191 / Anul 191 (XXXV) — No. 43 bis, 2022.
[8] Romanian Standards Association (ASRO). “SR 1343-1-Water supplies. Determination of potable water quantities for urban and rural localities”. / “SR 1343-1-Alimentări cu apă. Determinarea cantităților de apă potabilă pentru localități urbane și rurale”.June 2006.
[9] Meteoblue AG. Weather and climate data and services. Accessed August 29, 2023. https://www.meteoblue.com/.
[10] ***. “Calculation of tank volume required for the rainwater reuse system.” / “Calcul volum rezervor necesar sistemului de reutilizare a apei de ploaie.” https://www.scribd.com/document/93932269/Calcul-Volum-Rezervor-Apa-de-Ploaie. Accessed August 30, 2023.
[11] Emil, I. “Find out how much your washing machine consumes” / “Află cât consumă mașina de spălat rufe.” August 5, 2023. Accessed August 29, 2023. https://primodealz.net/masina-spalat-rufe-consum/.

Estimation of Flood Flow at Critical Point Aided by QGIS Software

Prof. Dr. Eng. **Henrique PIZZO**[1,2,*], M.Sc. Eng. **Vinícius GALIL**[3], Prof. Dr. Eng. **Celso RIBEIRO**[3], Asst. Prof. Dr. Eng. **Safa IBRAHIM**[4]

[1] Estácio University of Juiz de Fora, State of Minas Gerais, Brazil

[2] Municipal Sanitation Company of Juiz de Fora, Brazil

[3] Federal University of Juiz de Fora, Brazil

[4] University of Zakho, Kurdistan Region, Iraq

Abstract: *The present work presents the determination of the peak flow in a region strongly subject to flooding. This is Severino Meireles street, part of the Independência Stream Hydrographic Basin, in the municipality of Juiz de Fora, Brazil. After a review of the literature on local floods, it is a question of estimating the hydrological flow of floods. The basins contributing to the study site had their characteristic magnitudes (areas, topographic elevations, lengths of watercourses, etc.) obtained from the use of the QGIS software. The hydraulic drainage capacity of the street gallery in question is also calculated, verifying the condition conducive to the occurrence of floods. Finally, suggestions for mitigating the problem are listed*.

Keywords: *Floods, QGIS, Severino Meireles street, drainage gallery, upstream watersheds*

1. Introduction

The amount of impermeable soil and alterations in natural drainage systems are increasing as a result of the fast growth of metropolitan areas. As a result of the difficulty of rainfall infiltration, there is a significant rise in surface discharges, favoring the occurrence of floods [1].
It is advantageous for the community if the urban area is designed in an integrated manner, that is, if all public works are planned in a consistent manner. When the drainage system is not included from the beginning of the urban planning formulation, it is extremely likely that when developed, it will be both expensive and inefficient. System planning must be carried out in accordance with well-defined standards, while constantly taking into consideration local, physical, economic, and social characteristics. The objective must be a realistic, technically and economically efficient drainage system project that maximizes advantages while reducing costs, is compatible with other sector plans, and meets the needs of the community [2].
Reference [3] reports that, according to the International Disaster Database, between 2006 and 2016 floods caused 61,730 deaths and US$375 billion in property damage worldwide. As stated in [4], flood impacts and resulting damage can be reduced through structural (physical interventions) and non-structural (management) approaches, and more effectively by combining both.
Based on [5], Brazilian urban drainage is considered outdated, since the concept of channelling prevails over that of reservation and infiltration, prioritizing rapid drainage rather than the controlled disposal of reserved volumes. It is reported in [6] that studies on urban floods have been undergoing important conceptual advances and urban drainage actions have been aligned with the concept of sustainable development, adding social and environmental aspects to the technical conception.

2. Studies on Floods in the City of Juiz de Fora

An interesting retrospective on floods in Juiz de Fora is presented, with historical approaches to sanitation and territorial planning [7].
Questions about recent floods in the Ipiranga Stream [8, 9, 10], in the São Pedro Stream [9] and in the Matirumbide Stream [11] are addressed.
Analyses of the Drainage Plan for the North Zone of Juiz de Fora (2011) point out that the flooding areas generated for the urban area of the North Region indicate the neighborhoods Igrejinha,

Benfica, Bairro Araújo, Barbosa Laje, Bairro Industrial, Bairro Cerâmica, Monte Castelo and Remonta as being those, respectively, at greater risk.
According to [12], the Independência Stream Hydrographic Basin is one of the 156 sub-basins that drain the urban area of the municipality. It has 7.11 km^2 and 82,977 inhabitants (2015 estimate). The stream has a length of 5.47 km, of which 4.73 km are channelled and covered, and it covers an area with a strong residential, educational, health and commercial character. However, it should be noted that the Independência Stream Watershed still lacks studies to eliminate, or at least minimize to acceptable levels, the issue of flooding.

3. Methodology

The central point of the present work is to estimate the flood flow of a critical point, located in the Independência Stream Hydrographic Basin, in the city of Juiz de Fora, state of Minas Gerais, Brazil, and consequent comparison with the capacity of the drainage equipment of this site, which is a storm sewer. This expedient is intended to deepen the studies for the elimination or, at least, the attenuation of those phenomena in the place.
From searches in newspapers, news, available and disseminated knowledge, and manuals, 03 points very subject to flooding in the Independência Stream Basin were chosen: Severino Meireles street, a small extension of Rio Branco avenue, immediately adjacent to the first, and the corner of Morais e Castro street and 21 de Abril street. It was decided to have Severino Meireles street as the object of this study because, among the three points, it is the one with the highest frequency of floods and consequent damages. The problems are caused by precipitation from upstream neighborhoods such as Alto dos Passos, Bom Pastor and Guaruá which, not being properly drained at the source, have their surplus forwarding to the location object of research.

3.1 Geoprocessing

Regarding the operations via geoprocessing of the contributing hydrographic sub-basins, the first stage of this work consisted of the delimitation of the Independência Stream Basin. So that this task could be carried out consistently, a freely distributed and widely known application in the field of georeferencing called QGIS, an acronym for Quantum Georeferenced Information System, was used. Once the software was installed, a Digital Elevation Model - DEM was acquired. For that, it was necessary to access data from the ALOS PALSAR satellite, which uses L-Band reading with repeated pass interferometry, through the Alaska Satellite Facility website.
Once the collections of scenes were obtained, we opted for one that had an FBD type beam and Hi-Res Terrain Corrected detailing. The next stage of the procedure was to delimit the study area and, for this, a shape-file (SHF) of the municipality of Juiz de Fora was used. This operation aimed the study from an optimized file, providing a faster processing.
For the third stage, an SHF file of the taxpayers of the Paraíba do Sul River Basin was necessary, acquired on the website of the Brazilian National Water Agency which, in this case, was cut using the SHF file of the municipality as a delimiter. This operation was important to facilitate the identification of the Independência Stream Basin along with its outlet, a task that would be more complex due to the vast expanse of the Paraíba do Sul River Basin.
In the next step, with the DEM already optimized, it was possible to obtain images of the constituent watersheds of the entire municipality, as well as their respective directions and drainage segments. It was also possible to identify all the thalwegs that contribute, continuously or occasionally, to Independência Stream Basin. Finally, tools from the Geographic Resources Analysis Support System (GRASS) of QGIS were used, where it was possible to refine the pixels of the drainage line and their subsequent vectorization in order to generate the distances from the interfluves to their sub-outfalls. Such images were allocated over the model Google Earth image so that the adjustment between the basin and streets could be demonstrated. The georeferencing application also allows the extraction of other products, such as altimetric lines, sub-basin areas and total basin area, altimetric profile, slope index, contribution index, soil type and vegetation.

3.2 Hydrology

The Independência Stream Watershed is represented in Figure 1, delimited in green. The stream flows to Paraibuna River. The yellow lines define the natural waterways, the orange polygon encompasses the study area, subject to flooding, and the area in red denotes Severino Meireles street.

Fig. 1. Independência Stream Basin

Figure 2 presents a partial and closer view, in relation to the area under study, of the Independência Stream Hydrographic Basin, now delimited in light blue, still with the water lines in yellow and Severino Meireles street in red.

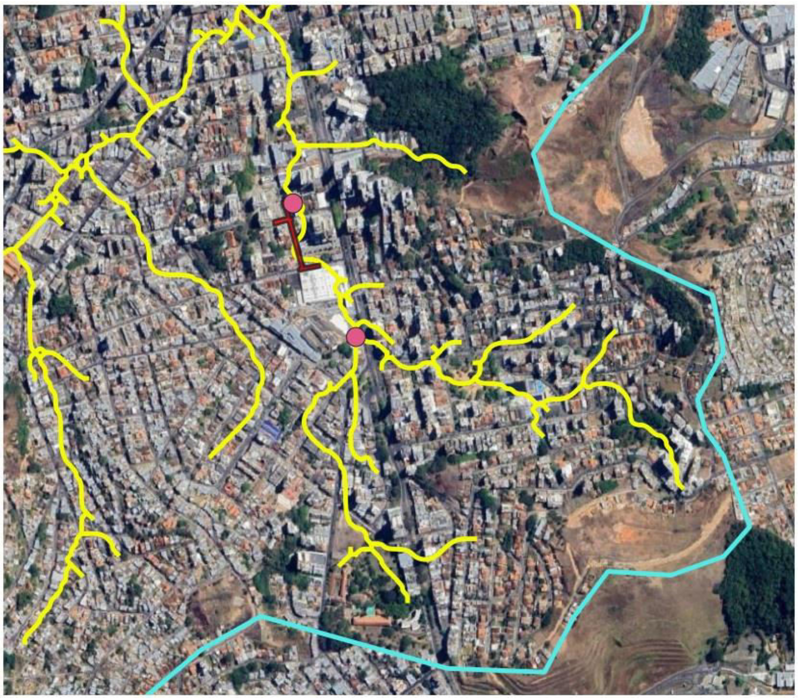


Fig. 2. Closer view of the study area

From the regions affluent to Severino Meireles street, in the same basin, three sub-basins were delimited (from that point on, simply called basins) and respective areas, through the previously exposed methodology. The main focus was given to basins 1 (burgundy) and 2 (brown), as they are the largest of the three basins. Basin 3 (blue) was considered to have integrated parameters from the others. The main watercourses whose length was materialized only partially through geoprocessing, had those complemented and extended to the watershed, through the monitoring of contour lines. The areas, length of the main watercourse, upstream terrain level and downstream terrain level (the latter common to the 2 basins) are, respectively, for basins 1 and 2, 518,162 m^2, 396,749 m^2, 1,399 m, 1,200 m, 825 m, 795 m, and 705 m (at the confluence point of both). Basin 3 has an area of 145,167 m^2. The scheme can be seen in Figure 3.

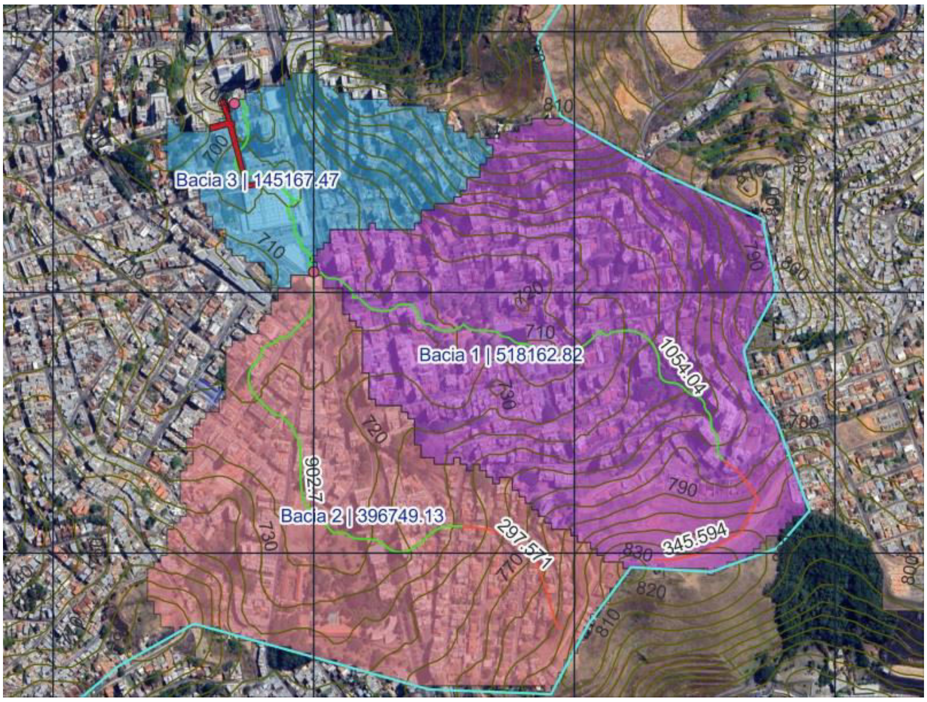


Fig. 3. Flood point upstream watersheds

The time of concentration is 10.7 minutes, determined by the average values adopted between those estimated by the formula of Shaake et al. (1) and those resulting from Kirpich formula (2) [13]. It is interesting to note that the time of concentration values referring to basins 1 and 2 were very close to each other when Shaake was used, as well as when Kirpich was used, although they differed when using one and the other formula. For this reason, it was believed that the average would have a better representativeness. The formulas are expressed in the following equations.

$$t_C = 0.0828\ L^{0.24} S^{-0.16} {A_{imp}}^{-0.26} \quad (1)$$

$$t_C = 0.0663\, L^{0.77} S^{-0.385} \quad (2)$$

Where t_C is the time of concentration (h), L is the length of the main watercourse of the basin (km), S is the average slope of the basin (level variation divided by the length of the main watercourse, m/m), and A_{imp} is a value between 0 and 1, which represents the percentage of impermeable area of the watershed.

A recurrence interval of 20 years was adopted, considering the type of situation studied in the present work. It should be added that, for the determination of peak flows, the Rational Method was adopted, emphasizing that it admits that the maximum flow occurs when the time of concentration of the basin is equal to the time of rain. And, thus, in the intensity-duration-frequency equation, such a consideration is admitted.

The value of rainfall intensity is 159.3 mm/h, determined by the intensity-duration-frequency equation for Juiz de Fora (3).

$$i = \frac{3{,}000\ T^{\,0.173}}{(t + 23.965)^{\,0.960}} \tag{3}$$

Where i is the rainfall intensity (mm/h), T is the recurrence interval (years), and t is the duration of rain (equivalent to the time of concentration, min).
The irregular rainfall distribution coefficient was calculated individually for each of the 03 basins, according to (4). A runoff coefficient of 0.75 was adopted, considering the upper limit value for residential areas with multiple conjoined units, as recommended by Ven Te Chow, in view of the situation presented.

$$C_d = A_{ac}^{\ -0.15} \tag{4}$$

Where C_d is the distribution coefficient (dimensionless), and A_{ac} is the accumulated area of each basin (ha).
The equation used to calculate the maximum flow was the Rational Formula, and is expressed in (5).

$$Q_{max} = 2.78\ C_e\ C_d\ i\ A \tag{5}$$

Where Q_{max} is the maximum flow (L/s), C_e is the runoff coefficient (dimensionless), A is the area of each basin (ha), and C_d and i are already defined.

3.3 Hydraulics

The rainwater drainage layer was obtained from the information system of the municipal sanitation company. This is expressed in Figure 4, where the drainage galleries are represented by blue lines, the Severino Meireles street gallery is surrounded by a yellow ellipse, and the level curves symbolized by red lines.

Fig. 4. Drainage gallery system

Based on a consultation with the Municipal Works Department, it was found that the gallery that drains Severino Meireles street is 2.0 meters wide by 3.0 meters high, and has a bottom slope of 0.46%. The estimated Manning coefficient is 0.018, equivalent to rough cement channels, bottom deposits, moss on the walls and tortuous layout.

The hydraulic flow capacity of the gallery was calculated by the Manning equation, described in (6). A clearance of 10% of the height was allowed, in order to contemplate small variations in the parameters adopted in relation to the field ones.

$$Q_{cap} = \frac{1}{n}\ A_m\ {R_H}^{2/3}\ I^{\,1/2} \tag{6}$$

Where Q_{cap} is the hydraulic flow capacity, n is the Manning coefficient (s/m$^{1/3}$), A_m is the cross sectional area of flow (m^2), R_H is the hydraulic radius (A_m / wetted perimeter, m), and I is the hydraulic gradient (considered as the gallery bottom slope, m/m).

4. Results and Discussion

Despite the great uncertainties inherent to the process, whether related to field conditions, the equations used, and the arbitrated parameters, the values found, reported below, suggest a reasonable favorability for the flood conditions, in fact verified in practice, at that location.
The peak flow due to rainfall was calculated for each of the three basins, according to section 3.2 and (5), and then added together, in order to obtain the total flow that discharges into Severino Meireles street, totalizing 20.3 m^3/s.
As for the hydraulic flow capacity of the gallery, this was estimated at 16.5 m^3/s, in view of what was exposed in section 3.3 and the application of (6).
In order to increase the hydraulic flow capacity of the galleries, some measures must be considered. The initial verification would be to verify if the swallowing capacity of the culverts is sufficient for the affluent flow. Another step would be to verify whether the topographical conditions and whether the connections of the upstream pipes with the gallery in question allow the elevation of its bottom slope, even if a little, considering that it is very small.
Checking the hydraulic flow capacity of the pipes upstream of the gallery in question would also be an excellent attempt, also because it is known that there is an accumulation of water at a nearby point, upstream. It would also be recommended that employees enter the gallery, provided that all safety conditions are verified, in order to clear and clean it, thus helping to facilitate the flow of water.

5. Conclusions

Floods and overflows affect urban traffic and facilities, as well as the existence of waterborne illnesses and vector propagation. They also have repercussions for the environment, such as polluting and degrading urban water supplies. Flooding, in more extreme circumstances, results in significant consequences, including the loss of human life.
It is possible to suggest that the city of Juiz de Fora has urban dynamics that make it sensitive to problems like floods and spillovers, due to the region's substantial precipitation levels as well as the consequences of urbanization-related changes.
A study was presented to estimate the hydrological flows of the regions contributing to Severino Meireles street, heavily subject to flooding, part of the Independência Stream Hydrographic Basin, city of Juiz de Fora, Brazil. This flow was contrasted with the flow capacity of the local drainage gallery, confirming the favorable conditions for flooding. Some proposals for mitigating or eliminating such floods were previously discussed.
It is intended that this study be continued with the discretization of the areas upstream and consequent verification of available spaces for the installation of small reservoirs to dampen flows. Therefore, from the simulation of such reservoirs, whether in series or in parallel, it will be possible to estimate a new flow affluent to Rua Severino Meireles, eliminating the condition of flooding in that location.

Acknowledgments

The first author is grateful for the grant received from the Pesquisa Produtividade (Research Productivity) 2023 Estácio Juiz de Fora Program.

References

[1] Kessler, A., and M. H. Diskin. "The efficiency function of detention reservoirs in urban drainage systems." *Water Resources Research* 27, no. 3 (1991): 253–258. https://doi.org/10.1029/90WR02143.

[2] Fugita, O. *Urban drainage - design manual: Planning / Drenagem urbana - manual de projeto: Planejamento*. São Paulo: Cetesb, 1986.

[3] Zhu, F., P. A. Zhong, Y. Sun, and W. W. G. Yeh. "Real-time optimal flood control decision making and risk propagation under multiple uncertainties." *Water Resources Research* 53, no. 12 (2017): 635–654. https://doi.org/10.1002/2017WR021480.

[4] Shrestha, B. B., and A. Kawasaki. "Quantitative assessment of flood risk with evaluation of the effectiveness of dam operation for flood control: A case of the Bago River basin of Myanmar." *International Journal of Disaster Risk Reduction* 50, no. 4 (2020): 1–15. https://doi.org/10.1016/j.ijdrr.2020.101707.

[5] Souza, R. C. C. "Method for efficient sizing of flood containment reservoirs for the city of Curitiba-PR / Método para dimensionamento eficiente de reservatórios de contenção de cheias para a cidade de Curitiba-PR." M.Sc. thesis, Federal Technological University of Paraná, Curitiba, 2018. http://repositorio.utfpr.edu.br/jspui/handle/1/3105.

[6] Augusto, D. L. "Conception, modeling and detailing of a detention reservoir in a square, as an alternative for flood control in the Guerenguê River basin / Concepção, modelagem e detalhamento de um reservatório de detenção em praça, como alternativa para o controle de cheias na bacia do Rio Guerenguê." M.Sc. thesis, Federal University of Rio de Janeiro, Rio de Janeiro, 2008. https://minerva.ufrj.br/F/?func=direct&doc_number=000706264&local_base=UFR01.

[7] Machado, P. J. O., and S. B. Cunha. "Juiz de Fora: floods, sanitation and territorial organization / Juiz de Fora: inundações, saneamento e ordenamento territorial." *Revista Geográfica de América Central* 2, no. 47E (2011): 1–15. https://www.revistas.una.ac.cr/index.php/geografica/article/view/2455.

[8] Silva, R. S., and P. J. O. Machado. "Urban flooding: the case of the Ipiranga Stream watershed - Juiz de Fora/MG / Inundações urbanas: o caso da micro-bacia hidrográfica do Córrego Ipiranga - Juiz de Fora/MG." *Periódico Eletrônico Fórum Ambiental da Alta Paulista* 7, no. 2 (2011): 152–165. https://doi.org/10.17271/19800827722011110.

[9] Gerheim, D. K. M. "Overflows, flash floods and inundations in the urban area of Juiz de Fora: a look at the hydrographic basins of the São Pedro and Ipiranga Streams / Alagamentos, enxurradas e inundações na área urbana de Juiz de Fora: um olhar sobre as bacias hidrográficas dos Córregos São Pedro e Ipiranga." B.Sc. thesis, Federal University of Juiz de Fora, Juiz de Fora, 2016.

[10] Galil, V. M., H. S. Pizzo, W. G. Oliveira, and V. F. Calcaterra. "Methodology for determination of discharges in the Ipiranga Stream basin in Juiz de Fora / Metodologia para determinação de descargas na bacia hidrográfica do Córrego Ipiranga em Juiz de Fora." *Brazilian Journal of Development* 7, no. 2 (2021): 20728–20752. https://doi.org/10.34117/bjdv7n2-629.

[11] Amaral, C. M., I. B. S. Giarola, and J. O. Almeida Neto. "Identification of areas susceptible to flooding in the Matirumbide Stream watershed, Juiz de Fora-MG / Identificação das áreas suscetíveis à inundação na bacia hidrográfica do Córrego Matirumbide, Juiz de Fora-MG." In Os Desafios da Geografia Física na Fronteira do Conhecimento, edited by A. Perez Filho and R. R. Amorim, 4141–4149. Campinas: 2018. https://doi.org/10.20396/sbgfa.v1i2017.2567.

[12] Machado, P. J. O. "Urbanization and water quality of the Independência Stream, Juiz de Fora/MG / Urbanização e qualidade das águas do Córrego Independência, Juiz de Fora/MG." *Revista Equador* 5, no. 5 (2016): 20–35. https://doi.org/10.26694/equador.v5i5.4926.

[13] Silveira, A. L. L. "Performance of time of concentration formulas in urban and rural basins / Desempenho de fórmulas de tempo de concentração em bacias urbanas e rurais." *Revista Brasileira de Recursos Hídricos* 10, no. 1 (2005): 5–23. http://dx.doi.org/10.21168/rbrh.v10n1.p5-29.

A Double-Acting Pneumatic Cylinder with Cushioning: A New Approach

Dipl. Eng. **Cătălin FRĂȚILĂ[1]**, PhD. Eng. **Tiberiu AXINTE[1]**, Dipl. Eng. **Mihai DIACONU[1]**, Dipl. Eng. **Lidia CALANCEA[1]**, Dipl. Eng. **Roxana DAMIAN[1]**, PhD. Mat. **Elena CURCĂ[1]**, Dipl. Eng. **Diana DUMITRAȘ[1]**

[1] Research and Innovation Center for Navy, Romania

*tibi_axinte@yahoo.com

Abstract: *The aim of the work is to present aspects related to the use of a double-acting cylinder with cushioning. In this manuscript two circuits using a double-acting cylinder with cushioning are presented: on one hand, a pneumatic circuit, and on the other, an electro-pneumatic circuit. The first pneumatic scheme contains the following devices: a double-acting cylinder with cushioning (Duacy 1), two throttle valves, 4/2-way valve type, an air filter and the compressed air supply. The second one is an electro-pneumatic circuit which consists of the following devices: double-acting cylinder (Duacy 2), two throttle check valves, a start-up valve with filter control valve, compressed air supply and two solenoid valves.*

Keywords: *Pneumatic, cylinder, cushioning, circuit, valve*

1. Introduction

Double-acting pneumatic cylinders have one hole at each end. In any double-acting pneumatic circuit, a piston moves the cylinder forward and backward by alternating the hole that receives the high-pressure air. This device is needed when a load is to be moved in both directions, such as, for example, opening and closing a gate. For the double-acting cylinder with self-adjusting damping, the air pressure is applied alternatively to opposite ends of the piston [1].
The pneumatic cylinders can have the following cushioning types: external, mechanical, adjustable and self-adjusting, Fig. 1.

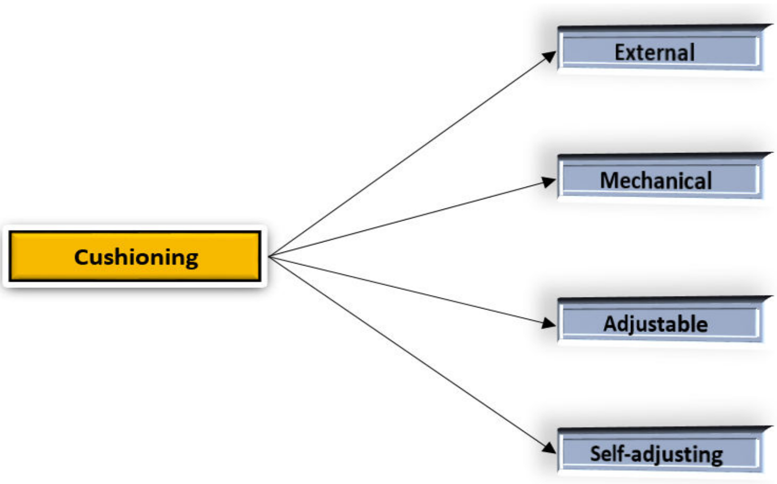


Fig. 1. Types of cushioning

In this manuscript, only cylinders with adjustable cushioning were studied. The adjustable air cushioning technology limits the air volume released at the pneumatic cylinder stroke's end. Any construction of cushioning includes a variable orifice and spuds, which are small metal rods mounted on either side of the piston. They close off the airflow to the main piston chamber, trapping fluid in the cylinder's end cap. This trapped fluid is then bled off through a small passage controlled only by a throttle check valve [2].
In specialized literature, a double-acting cylinder with cushioning and position sensing has a specific symbol, Fig. 2.

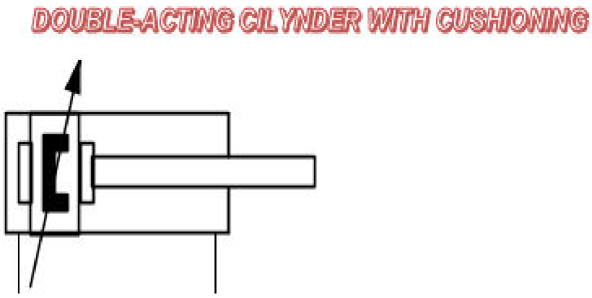


Fig. 2. Symbol of double-acting cylinder with cushioning

2. Analysis of the functioning of a double-acting cylinder with cushioning

In practice, different types of double-acting cylinder with cushioning are used. In our case, some double-acting cylinders with cushioning of type DNC-50-50-P-A were used, Fig. 3.

Fig. 3. Pneumatic cylinder DNC-50-50-P-A

Pneumatic cylinders DNC-50-50-P-A are in accordance with standard ISO 15552 (which corresponds to the withdrawn standards ISO 6431) [3].
Parameters of a double-acting cylinder DNC-50-50-P-A are shown in the table below.

Table 1: Double-acting cylinder with cushioning specification

Parameters	**Value**	**Unit**
Piston diameter	$50 \cdot 10^{-3}$	m
Stroke	$50 \cdot 10^{-3}$	m
Operating pressure	$8 \cdot 10^{5}$	Pa
Impact energy in end positions	0.2	J
Cushioning length	$22 \cdot 10^{-3}$	m
Basic weight	$1260 \cdot 10^{-3}$	kg

The pneumatic circuit studied has one double-acting cylinder with cushioning, Fig. 4.

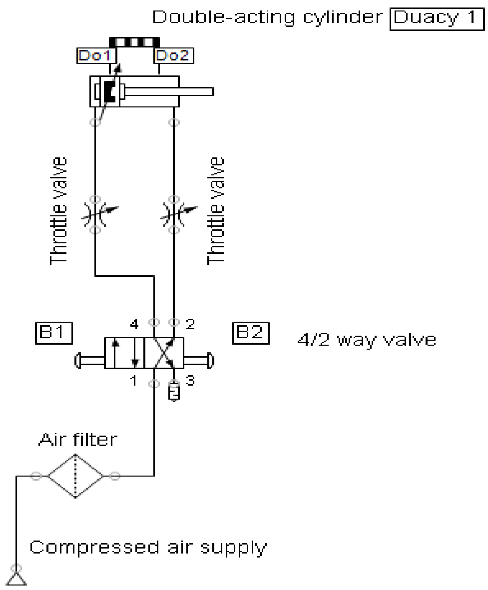


Fig. 4. Pneumatic circuit using double-acting cylinder (Duacy 2)

The components used in the pneumatic circuit are presented in the table below [4].

Table 2: The devices of the pneumatic circuit

Description	Number of components
Double-acting cylinder with cushioning (Duacy 1)	1
Throttle valve	2
4/2-way valve	1
Air filter	1
Compressed air supply	1

Operator presses the B1 button to the 4/2-way valve. Then, the piston rod moves from point Do1 to point Do2, Fig. 5.

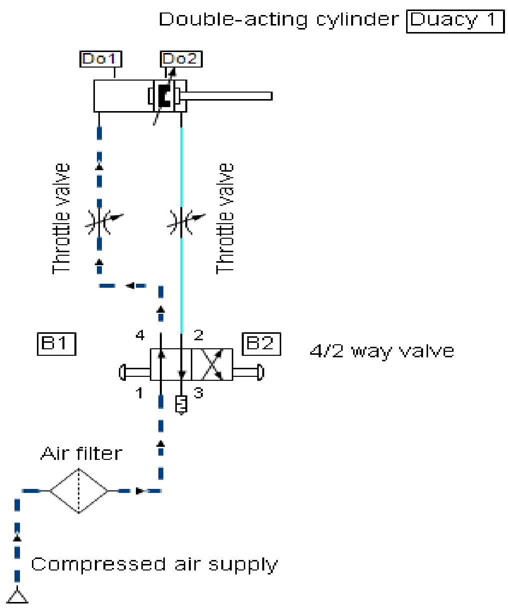


Fig. 5. Pneumatic circuit using a double-acting cylinder (Duacy 1). Simulation I.

If operator presses B2 button belonging to the 4/2-way valve, the piston rod moves from point Do2 to point Do1, Fig. 6.

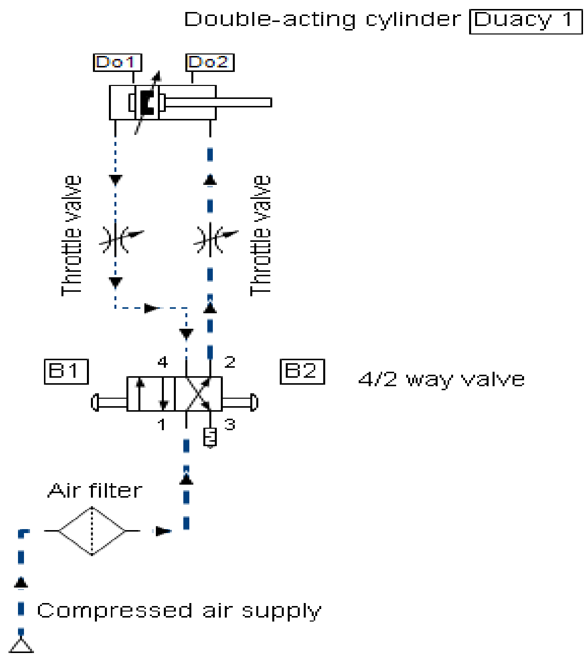


Fig. 6. Pneumatic circuit using double-acting cylinder (Duacy 1). Simulation II.

The diagrams show variation of the following functional parameters of the double-acting cylinder with cushioning (Duacy 1), Fig. 7.

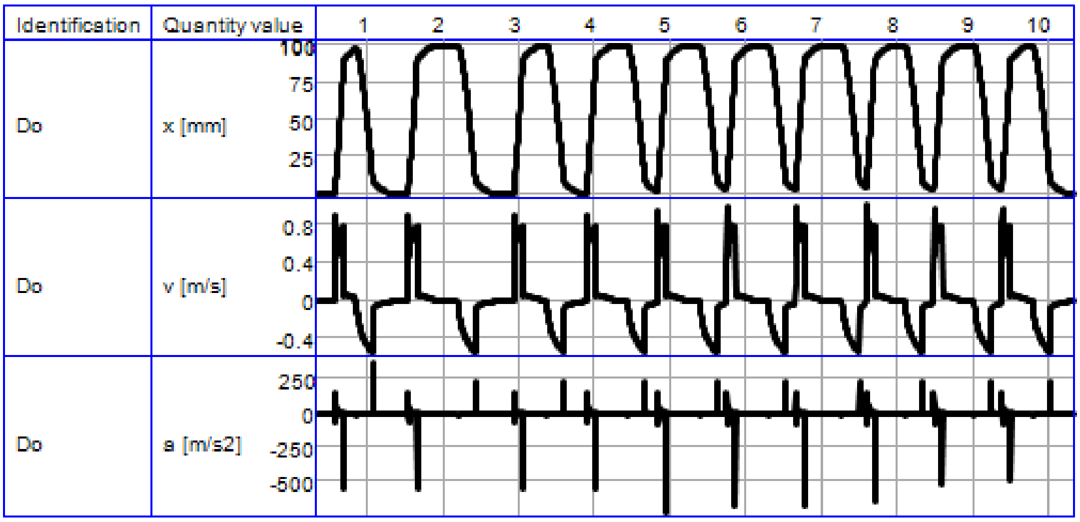


Fig. 7. Diagrams of parameters variations from the double-acting cylinder (Duacy 1)

Furthermore, an electro-pneumatic circuit has a double-acting pneumatic cylinder (Duacy 2) with cushioning [5], Fig. 8.

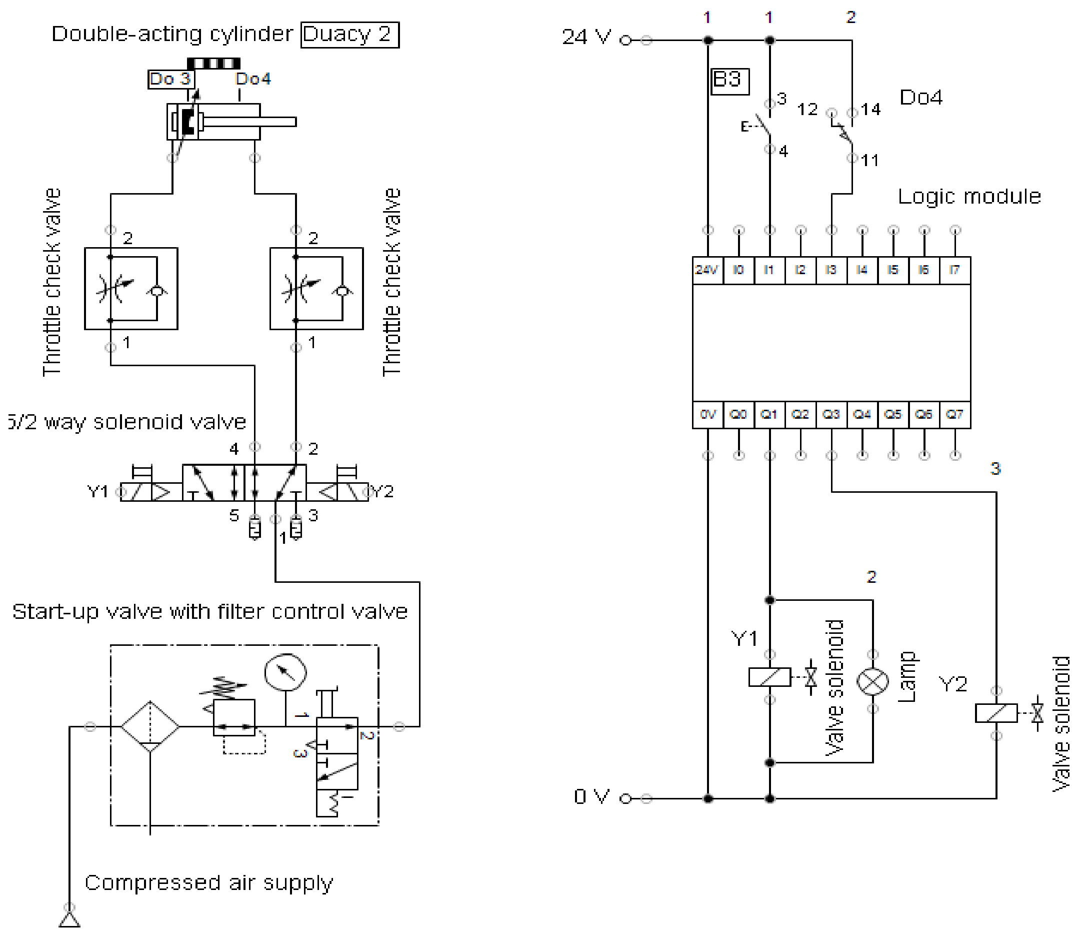


Fig. 8. Electro-pneumatic circuit using cylinder (Duacy 2)

Table 3 below shows nine component devices used in the electro-pneumatic circuit [6].

Table 3: The devices of the electro-pneumatic circuit

Description	Number of components
Double-acting cylinder (Duacy 2)	1
Throttle check valve	2
5/2-way solenoid valve	1
Start-up valve with filter control valve	1
Compressed air supply	1
Logic module	1
Solenoid valve	2

If operator presses button B3, the piston rod of the double-acting cylinder (Duacy 2) moves from point Do3 to point Do4 and a lamp shows an orange signal, Fig. 9.

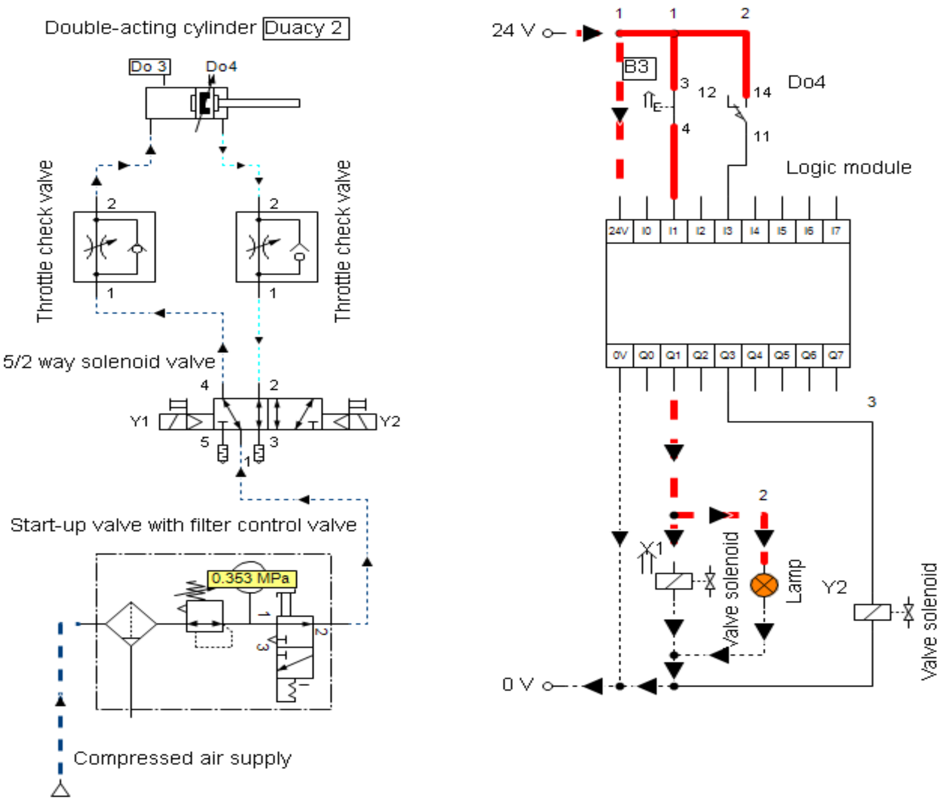


Fig. 9. Electro-pneumatic circuit using cylinder (Duacy 2). Simulation I.

After five seconds, the piston rod of the double-acting cylinder (Duacy 2) moves from point Do4 to point Do3, Fig. 10.

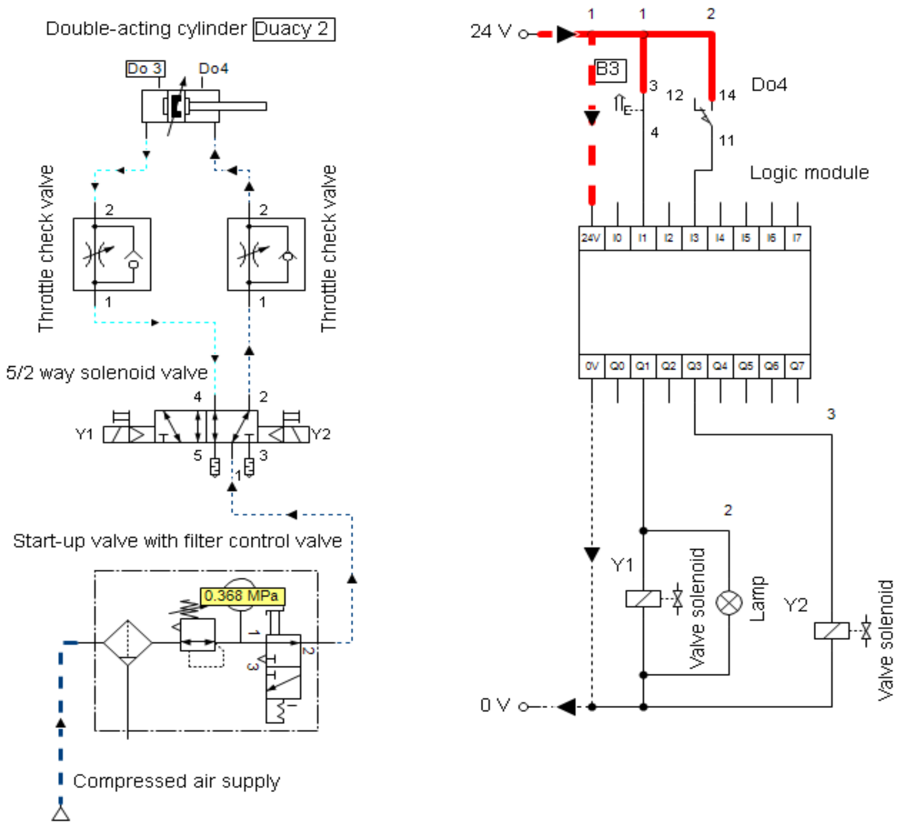


Fig. 10. Electro-pneumatic circuit using cylinder (Duacy 2). Simulation II.

3. Conclusions

The study showed that pneumatic cushioning slows and absorbs the impact of the piston as it reaches the end of its stroke. Nevertheless, if the pneumatic cylinder is without cushioning, the effect of the piston striking the end cap can cause damages in the respective installation. Moreover, adjustable cushioning improves safety by limiting the piston's noise when it hits the end cap. An important thing is that the silencer protects the hearing of operators frequently using such pneumatic installations.
A future manuscript on this topic will focus on the implementation in pneumatic circuits with double-acting cylinders and with several actuators in their construction.

Acknowledgments

We wish to thank Associate Professor Iulian Claudiu Dutu from the Faculty of Biotechnical Systems Engineering, University Politehnica Bucharest (UPB) for his unwavering guidance and support in the preparation of this manuscript.

References

[1] Memet, F., D.E. Mitu, and M. Panaitescu. "A point of view on efficiency and innovation in refrigeration." *Recent Advances in Energy, Environment, Economics and Technological Innovation*. Proceedings of the 4th International Conference on Development, Energy, Environment, Economics (DEEE '13). Proceedings of the 4th International Conference on Communication and Management in Technological Innovation and Academic Globalization (COMATIA '13). Paris, France, October 29-31, 2013. World Scientific and Engineering Academy, *Mathematics and Computers in Science and Engineering Series*, no.19 (2013): 237-241.
[2] Drumea, P., M. Blejan, L. Dumitrescu, M. Comes, I. Dutu, and I. Ilie. "Mechatronic system for air pressure control." Paper presented at the 29th International Spring Seminar on Electronics Technology IEEE 2006, St. Marienthal, Germany, May 10 - 14, 2006.
[3] Damian, R.G. "Navigation algorithms for autonomous underwater vehicles (AUVs)." *AIP Conference Proceedings* 2449 (2022): 020002. Paper presented at the 10th International Scientific Conference "TechSys 2021" – Engineering, Technologies and Systems, Plovdiv, Bulgaria, May 27–29, 2021.
[4] Nutu, C. "Perspectives on Advanced and Basic Engineering Technologies." *Scientific Bulletin of Naval Academy* 1, no. 24 (2021): 83-87.
[5] Nastasescu, V., and S. Marzavan. "An overview of functionally graded material models." *Proceedings of the Romanian Academy*, Series A, no. 3 (2022): 259-267.
[6] Sotir, A., A. Balagiu, I. Datcu, A. Baciu, and E. Patroi. "A physical electric model of the human body exposed to the action of the electromagnetic environment aboard a navy ship." *Buletinul Institutului Politehnic din Iași,* Tome LVIII, Fasc. 3, Sectia Electrotehnica, Energetica, Electronica (2012): 87-96.

ISSN 1453 – 7303 “HIDRAULICA” (No. 3/2023)
Magazine of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics

Experimental Research on Efficient Pumping at High Pressure Rates

PhD. Eng. **Teodor Costinel POPESCU**[1,*], PhD. Eng. **Alexandru-Polifron CHIRIȚĂ**[1],
Res. Assist. **Ana-Maria Carla POPESCU**[1], Dipl. Eng. **Alina Iolanda POPESCU**[1]

[1] National Institute of Research & Development for Optoelectronics/INOE 2000, Subsidiary Hydraulics and Pneumatics Research Institute/IHP

* popescu.ihp@fluidas.ro

Abstract: *High-pressure pumping units consisting of low-pressure pumping units and oscillating minibooster-type pressure intensifiers are an efficient solution for generating high pressure rates in hydraulic drive systems. Such pumping units are typically used in static applications (burst tests for pipelines and tanks) and mobile applications with high loads on small strokes of hydraulic cylinders (hydraulic tools and presses). Through experimental research, carried out on a test stand that can load a high-pressure hydraulic cylinder with heavy, high-magnitude loads, the authors demonstrated the possibility of expanding the range of technical applications of these pumping units to mobile applications with high loads over the entire stroke of hydraulic cylinders. A low-pressure pumping unit - 4 kW, 1500 rpm, 0...200 bar - was used; it was successively equipped with three types of miniboosters with different gain factors (i) (i=5.0; i=6.6; and i=7.6, respectively).*

Keywords: *Low-pressure pumping units, minibooster, high-pressure pumping units, high-magnitude load hydraulic cylinders*

1. Introduction

There are known two solutions for generating high pressure in hydraulic drive systems: an expensive one, based on pumps and equipment for adjusting / controlling high-pressure hydraulic parameters, and a cheaper one, based on pumps and equipment for adjusting / controlling low-pressure hydraulic parameters, plus hydraulic pressure intensifiers. For example, Fig. 1 shows the two drive solutions for a hydraulic cylinder with a load of 700 bar.

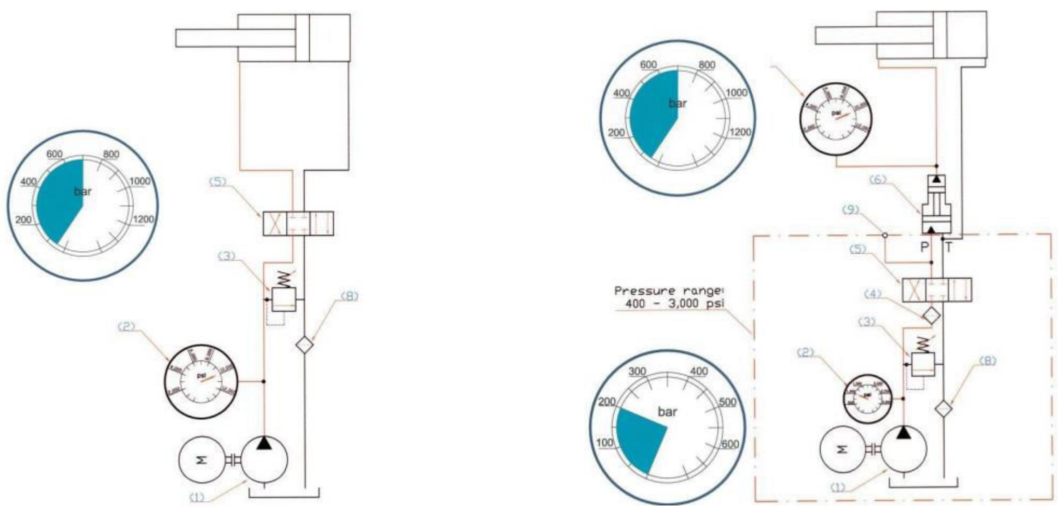


Fig. 1. Generating a pressure of 700 bar for actuating a hydraulic cylinder: left - with high-pressure pump; right - with low-pressure pump and hydraulic intensifier

In the hydraulic drive diagram [1] shown in Fig. 1-left, motor **M** drives **high-pressure pump (1)**, to direct hydraulic oil, at a pressure of 700 bar, indicated on pressure gauge (**2**), limited by valve (**3**), via directional control valve (**5**), switched to the field of parallel arrows, to the cylinder rod chamber. The cylinder piston chamber discharges into the tank via return filter (**8**), and the hydraulic cylinder moves to the right with a load of 700 bar.

One can move the same hydraulic cylinder to the right, with a load of 700 bar, according to the hydraulic drive diagram [1] shown in Fig. 1-right, where **low-pressure pump (1)**, pressure relief valve (**3**) and directional control valve (**5**) operate at 200 bar, indicated on pressure gauge (**2**). Return filter (**8**) remains, while additional low-pressure filter (**4**) and **pressure intensifier** (**6**) appear; the latter is fed via connecting fitting **P**, from the primary side, by pump (**1**), and on the outlet of the secondary side, it delivers hydraulic oil at 700 bar in the cylinder rod chamber. Due to the pulsating mode of operation of the pressure intensifier, one uses this drive diagram for **short displacements** of the hydraulic cylinders **under load,** or with the purpose of **achieving and maintaining the load at stroke end**.

2. Low-pressure pumping unit / system equipped with a minibooster; static applications

2.1 Building a low-pressure pumping unit / system equipped with miniboosters

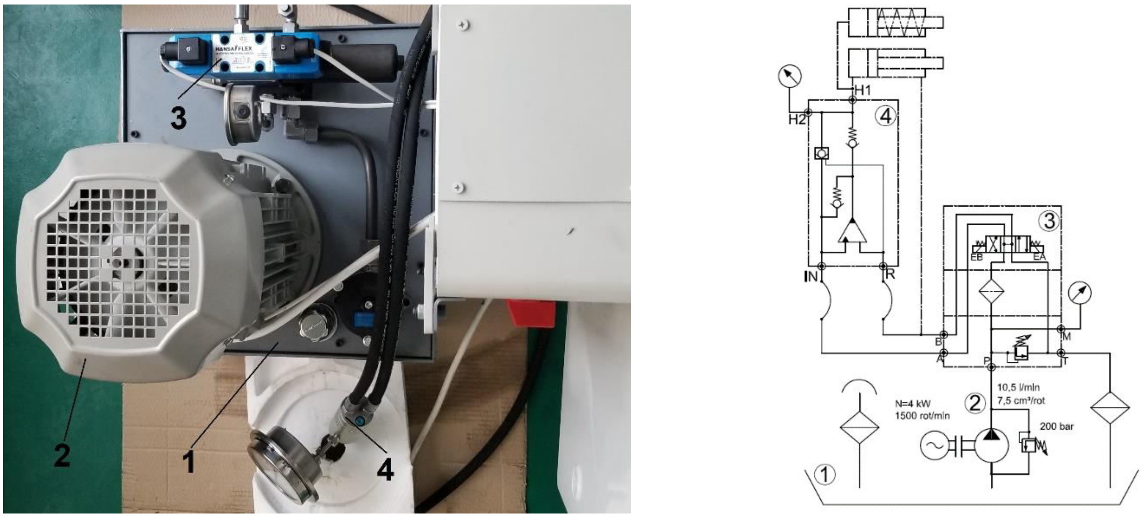


Fig. 2. Low-pressure pumping unit equipped with a minibooster: left side - physical model; right side - hydraulic schematic diagram

The authors developed the pumping unit shown in figure 2, where the notations have the following meanings: **1** – hydraulic oil tank, with return filter and fill/vent filter; **2** – low pressure electric pump, 4 kW, 1500 rpm, 200 bar, 10.5 l/min; **3** – block with hydraulic devices and pressure gauge (pressure valve, pressure filter, 4/3 hydraulic open center directional control valve, low pressure gauge); **P**, **T**, **M**, **A, B** - hydraulic block connections (pressure, tank, low pressure gauge, hydraulic test cylinder connections); **4** - minibooster (i=5, i=6.6, i= 7.6); **IN** - low pressure inlet connection (primary); **H1** - high pressure outlet connection (secondary); **H2** - high pressure gauge outlet connection (secondary); **R** - return connection.

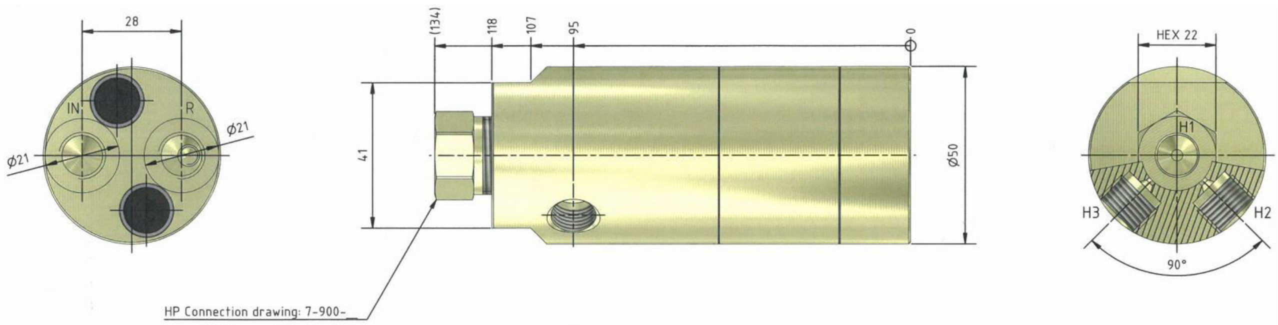


Fig. 3. Dimensions of the HC7 minibooster

The pumping unit in fig. 2 was successively equipped with three types of the HC7 minibooster [2], figure 3, which have the technical characteristics from table 1.

The maximum flow rate from the primary of the miniboosters, provided by the low-pressure pumping unit, is 10.5 l/min; this, being lower than the maximum allowed flow rate (from the manufacturer catalog) of the three miniboosters, allows the pumping unit to be equipped with any of the three minibooster variants.

Table 1: Technical characteristics of the HC7 minibooster

Gain factor i [-]	Pressure in primary / Pressure in secondary [bar]	Maximum primary flow rate [l/min]		Maximum secondary flow rate [l/min]		Primary connection dimensions		Secondary connection dimensions	
		Catalogue	Used	Catalog	Used	IN	R	H1	H2
5.0	0...200 / 0...1000	14.0	10.5	1.6	1.2	¼" BSP	¼" BSP	M22x 1.5	9/16-18UNF
6.6	0...200 / 0...1320	13.0	10.5	1.3	1.05	¼" BSP	¼" BSP	M22x 1.5	9/16-18UNF
7.6	0...200 / 0...1520	13.0	10.5	1.1	0.88	¼" BSP	¼" BSP	M22x 1.5	9/16-18UNF

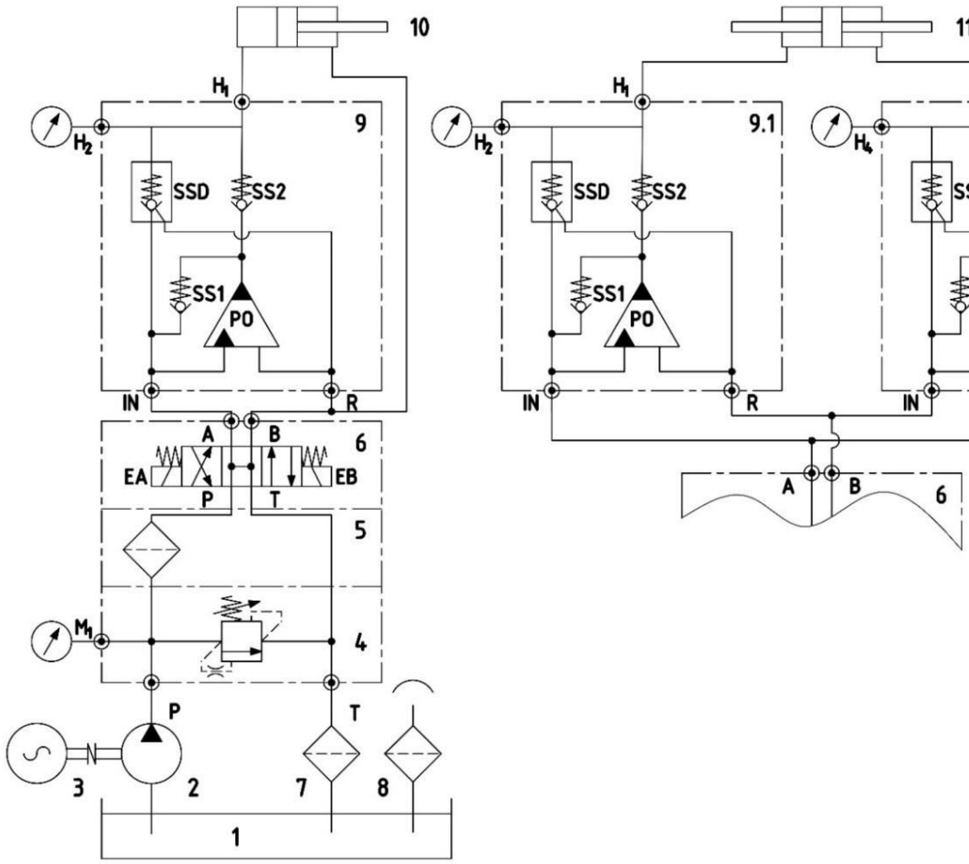


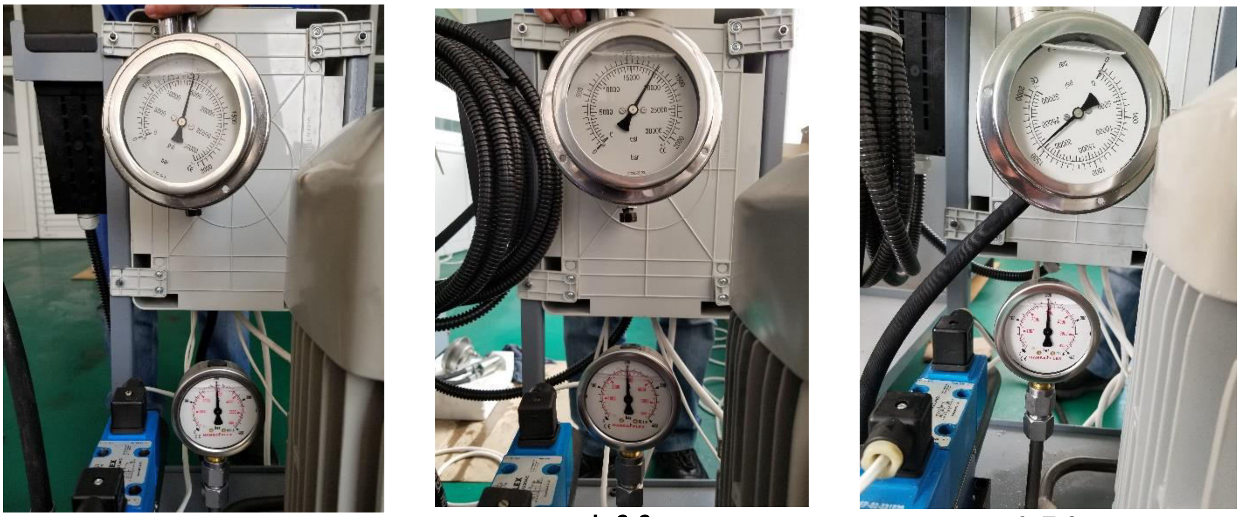
Fig. 4. High-pressure pumping system equipped with one or two miniboosters - hydraulic schematic diagram

The pumping **unit** in fig. 2 can be converted into the high-pressure pumping **system** [3] equipped with miniboosters shown in figure 4. It consists of an oil tank (**1**), from which a fixed flow rate low-pressure pump (**2**) sucks; the latter is driven by a constant speed electric motor (**3**) and discharges into the connection (**P**) of a normally closed modular pressure control valve (**4**), the pump discharge circuit passing through a modular pressure filter (**5**) and through the connection (**P**) of an 4/3 electrohydraulic open center modular directional control valve (**6**), and the connection (**T**) of the directional control valve being connected to the tank, through a hydraulic circuit that passes through the body of the modular pressure filter, the body of the modular pressure control valve, the connection (**T**) of this valve, and the return filter (**7**), located on the oil tank cover, in the vicinity of a fill and vent filter (**8**).

The system is characterized by the fact that the connections (**A**) and (**B**) of the electrohydraulic directional control valve can be connected to either the inlet and return connections (**IN**, **R**) of a minibooster (**9**), with the high-pressure connection (**H1**) coupled to the piston chamber connection of a hydraulic cylinder (**10**), which operates under heavy load only on the advance stroke, which has the rod chamber port connected to the directional control valve port (B), or to the inlet and return connections (**IN**, **R**) of two miniboosters (**9.1**) and (**9.2**), connected in series in the sequence ($IN_{9.1}$-$R_{9.2}$) and ($R_{9.1}$-$IN_{9.2}$), the high-pressure connections of these miniboosters being coupled to the connections of the volumetric chambers of the hydraulic cylinder (**11**), which operates under heavy load in both directions of displacement.

2.2 Testing a low-pressure pumping unit equipped with miniboosters; static applications

Testing of the low-pressure pumping unit, successively equipped with the miniboosters listed in table 1, was carried out, by plugging the **H1** high-pressure connection of the minibooster (fig. 2-right) and adjusting the pressure on the **IN** inlet connection of the minibooster (fig. 2-right), in the range 0...200 bar.
The proportionality between the pressures on the **IN** and **H1** connections (fig. 2-right) of the minibooster was noticed, the proportionality factor being approximately equal to the gain factor (**i**) of the minibooster.
The maximum pressure rates generated by the pumping unit, which can be read on the high pressure gauge mounted in the **H2** connection of the minibooster, are shown in figure 5.



i=5.0	**i=6.6**	**i=7.6**
p_{IN}=200 bar; p_{H2}=960 bar	p_{IN}=200 bar; p_{H2}=1290 bar	p_{IN}=200 bar; p_{H2}=1540 bar

Fig. 5. Tests on static applications of low-pressure pumping unit equipped successively with three types of miniboosters

3. Test stand for low-pressure pumping units equipped with a minibooster; dynamic applications

Among the applications of pumping units / systems equipped with miniboosters, **specific to fixed hydraulics** [4], there are: high-load bolt hydraulic pretensioners, figure 6-a; tunnel boring machines; installations on offshore oil platforms; railway maintenance equipment; life-saving equipment (extrication of car accident or earthquake victims); rock and stone splitters; hydraulic torque wrenches; hydraulic clamping systems of machine tools.
Among the applications of pumping units / systems equipped with miniboosters, **specific to mobile hydraulics** [5], comprising small cylinders with high forces, there are: heavy duty mobile stone crushers, figure 6-b; hook-lift trailers, figure 6-c; excavators and mini excavators, figure 6-d; hydraulic concrete crushing and breaking equipment used in demolitions, figure 6-e; mobile hydraulic jacks, figure 6-f; hydraulic tools mounted in aerial lifts. In most of these applications the hydraulic cylinders have heavy and variable dynamic loads.

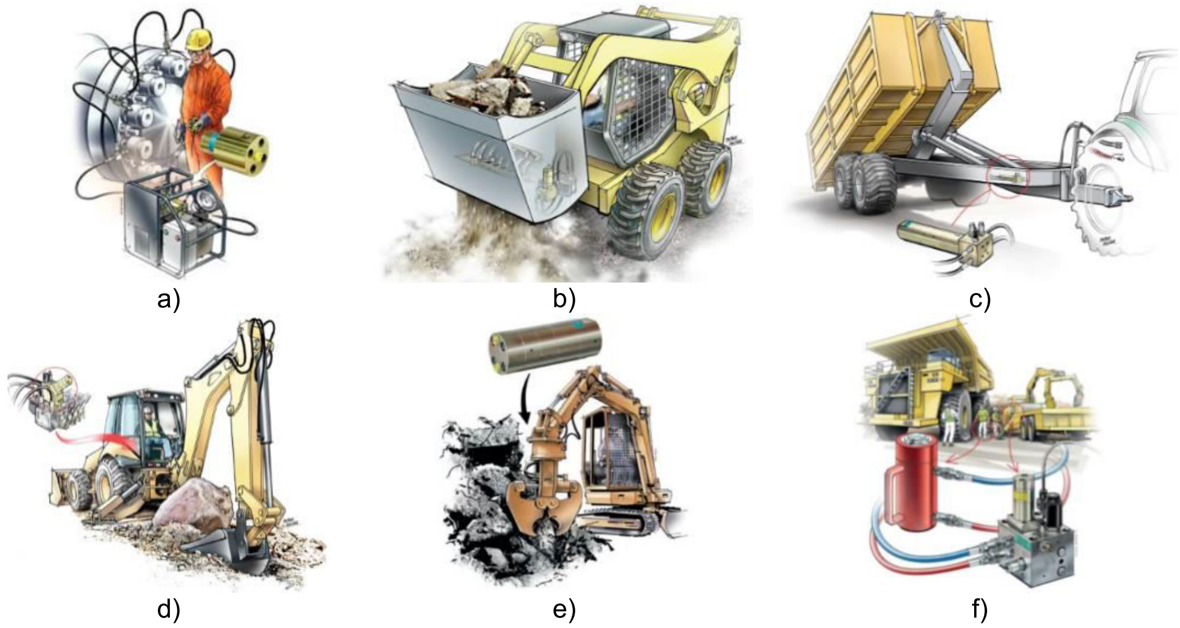


Fig. 6. Applications of pumping units / systems equipped with miniboosters

3.1 Building a stand for testing pumping units / systems equipped with miniboosters

The stand [6] in figure 7 consists of a support (**1**) for fixing two hydraulic cylinders, closed metal frame type, on which the body of a test cylinder (**2**) and the body of a load cylinder (**3**) are attached, with the rods fixed in the coupling (**C**), the *active chamber of the test cylinder* being supplied, alternatively left and right depending on the direction of displacement of the cylinder, from a tank (**4**), through the high-pressure connection (**H1**) of a minibooster (**13**), with a high-pressure pumping system comprising a low-pressure pump (**6**), driven by the electric motor (**7**), whose discharge pressure is controlled by a normally closed valve (**8**) and whose oil flow is filtered with a pressure filter (**9**); the active chamber of the test cylinder distributes oil flow by means of an 4/3 electrohydraulic open center directional control valve (**10**) which has consumers (**A**, **B**) coupled to the inlet and return connections (**IN**, **R**) of the minibooster, respectively, the consumer (**B**) being connected, alternately left and right depending on the direction of displacement of the cylinder, to the *passive chamber of the test cylinder*; the high-pressure pumping system is also provided with a return filter (**11**), and a fill and vent filter (**12**), both located on the tank cover, and the stand is also equipped with an electrical panel (**19**) for control and data acquisition, which sends the electric control signals (**EA**, **EB**) to the electrohydraulic directional control valve, (**a**)- to the pump drive electric motor, (**b**)- to the load control proportional pressure valve, and acquires the data (**c**,**d**,**e**,**f**) from the (**P1**, **P2**) pressure and (**Q1**, **Q2**) flow transducers, respectively, located on the filling / discharging circuits of the load cylinder chambers, as well as the data (**g**), from the stroke transducer embedded in the load cylinder.

This stand is characterized by the fact that, although intended for high-pressure tests for dynamic applications, hydraulic devices for pressure control, oil filtration and oil flow distribution that equip the stand are low pressure, and pressure and flow sensors are cheaper, because they are of lower pressure than the test pressure, because they are mounted on the hydraulic circuits of the load cylinder, which has larger active working surfaces in the piston chamber and rod chamber than those of the test cylinder, filling the *active chamber of the load cylinder* being done by free fall from a tank (**5**) located at height, alternatively left and right depending on the direction of displacement of the cylinder, through a check valve (**14**), or another check valve (**16**), respectively, and the *passive chamber of the test cylinder* being discharged to the same tank, alternatively left and right depending on the direction of displacement of the cylinder, through a check valve (**15**) and a proportional pressure valve (**18**) for load control, or another check valve (**17**) and the same proportional pressure valve (**18**), respectively.

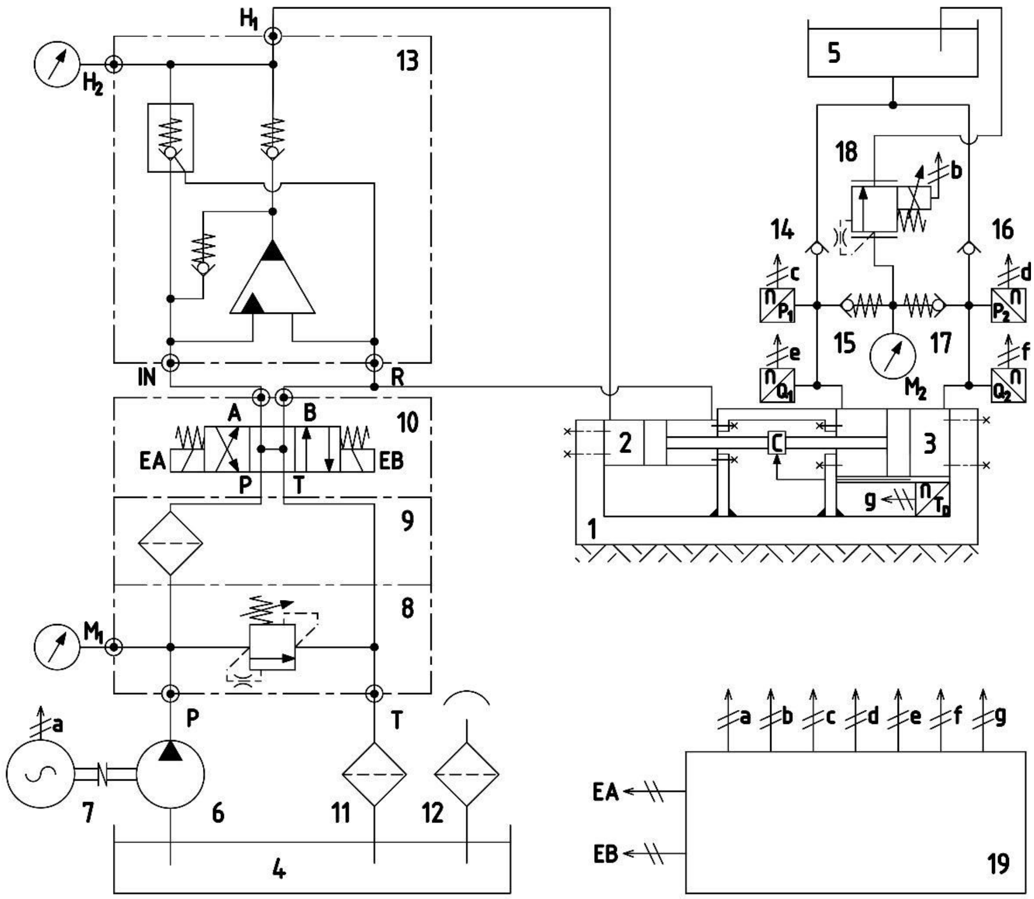


Fig. 7. Stand for testing high-pressure pumping systems equipped with a minibooster
- *hydraulic schematic diagram*

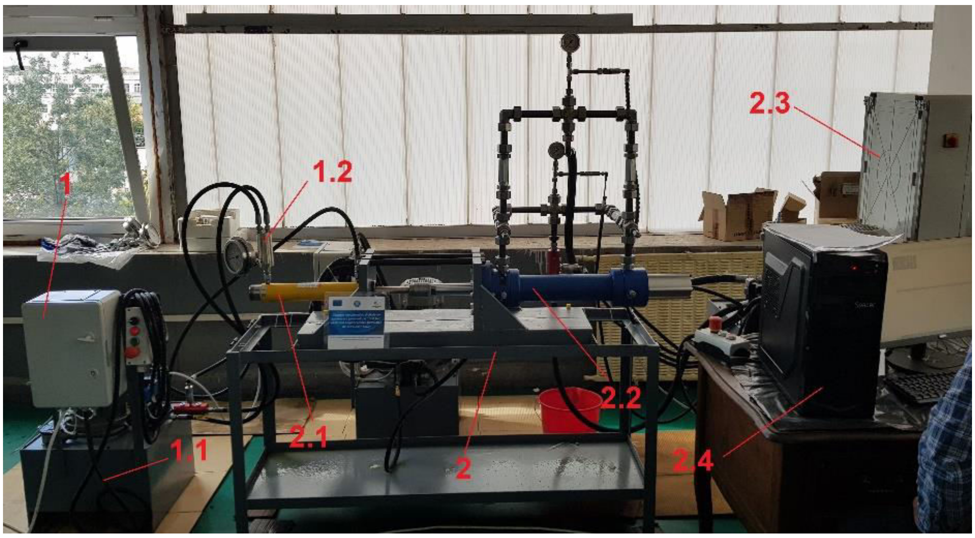


Fig. 8. Stand for testing high-pressure pumping systems equipped with a minibooster - *physical model*:
1- high-pressure pumping unit (HPPU); **1.1**- low-pressure pumping unit; **1.2**- minibooster; **2**- stand for testing the HPPU; **2.1**- test cylinder (TC); **2.2**- load cylinder (LC); **2.3**- pumping unit for feeding the LC; **2.4**- control and experimental data acquisition system

Compared to the principle hydraulic diagram in fig.7, in the physical model of the stand in fig.8 the feeding of the load cylinder is done with a pumping unit - item **2.3** (fig.8), not by free fall, from the tank at height - item **5** (fig.7).

3.2 Testing a low-pressure pumping unit equipped with miniboosters; dynamic applications

Figure 9 shows a comparison between the displacements of the test cylinder on the stand, coupled with the load cylinder equipped with a displacement transducer, under the following conditions:
- the low-pressure pumping unit, which feeds the test cylinder of the stand, is successively equipped with 3 miniboosters, with different gain factors (i=5.0; i=6.6; i=7.6);
- for the minibooster with gain factor **i=5.0:** number of data records acquired = **1050**; duration of recordings = **44.075 s**;
- for the minibooster with gain factor **i=6.6:** number of data records acquired = **1190**; duration of recordings = **55.309 s**;
- for the minibooster with gain factor **i=7.6:** number of data records acquired = **1281**; duration of recordings = **62.120 s**;
- the (test and load) cylinders on the stand make two complete strokes of ***250 mm*** for each direction of travel;
- the load cylinder creates approximately equal and constant **resistive forces** for the test cylinder (corresponding to a pressure adjusted with the proportional valve of **800 bar**) on the **advance stroke** of the latter, and **zero load** on the **retreat stroke** of the latter.

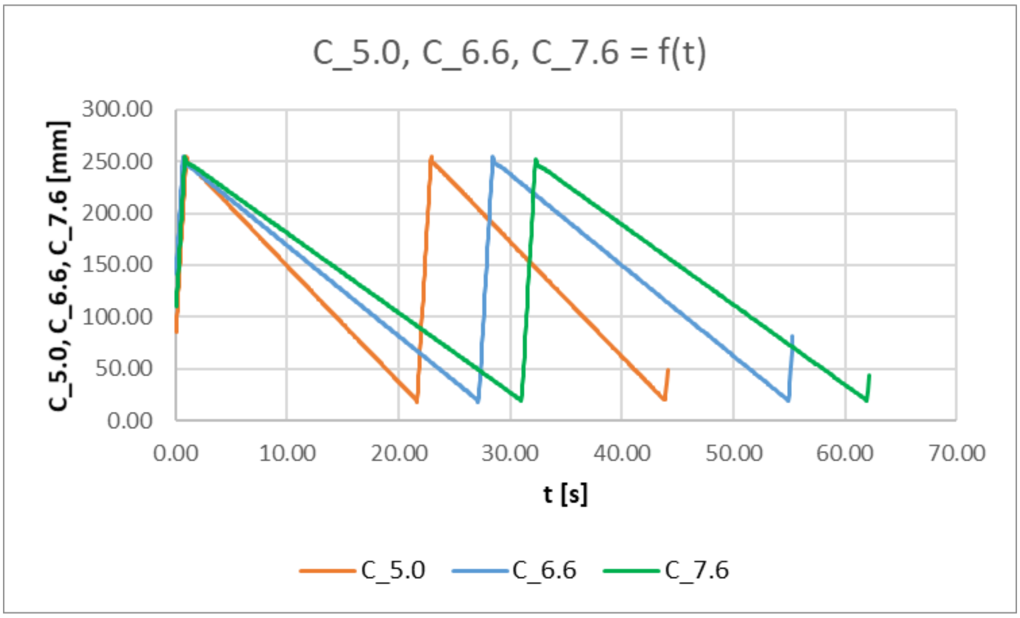


Fig. 9. Comparison between the displacements of the test cylinder, connected to the pumping unit successively equipped with three miniboosters (i=5.0, i=6.6, i=7.6)

Superimposing the results of the three tests on the graph in figure 9, **it is found that**:
- **displacement of the cylinders** on the stand is approximately linear, for the three cases of equipping the pumping unit with a minibooster;
- **forward speed rate under load** of the test cylinder (displacement slope) decreases with the increase in the gain factor of the minibooster;
- **idle** (no load) **backward speed rate** does not depend on the gain factor of the minibooster;
- **the test cylinder moves slowly**, but no restraints or stiffening, **on the advance stroke** and **fast**, **on the retract stroke**;
- **the resistive force** that the test cylinder can overcome is directly proportional to the gain factor of the minibooster.

4. Conclusions

- for **mobile applications** with **high-magnitude loads over the entire cylinder stroke**, the low-pressure pumping unit can be **equipped with any of the three miniboosters**;

- if used in applications with hydraulic cylinders that need to overcome **smaller loads**, which it has to move **faster**, the unit will be equipped with a minibooster with **i=5.0**, and for **higher loads** and **lower** displacement **speed rates**, the unit will be equipped with miniboosters with **i= 6.6** or **i=7.6;**
- if the pumping unit is used for displacement under load only on the advance stroke of a hydraulic cylinder, then the unit is equipped with a single minibooster, while if used for two-way displacement under load, the pumping unit will turn into a pumping system, which will be equipped with two miniboosters connected according to the hydraulic schematic diagram in figure 4.

Acknowledgments

This work was carried out through the Core Program within the National Research Development and Innovation Plan 2022-2027, carried out with the support of the Romanian Ministry of Research, Innovation and Digitalization (MCID), project no. PN 23 05. The research was financially supported by a project funded by MCID through Programme 1 – Development of the national research & development system, Sub-programme 1.2–Institutional performance–Projects financing the R&D&I excellence, Financial Agreement no. 18PFE/30.12.2021.

References

[1] Scanwill Fluid Power ApS. “SCANWILL FLUID POWER – UNIQUE HYDRAULIC PRESSURE INTENSIFIER SOLUTIONS.” September, 2015. Accessed August 29, 2023. https://www.luvra-hydraulik.de/fileadmin/web_data/downloads/Luvra-Hydraulik-Scanwill-0915.pdf.
[2] miniBOOSTER Hydraulics A/S. “HC7.” Accessed August 29, 2023. https://www.minibooster.com/hc7/.
[3] Popescu, Teodor Costinel, Alexandru-Polifron Chiriță, Andrei Vlad, and Constantin Teodoru. “High pressure pumping system equipped with miniboosters” / “Sistem de pompare la presiuni înalte echipat cu miniboostere”. Patent application No. A / 00251-18.05.2023.
[4] miniBOOSTER Hydraulics A/S. “Hydraulic Power Pack.” Accessed August 29, 2023. https://www.minibooster.com/hydraulic-power-pack/.
[5] miniBOOSTER Hydraulics A/S. “Mobile from miniBOOSTER Hydraulics A/S.” Accessed August 29, 2023. https://www.minibooster.com/mobile/.
[6] Popescu, Teodor Costinel, Alexandru-Polifron Chiriță, Andrei Vlad, and Constantin Teodoru. “Stand for testing high-pressure pumping systems equipped with miniboosters” / “Stand pentru testarea sistemelor de pompare la presiuni înalte echipate cu minibooster”. Patent application No. A / 00252-18.05.2023.

ISSN 1453 – 7303 "HIDRAULICA" (No. 3/2023)
Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics*

Energy Efficient Refrigeration Solutions

Eng. **Adrian MIHAI**[1], Assoc. Prof. PhD. Eng. **Adriana TOKAR**[2,*],
Assoc. Prof. PhD. Eng. **Mihai CINCA**[2], R. A. PhD. student Eng. **Daniel MUNTEAN**[2]

[1] Sildor Prod S.R.L., Romania

[2] University Politehnica Timisoara, Romania

* adriana.tokar@upt.ro

Abstract: *The current situation of Fluorinated Greenhouse Gases (F-Gas) Regulation and discussion regarding per- and polyfluoroalkyl substances (PFAS) gases problems with actual refrigerants from refrigeration installations with global warming potential (GWP) higher than 150 units will damage even more the environment. On top of the environment crises, caused by global warming and the Russia-Ukraine war, the prices of the energy increase more than 50%. So, this study shows that actual refrigerants like R404A, R448A, R449A and other refrigerants with GWP higher than 150 can be replaced for long term solution with* CO_2.

Keywords: *CO_2, GWP, climate change, environment*

1. Introduction

For the refrigeration field, refrigerants represented a revolutionary discovery, but their contribution to the destruction of the ozone layer and the retention of rising thermal radiation in the earth's atmosphere brings them back to the attention of specialists in the field of environmental protection.
So, in the current context of climate change and in accordance with the new Fluorinated Greenhouse Gases (F-Gas) Regulation that comes to accelerate the reduction of greenhouse gas emissions and to lower the Global Warming Potential (GWP) level from 2,500 units to 150 units starting from January 2024 in new installations, the refrigeration equipment industry must adapt to the new provisions [1].
The impact of the Montreal Protocol, finalized in 1987, which is a global agreement to protect the stratospheric ozone layer by phasing out the production and consumption of ozone-depleting substances (ODS) such as refrigerants, is shown in Fig. 1 [2].

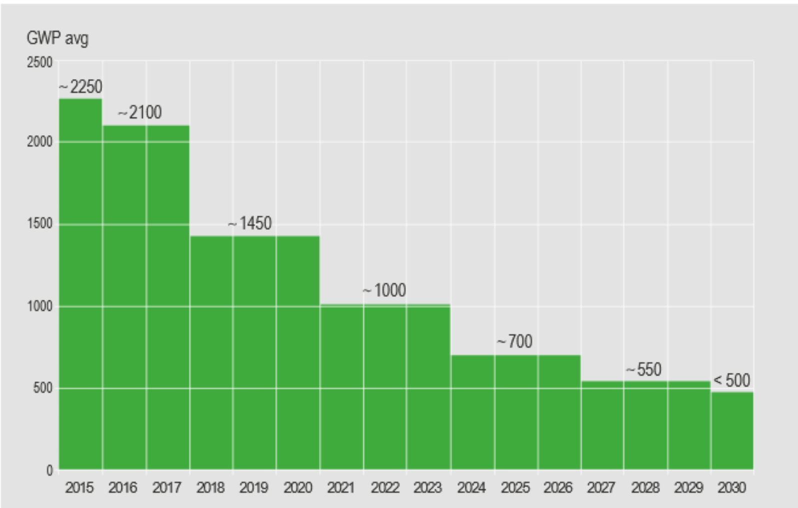


Fig. 1. Average of Global Warming Potential (GWP) [2]

In Fig. 1, the stages of reducing the refrigerant quota were considered as follows:
- 2015 – represents the reference year: 100%;
- 2016-2017 first reduction, to 93%;

- 2018-2020 second reduction, to 63%;
- 2021-2023 third reduction, to 45%;
- 2024-2026 fourth reduction, to 31%;
- 2027-2029 fifth reduction, to 24%;
- 2030 - reduction to 21%.

Also, the cost of electricity has grown considerably, comparatively with the year 2018 (Banat Enel Energie - 0.4785 lei/kWh in 2018, for consumption over 300 kWh, price 1.09 lei/kWh in 2023). In this context, refrigerants with a GWP greater than 150 units will be gradually replaced with those which are under this limit, but all of them are mildly flammable, as one can see in Fig. 2 [3].

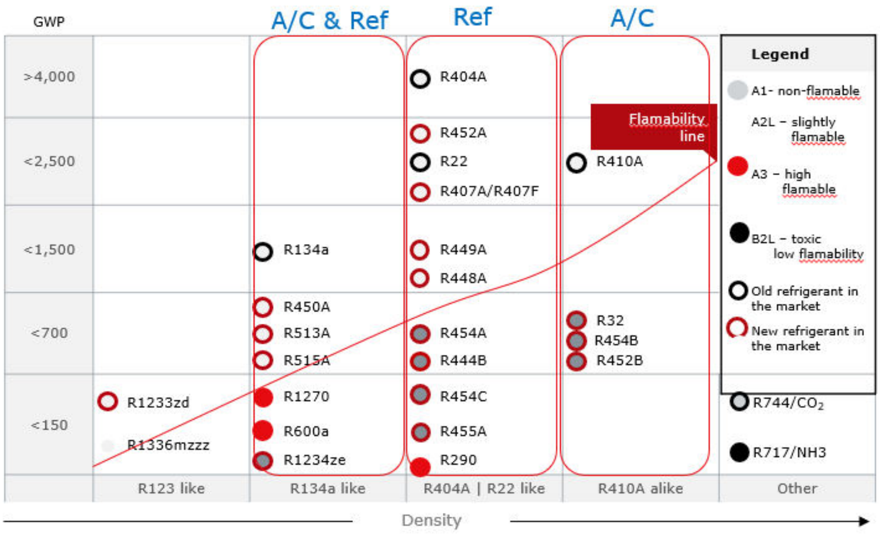


Fig. 2. Refrigerants - Present and future [3]

2. Case study

The study is made for a comparation between one installation with R404A and the new one with CO_2.

Initial conditions:

The space is the small proximity store as is shown in the Fig. 3 and was equipped with:

- vertical refrigerated display cases, 2,700mm x 3 pieces;
- 2 cold rooms, 10 m³ / room.

Fig. 3. Initial store
1 - Condensing unit, 2 - Discharge pipe, 3 - Suction pipe, 4 - Vegetable/fruit room, 4.1 - Separation valves, 4.2 - Solenoid valve, 4.3 – Evaporator, 4.4 - Control panel, 5 - Meat/sausage room, 5.1 - Isolation valves, 5.2 - Solenoid valve, 5.3 – Evaporator, 5.4 - Control panel, 6 - Refrigerated showcase, 7 - Refrigerated showcase, 8 - Refrigerated showcase

These cold consumers are driven by one condensing unit with scroll digital technology model ZXDE-050E-TFD (Fig. 4), which works with refrigerant R404A having an evaporation temperature of -10ºC and GWP = 3,922.

Fig. 4. Data sheet ZXDE-050E-TFD [3]

The performances of the ZXDE-050E-TFD unit at the point of operation are shown in Table 1, and the mechanical and physical characteristics in Table 2 [4].

Table 1: Performance at specified operating point ZXDE-050E-TFD data al 50 Hz [4]

Characteristics	Notation	Unit	Value
Cooling Capacity	Q_C	kW	7.79
Total Power Input	P	kW	4.30
Performance coefficient	COP	W/W	1.81
Current at 400 V	I	A	7.45
Mass Flow	q	g/s	78.10
Heating Capacity	Q_H	kW	11.65
Condensing Temperature	T_c	ºC	46.00
Subcooling	T_{SC}	K	0.00

Table 2: The characteristics and sound conditions for condensing unit Type ZXDE-050E-TFD [4]

Characteristics	Unit	Value
Mechanical and physical		
Condenser/Fan/Type	-	ZXM_2F/60 W
Base mounting (hole dia.)	mm	580 x 388 (12)
Number of fans	pcs	2
Air Flow	m^3/s	1.64
Total Fan Power Input	W	246
Height	mm	1,244
Depth / Width	mm	1,035/447
Suction Diameter	inch	7/8
Liquid Line	inch	½
Suction Type		Cu Type
High Side PS gauge	bar	21
Net Weight	kg	108
Sound		
Mean temperature for refrigeration applications (MT)	°C	-10-0
Sound Pressure at 10 m (MT)	dBA	41
The temperature conditions (Evap./Cond./Suction at freq./speed) for which the noise level of 41 dBA was obtained	°C	-10.0/45.0/20.0 at 50 Hz

After the remodeling the store, the upgraded space is shown in Fig. 5:

- 3 vertical 3750 mm refrigerated showcases, on CO_2;
- 2 cold rooms with CO_2 evaporators, 15 m³/room.

Fig. 5. Updated store
1 - Condensing unit, 2 - Discharge pipe, 3 - Suction pipe, 4 - Vegetable/fruit room, 4.1 - Separation valves, 4.2 - Solenoid valve, 4.3 – Evaporator, 4.4 - Control panel, 5 - Meat/sausage room, 5.1 - Isolation valves, 5.2 -Solenoid valve, 5.3 – Evaporator, 5.4 - Control panel, 6 - Refrigerated showcase, 7 - Refrigerated showcase, 8 - Refrigerated showcase

The new refrigerating installation related to these cold consumers is one condensing unit with scroll inverter model technology OP-UPAC015COP04E (Fig. 6), at 5,263 rpm having a refrigerating power of 16 kW, and an hourly electricity consumption of 9.95 kW; at the evaporation temperature of -10°C, resulting in a COP=1.61 OP-UPAC015COP04E at 2,834 rpm having a refrigeration power of 8 kW, and an hourly electricity consumption of 5.43 kW; at the evaporation temperature of -10°C, resulting in a COP=1.47. The refrigerant CO_2 has GWP =1. The operating conditions for type OP-MPAM005COP04G are presented in Table 3 and selection result - in Table 4 [5].

Fig. 6. Danfoss Optyma iCO_2 P04, OP-UPAC015COP04E [5]

Table 3: Condensing unit CO_2 [5]

Characteristics	Unit	Value/Type
Operating conditions		
Refrigerant	-	R744
Evaporating dew point temperature	°C	-10
Evaporating pressure	bar	26.49
Useful superheat	K	10.0
Additional superheat	K	0
Return gas temperature	°C	0.0
Ambient temperature	°C	37.0
Subcooling	k	0
Additional subcooling	K	0
Altitude	m	38.4

Table 4: Selection result [5]

Characteristics	Unit	Value/Type
Selection : OP-UPAC015COP04E,R744-5266 rpm		
Model	-	OP-UPAC015COP04E
Code number	-	114X6003
Compressor model	-	VCO015T4E
Product range	-	Optyma™iCO2
Product version	-	P04
Refrigerant	-	R744
Cooling	kW	16.00
COP cooling	W/W	1.61
Total power	kW	9.953
Frequency	Hz	
Power supply	-	-

3. Comparative analysis

The economic evaluation of the investment, as presented in Fig. 7.a, is observed to be obviously against CO_2. This shows once again that CO_2 technology is more expensive compared to the technology related to R404A components.
When we talk about the operating cost, according to the design conditions in the most unfavorable operating point considered, we notice that the differences are no longer so high compared to that of the investment in equipment. The operating cost of the CO_2 installation becomes comparable to that of the R404A installation (Fig. 7.b).
For evaluation of investment cost, exploitation, and GWP, we take into account the graphs below that show the comparative cost of initial investments (Fig. 7.a), the cost of one year of operation (Fig. 7.b), and in Fig. 7.c, we can see a significant reduction of the GWP (Global Warming Potential) index, which proves that CO_2 has a minimal impact on the environment compared to R404A.

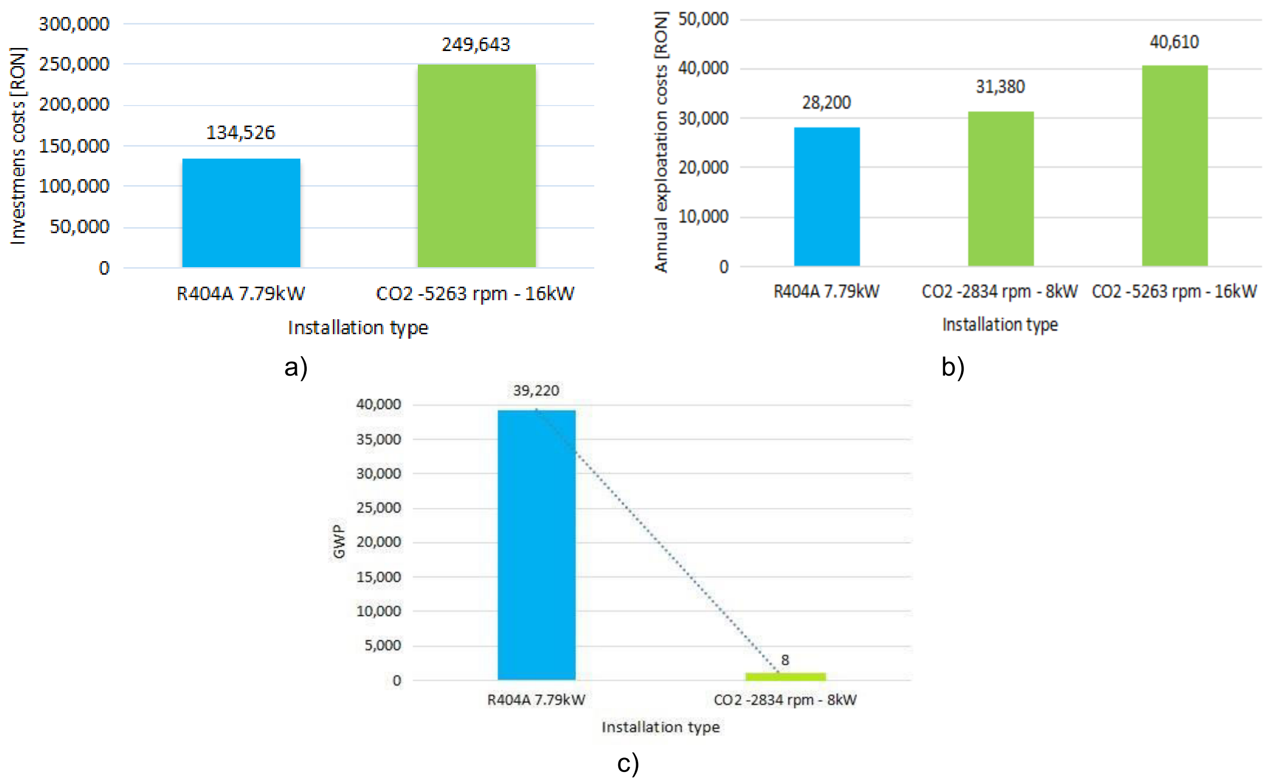


Fig. 7. The investment and exploitation costs (in RON), and the GWP, respectively
a) Investments costs; b) Operating costs; c) GWP

In figure 7.b, one can see that when we compare the two technologies (R404 with CO_2), at the same refrigeration capacity, the operating cost is similar. This comparison is possible because the inverter technology in the unit that works with CO_2 allows the regulation of the refrigeration capacity due to changing the speed of the electric motor. At a speed of 2,834 rpm for CO_2 technology, we get the same refrigeration capacity, but with an additional annual operating cost of 3,180 RON. For doubling the cooling capacity, for CO_2 technology, it is noticed that increasing the speed to 5,263 rpm is much more advantageous compared to using two equipment items to obtain the same cooling capacity. This is highlighted in Fig. 7.b. Thus, using two units at 2,834 rpm for CO_2 technology (similar to units using R404) an operating cost of 62,760 RON (for CO_2) and 56,400 RON (for R404) is recorded, while using only one unit with CO_2 technology, at a speed of 5,263 rpm, an operating cost of 40,610 RON for CO_2 is recorded. Therefore, from a technical-economic point of view, the economy of 22,150 RON for CO_2 technology and 15,790 RON for R404 is an asset for CO_2 technology used at optimal speed. On the other hand, no matter how we look at things, from the point of view of environmental impact, CO_2 technology compared to the usual refrigerants (R404A, R448A, R449A) is more ecological. The CO_2 technology is clearly superior in terms of GWP compared to the R404A refrigerant (Fig. 7.c), which is why it is worth using even if the investment cost is higher.

4. Conclusions

The efficiency of technical solutions has a new challenge raised by environment protection. Due to the high energy prices, it is important to combine several technologies in the same technical solution such as: frequency converter, digital scroll technology, more efficient and less polluting refrigerants such as CO_2, propane or ammonia, the use of primary refrigerant and secondary refrigerant, the use of very efficient EC (Electronically Commutated) fan motors. Installations in operation that have exceeded their useful life can now be replaced with new generation refrigerant installations with almost zero impact on global warming.
Analyzing the working pressures, the current installations with R404A refrigerant have condensing pressures between 15 and 25 bar, and the CO_2 installation has a pressure in the gas cooler of almost 90 bar. These high pressures require more attention when they will be designed, installed, and serviced by personnel qualified to work with CO_2.
Analyzing from the point of view of investment and exploitation costs, it can be noticed that CO_2 becomes more and more efficient with the increase in the refrigeration capacity. From the point of view of reducing greenhouse gases, CO_2 is the solution for the present and possibly for the future. CO_2 may be the natural choice to avoid F-Gas limitations forever, but design, installation and management require vast knowledge and qualification.

References

[1] Kreider, Jan. *Handbook of Heating, Ventilation and Air Conditioning.* London, CRC Press LLC Publishing House, 2001.
[2] Bitzer Kühlmaschinenbau GmbH. ”EU F-Gases Regulation No. 517/2014 Consequences for the refrigeration, air conditioning and heat pump industry”, August 7, 2018. Accessed July 21, 2023. https://cold.world/know-how/eu-f-gases-regulation.
[3] OmniRef Ltd. “Danfoss solutions for commercial refrigeration approved for use with alternate refrigerants R448A, R449A and R452A”, July 2, 2018. Accessed July 21, 2023. http://www.omniref.gr/blog.php?title=Danfoss+solutions+for+commercial+refrigeration+approved+for+use+with+alternate+refrigerants+R448A%2C+R449A+and+R452A&article=1&lang=en.
[4] Copeland Europe GmbH. ”ZXME-050E-TFD-304 - Specifications”. Accessed July 21, 2023. https://www.copeland.com/en-gb/shop/1/copeland-eu-sku-3206669-en-gb.
[5] Danfoss A/S. ”Danfoss Climate solutions for cooling”. Accessed July 21, 2023. https://www.danfoss.com/en/about-danfoss/our-businesses/cooling/.

Specific Characteristics of Lubricating Fluids for Optimizing Industrial Technological Systems with Electrohydraulic Actuation

PhD. Chem. **Adriana Mariana BORȘ[1],** Dipl. Eng. **Liliana DUMITRESCU[1,*],**
MSc. Eng. **Ștefan-Mihai ȘEFU[1]**

[1] National Institute of Research & Development for Optoelectronics / INOE 2000 – Subsidiary Hydraulics and Pneumatics Research Institute / IHP, Bucharest, Romania

* lilianad.ihp@fluidas.ro

Abstract: *The lubrication process carried out by hydraulic fluids represents one of the important aspects of simple or complex industrial technological systems. The identification of hydraulic oils and the operating conditions of the component elements led to the systemic approach to the lubrication process in order to achieve an efficient productivity, to permanently keep control over the equipment used and the processes performed, but also to ensure the best conditions of development of electrohydraulic systems. There are intense concerns about reducing wear and tear, reducing maintenance costs and extending service life between repairs of machine tools and hydraulic equipment, as well as some environmental protection issues. Thus, the choice and appropriate use of lubricating fluids, the optimization of industrial electrohydraulic systems, the approach of solutions related to the quality and characteristics of the chosen lubricant, but also to the maintenance of fluid-based functional systems, are required. The hydraulic machine performance is closely related to the oil film quality, which ensures a quick and precise response of the electrohydraulic system, maintains good protection against corrosion and optimal operation of the hydraulic components.*

Keywords: *Fluids, lubrication, corrosion, electrohydraulic system, industrial machine tools*

1. Introduction

The requirements regarding the performance parameters of the drive equipment are in a continuous competition, which led to the improvement of each of these technologies and towards the maximization of these performances. The informational explosion, the rapid pace of development and accumulation of a huge volume of knowledge makes it increasingly difficult to follow, assimilate and use these informational flows. In this context, informatics represents the current technique of recording, storing, processing and transmitting information that has become indispensable to any field of activity and especially in the field of equipment and industrial CNC machine tools. This line also registers the field of hydraulic drives in order to make full use of modern analysis and synthesis techniques, to design equipment structures with constructive-functional parameters and predetermined performances. It is also aimed at streamlining the choice of implementing and using hydraulic actuation equipment in the most diverse fields of current technique and technology, and especially in the field of numerical controls (industrial robots, industrial CNC machine tools, etc.) [1]. The progress performed in various industrial fields has further highlighted the remarkable qualities of electrohydraulic actuation systems. They cover a wide range of applications, from machine tools with numerical controls to industrial robots controlled by microprocessors, capable of the most complicated and fine maneuvers. The expansion and diversification of electrohydraulic actuation equipment takes place in proportion to the increase in technical performance and their quality. The reliability of these electrohydraulic actuation equipment is one of the basic qualitative indicators, which is required to evolve simultaneously with the increase in working pressures. Research in the field has shown that one of the weak elements of a hydraulic circuit can become the hydraulic environment due to the transformations produced on the fluids used during the executed processes, which represents a significant percentage of hydraulic system failures [2]. Another element that can cause malfunctions in operation are the seals. These faults appear when the maintenance schedule is not respected. The increase in reliability and life span is conditioned by raising the precision of the execution of the components, the use of materials with superior characteristics, appropriate heat treatment methods, the hydrostatic discharge of the friction couplings, as well as the use of suitable lubricating liquids with the maintenance over time of optimal characteristics [3]. Fluids transmit energy in hydraulic actuation systems, so energy circuits can cyclically suffer significant variations in pressure, speed and temperature. They come into contact with different materials and can be exposed to the electromagnetic field, nuclear radiation, etc. [4]. The difficult conditions of use impose the following requirements on the functional fluids: lubricating qualities, good viscosity in any operating conditions of the system, stable physical and chemical properties, compatibility with the system materials, compressibility, volatility, foaming tendency, density, coefficient of thermal expansion, price and low toxicity, as well as antioxidant and dielectric qualities, easy storage and handling.

2. Industrial machinery with electrohydraulic actuation

Hydraulic actuation is still current and preferred in the field of high powers and sometimes becomes irreplaceable in the case of heavy industrial machinery (machine tools - CNC), characterized by large dimensions and own weights, large working space, large manipulated loads, difficult working environment. The advantages of using these CNC industrial devices mainly consist in the automation of manufacturing processes, improvement of the finished products quality, increase in productivity, handling of heavy weights, multi-functionality, flexible programming, adaptability, avoidance of toxic environments, harmful atmosphere and noise. The electrohydraulic actuation consists of a set of technical functions through which the relative movement of some process elements is achieved. The non-mechanical energy source of the actuation system is hydraulic type. The choice of the actuation system is made taking into account a series of factors such as: operating conditions, handling capacity, workspace, temperature and degree of pollution of the working environment, positioning precision, control and management possibilities, etc. Each actuation system must be dynamically sized to support and drive all structural elements, including the object to be handled or the work device, in motion. The main advantages of hydraulic actuation are:

- the working agent, hydraulic oil at high pressures, up to 700 bar [5], develops forces, respectively high torques at small dimensions of hydraulic motors, being a good energy index;
- the reduced compressibility of the hydraulic agent; it provides the necessary rigidity to the drive system, and the strokes size can also be determined by the phase shift of the oil volume;
- reduced wear of moving elements, because the hydraulic agent is a good lubricant, which contributes to improving the reliability index;
- use in humid, irradiated environments, with high intensity magnetic fields without danger of accidents;
- the possibility of obtaining variable speeds of the execution element, stops at fixed points with high precision;
- technological developments in various fields, especially in the fields: space, military, and medical;
- the provision of new techniques, principles and control devices such as servo valves and proportional directional control valves, which are key elements in the field of precision hydraulic drives.

There are a number of disadvantages of electrohydraulic drive systems such as:

- lower global yield than in the case of electric drives;
- the need for additive hydraulic fluids with special characteristics, which increases the complexity and raises the cost of the actuation;
- requires specific seals for high pressures, qualified personnel for maintenance and repairs;
- the need for cooling installations for the actuation system.

Electrohydraulic systems combine the special qualities of electrical and electronic systems in terms of automatic controls with the remarkable advantages of hydraulic systems, under the transmission aspect of large energies. The association led to the realization of electrohydraulic systems of automatic tracking and in general automatic regulation, with superior performances. The expansion of electrohydraulic actuation and control systems has led to remarkable successes regarding the realization of servo systems, some complex interface elements, as well as the manufacture of proportional equipment with a wide application in the control and actuation of industrial CNC machine tools. The appearance of these servo systems allowed the development of hydraulic

systems applicable in situations where the repeatability of cycles is required, the programming of forces, displacements and speeds, the provision of different functions for switching from one speed level to another and a great flexibility in programming. This type of equipment ensures the ordered electrohydraulic actuation that meets the requirements imposed on industrial devices in terms of positioning precision, reliability, speed control range, etc. Starting from this type of electrohydraulic actuation control system, two types of actuation systems used by various industrial equipment have been developed, namely:
- electrohydraulic actuation, analog servo control (hydraulic tracking systems);
- digitally servo-controlled electrohydraulic actuation (with numerical control).

The electrohydraulic actuation remains a basic solution in the case of heavy machinery, for which the other modes of actuation do not meet the requirements due to the large size and high energy consumption. Although the solutions seem more complicated, electrohydraulic actuation systems are cheaper than electric ones at the same installed power, because with low power servo elements hydraulic powers hundreds of times higher can be commanded. The electrohydraulic actuation has taken full advantage of the remarkable advances in electronics and microelectronics and through an intelligent technological tandem it was possible to achieve high-performance mixed electrohydraulic equipment. The control and regulation equipment achieves at the output a flow rate proportional to the size of the input electrical signal, through throttling (reducing the flow section).

3. Specific characteristics of hydraulic fluids used for machine tools and industrial equipment

Currently there is a wide range of functional fluids, chemically belonging to several classes, but none of them present all the qualities required for a given transmission. As a result, the choice of hydraulic fluid is generally a compromise that ensures the satisfaction of the essential requirements, but imposes restrictions on the structure of the system and the conditions of use.

The main necessary elements with a role in choosing a lubricating fluid are:
- the range of temperatures for use and storage, normal and accidental;
- the range of pressures to which the liquid is subjected in normal and accidental mode;
- the requirements of certain materials or components of the system;
- safety requirements;
- economic conditions.

If several liquids comparably satisfy these requirements, the final choice is determined by the fulfillment of the other criteria. The liquids used in electrohydraulic systems are practically incompressible fluids, they do not have their own shape, they are perfectly elastic to the compression effort. Liquids in small quantities take the spherical shape and in large quantities take the shape of the container, presenting a free surface. Lubricating fluids must have parameters that ensure the maximum requirements of the technology. Modern trends in the development of electrohydraulic systems aim at the following aspects:
- increase in working pressure and temperature;
- increase in power in relation to the mass of the hydraulic fluid;
- reduction of the working space of the system elements;
- increase in the operating period of the lubricant.

Lubricating fluids must fulfill the following characteristics:
- thermooxidative stability - resistance to oxidation reactions that occur at high temperatures;
- filterability - the ability to extract possible chemical impurities from the liquid with a filter;
- anti-wear properties – the hydraulic oil must protect the actuation device of the machine tool;
- hydrolytic stability - protection of equipment elements against corrosion and chemical attack;
- anti-foam properties – the fluid must not foam under various operating conditions.

Fluids used in electrohydraulic actuation systems cyclically undergo significant variations in pressure, velocity and temperature.

The difficult conditions of use impose certain specific requirements on these fluids:
• good lubrication properties;
• optimal viscosity throughout the range of temperatures used;

• stability over time of physical and chemical properties;
• high mechanical resistance of the film;
• high flash point;
• compatibility with the materials of the hydraulic system, especially with the sealing elements;
• reduced compressibility and foaming tendency.

Table 1[1]: Presentation of the most important performance classes for hydraulic oils

FLUID CODE	MINERAL BASED HYDRAULIC OILS
HLP DIN 51 524 T.2	Mineral oils with antioxidant and anticorrosive additives, with extreme pressure properties
HVLP DIN 51 524 T.3	HLP oils, superior quality, with high viscosity indices (IV>150) and multifunctional characteristics
HLP-D HLP	Detergent oils, with additional absorption properties of water and keeping the hydraulic circuit clean
HVLP-D HLP-D	Oils with a high viscosity index (IV>150), detergents, with additional water absorption properties and keeping the hydraulic circuit clean
FLUID CODE	HYDRAULIC OILS WITH FAST BIODEGRADABILITY
HEES VDMA (Hydraulic oil Environment Ester Synthetic)	fluids with rapid biodegradability, based on synthetic esters, with high performance properties
HEPG (Hydraulic oil Environment Polyglycole)	fluids with rapid biodegradability, based on polyglycols, for special uses (must not be mixed with other hydraulic fluids)
HETG (Hydraulic oil Environment Triglyceride)	rapidly biodegradable fluids based on vegetable oils with reduced (limited) performance properties

The density changes as a function of pressure and temperature; if the change of density with pressure can be considered negligible, the change of density as a function of temperature takes into account the volume coefficient of thermal expansion. The change in the volume of fluids depends on the increase in pressure, so if the force acting on the liquid is removed, it returns to its original volume without suffering residual deformations, therefore fluids can be characterized by means of the modulus of elasticity (ε). This parameter increases linearly with pressure. For most oils used in hydraulic drive systems, ε = 17000-18000 daN/cm^2 [6]. Due to the high values of the modulus of elasticity for liquids, it can be considered that at pressures up to 2x104 kPa the fluids used in hydraulic systems are incompressible. The situation changes dramatically when undissolved air is found in the liquid mass, in which case the modulus of elasticity decreases greatly, with negative influences on the operation of the system. Viscosity is also an important parameter that determines the fluidity of the hydraulic oil and characterizes the sliding resistance of the liquid layers. The amount of viscosity varies significantly with temperature, which affects the lubrication capacity of the drive system elements. The viscosity of hydraulic fluids gives the ability to optimize, by developing tangential efforts. Many hydraulic oils, especially synthetic ones, contain additives with high molecular weights, due to which they have a non-Newtonian character, so their viscosity decreases with the increase of their deformation speed. The addition of additives changes the properties of the oil, so it makes it possible for these fluids not to liquefy at higher temperatures or to crystallize at low operating temperatures. The optimum viscosity value for each mechanism is its own, the permissible viscosity index is assigned by the unit manufacturer. Viscosity is an essential characteristic of hydraulic fluids because it provides lift to the bearings, limits liquid losses through the sealing elements and generates forces that dampen the oscillations of the functional parameters. The viscosity of fluids increases with pressure.
At high temperatures, the internal leaks of bulky machine tools with electrohydraulic actuation and distribution elements alter the efficiency of transmissions. At the same time, the decrease in the

[1] www.lubricants.ro

lubrication capacity of the film in the hydraulic contact areas can cause malfunctions at the level of the mechanism [7].
The excessive viscosity that occurs at low temperatures generates high pressure losses that create suction difficulties for pumps (cavitation), reduce engine speed and transmission efficiency.
These phenomena explain the major interest in fluids whose viscosity varies little with temperature. Several "viscosity indices" have been proposed to evaluate this quality. The influence of temperature must be taken into account, because the transport of energy between the pump and the motor takes place with irreversible losses, accompanied by the release of heat that changes the temperature of the oil/fluid. According to performance characteristics, hydraulic fluids are divided into several groups:
1 - oils without additives, applicable in lightly loaded hydraulic systems;
2 - additive oils to prevent oxidation and corrosion reactions, designed for medium load hydraulic systems;
3 - fluids that inhibit oxidation reactions, reduce corrosion processes, prevent mechanism wear, operating at temperatures above 90 ^{o}C.

4. Interactions between the structural elements of the tribological system

The strains that appear on the structure of the hydraulic system from a tribological point of view are contact processes and relative movements between the structural elements due to the dynamic action of friction and wear, of a physical and chemical nature, but also processes in the intense areas of contact, which lead to energy and efficiency losses. The set of strains is imposed by the physico-chemical parameters that affect the structure of the system, but also by techniques that ensure its operation. The most important characteristics of these strains can be determined by variable elements such as: type of movement, cycle of movement, loads, temperature, contact time, nature of the fluid used. The wear process is influenced by the parameters that depend on:
- construction: dimensions, shape;
- operation: energy, environment, lubrication.
Appreciation amounts of wear and tear depend on:
- constructive and operating parameters;
- the level of noise or vibrations produced as a result of the increase in the clearance between the elements (bearing),
- speed, applied or transmitted load, received or developed energy;
- parameters related to the material (technological and temperature);
- operating parameters (magnitude of the load, characteristics of the lubricating fluid and of the working environment, type of contact) etc.
The wear process can be influenced/accelerated by fluid mass action, fluid pressure, travel speed and temperature. For optimal results from the technological and economic point of view, mechano-hydraulic processes must form a unitary functional system of the following components: operating equipment, operating environment, process parameter settings, type of fluid used.
Fluids used by hydraulic systems must demonstrate a series of characteristics that allow them to satisfy a wide variety of requirements depending on the operation for which they are used. There is a wide variety of uses of the machine tools depending on the special requirements of the various activities undertaken. During the use of electrohydraulic actuation systems, fluids can change their characteristics as a result of changes in some of their physico-chemical parameters. These changes also occur as a result of the environment of use, foreign bodies and the mechanisms involved. In order to optimize the fluids used and expand the possibilities of operating the machines, additives are added that change both the physical and chemical characteristics of the base fluids. The categories of added substances are: anti-wear additives that favor the formation of a lubricating film, high-pressure additives, anti-foaming agents, anti-corrosive agents, etc.
The entire technological flow is directly or indirectly influenced by the characteristics and composition of the fluids used, as such aspects can be established regarding:
- the effectiveness of the process (minimum wear and tear);
- productivity (adequate operating time);
- process safety (type of activity).

5. Conclusions

Irregular operation, oxidation, contamination with water or foreign particles, leaky gaskets, lead to degradation and shortening of the service life of the hydraulic oil.
Tribological assessment criteria can establish methods for optimizing the selection of lubricating fluids in relation to the nature of the execution process and can provide methods for estimating its degree of wear.
Through the tribological study at the level of the industrial technological system with electrohydraulic actuation, relevant data can be provided for the formulation of lubricating fluids, for the estimation of functional stability and for the assessment of the life span of the oil and industrial equipment.

Acknowledgments

This work was carried out through the Core Program within the National Research Development and Innovation Plan 2022-2027, carried out with the support of the Romanian Ministry of Research, Innovation and Digitalization (MCID), project no. PN 23 05. The research was financially supported by a project funded by MCID through Programme 1 – Development of the national research & development system, Sub-programme 1.2–Institutional performance–Projects financing the R&D&I excellence, Financial Agreement no. 18PFE/30.12.2021.

References

[1] Pădurean, Ioan. *Fluid mechanics and hydraulic machines. Theoretical foundations and applications / Mecanica fluidelor si masini hidraulice. Fundamente teoretice și aplicații*. Timisoara, Eurostampa Publishing House, 2001.
[2] Marian, Lazăr, and Radu Indolean. *Hydraulics and hydraulic machines*. Vol. 3 *Laboratory works* / *Hidraulică și mașini hidraulice*. Vol. 3 *Lucrări de laborator*. Cluj-Napoca, 1995.
[3] Constantinescu, V.N. *Dynamics of viscous fluids. The stability of laminar movements / Dinamica fluidelor vâscoase. Stabilitatea mișcărilor laminare*. Bucharest, Publishing House of the Romanian Academy, 1993.
[4] Vacca, Andrea, and Germano Franzoni. *Hydraulic Fluid Power: Fundamentals, Applications, and Circuit Design*. 1st Edition. Wiley, 2021.
[5] Fifth Metal Industrial Co, Ltd. "CNC manufacturing." / "CNC de fabricaţie." Accessed August 28, 2023. http://ro.dgcncmachining.com/cnc-milling-parts/cnc-manufacturing/.
[6] Roşca, Radu. *Elements of fluid mechanics and hydraulic drives* / *Elemente de mecanica fluidelor si actionari hidraulice*. Iasi, "Ion Ionescu de la Brad" Publishing House, 2015.
[7] S.C. PH Technique S.R.L. "Archive of labels: Hydraulic systems." / "Arhiva etichetelor: Sisteme hidraulice." *PH-T.RO – Blog*. Accessed August 28, 2023. http://www.ph-t.ro/blog/tag/sisteme-hidraulice/.

Efficacy of Using the Double-Acting Hydraulic Cylinder

PhD. Eng. **Tiberiu AXINTE**[1], PhD. Eng. **Ionuț DATCU**[1], PhD. Eng. **George SURDU**[1],
Dipl. Eng. **Alexandru SAVASTRE**[1], Dipl. Eng. **Victor BĂDĂNĂU**[1], Dipl. Eng. **Camelia PASCU**[1],
Dipl. Eng. **Iulia TOMOZEI**[1]

[1] Research and Innovation Center for Navy, Romania

*tibi_axinte@yahoo.com

Abstract: *In this paper, the authors present aspects related to the use of a double-acting cylinder with return spring. Three circuits using a double-acting cylinder with return spring are presented in this manuscript, that is, a hydraulic circuit and two electro-pneumatic circuits. Thereby, the hydraulic scheme contains the following devices: double-acting cylinder with return spring (Doub 1-1), two throttle valves, 4/2-way hand lever valve, pump unit, and tank. Likewise, first electro-hydraulic circuit has the following devices: double-acting cylinder (Doub 2-1), two throttle check valves, pump unit, and tank. Second electro-hydraulic circuit has the following devices: double-acting cylinder (Doub 3-1 and Doub 3-2), pressure relief valve, 4/3-way solenoid valve, two lamps, pump unit, relay, and solenoid valves.*

Keywords: *Hydraulic, cylinder, spring, circuit, button*

1. Introduction

In hydraulic circuits several actuators can be used. The main hydraulic actuators are: single-acting, double-acting, loading unit, hydraulic motor and semi-rotary motor.
The double-acting hydraulic cylinders can be equipped with return spring; these return spring are to left or to right, Fig. 1.

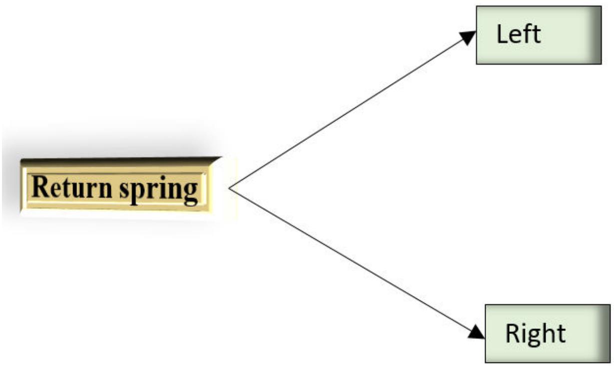


Fig. 1. Return spring

In this manuscript, all hydraulic cylinders are equipped with return springs right, [1].
In specialized literature, a double-acting hydraulic cylinder with return spring right has a specific symbol, Fig. 2.

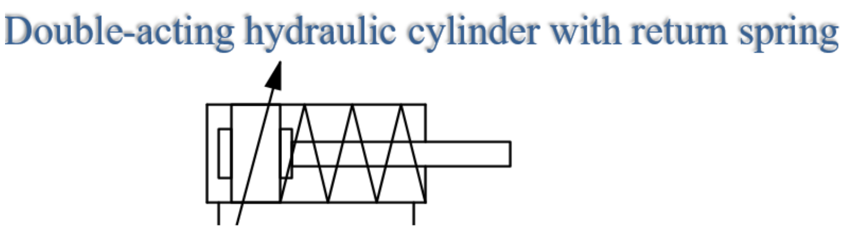


Fig. 2. Symbol of double-acting cylinder with return spring

In practice, different types of double-acting cylinder with cushioning are used. But, in our case we use some double-acting cylinders with cushioning type DNG-50-80-PPV-A, Fig. 3.

Fig. 3. Hydraulic cylinder with return spring

Anyway, the pneumatic cylinders DNG-50-80-PPV-A are in accordance with standard ISO 15552, [2].
Parameters of double-acting cylinder DNG-50-80-PPV-A are shown in the table below.

Table 1: Double-acting cylinder with cushioning specification

Parameters	Value	Unit
Bore	$50\cdot10^{-3}$	m
Stroke	$80\cdot10^{-3}$	m
P_{max}	10^6	Pa
Basic weight	1.4	kg

2. Study of hydraulic circuits with a double-acting cylinder

In practice, simple hydraulic circuits use a single double-acting cylinder, [3].
That is why the first studied hydraulic scheme has a single double-acting cylinder with spring return, Fig. 4.

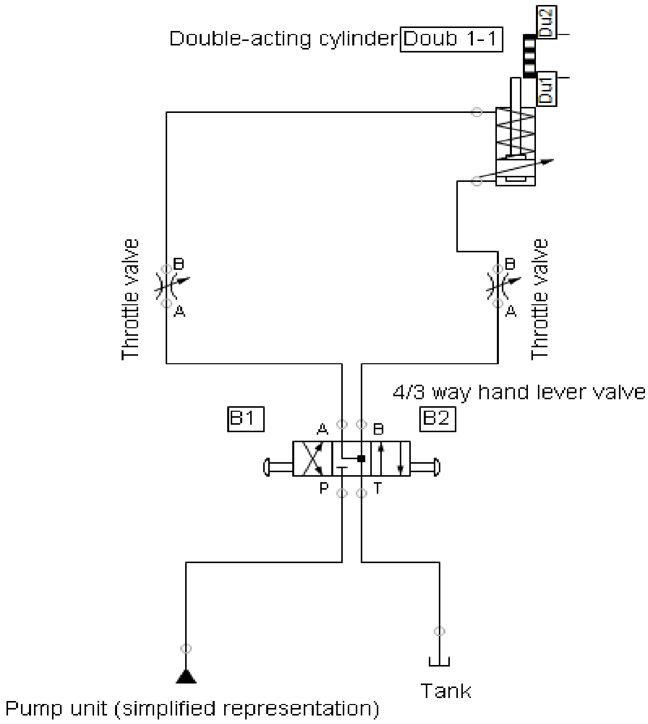


Fig. 4. Hydraulic circuit using double-acting cylinder (Doub 1-1)

Table 1 below shows six component devices used in the hydraulic scheme [4].

Table 2: The devices of the hydraulic circuit

Description	Number of components
Double-acting cylinder with return spring (Doub 1)	1
Throttle valve	2
4/3-way hand lever valve	1
Pump unit	1
Tank	1

In the first circuit, operator presses the B1 button to the 4/2-way hand lever valve. Then, the piston rod moves from point Du1 to point Du2, Fig. 5.

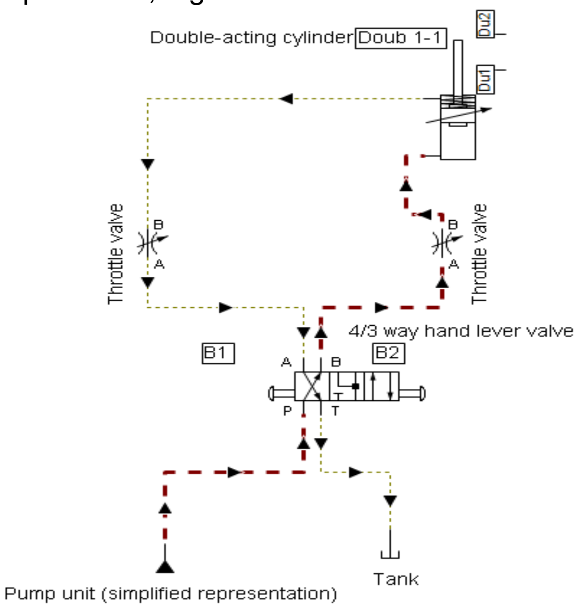


Fig. 5. Hydraulic circuit with double-acting cylinder (Doub 1-1). Simulation I.

If operator presses B2 button belonging to the 4/2-way hand lever valve, as in second simulation, the piston rod moves from point Du2 to point Du1, Fig. 6.

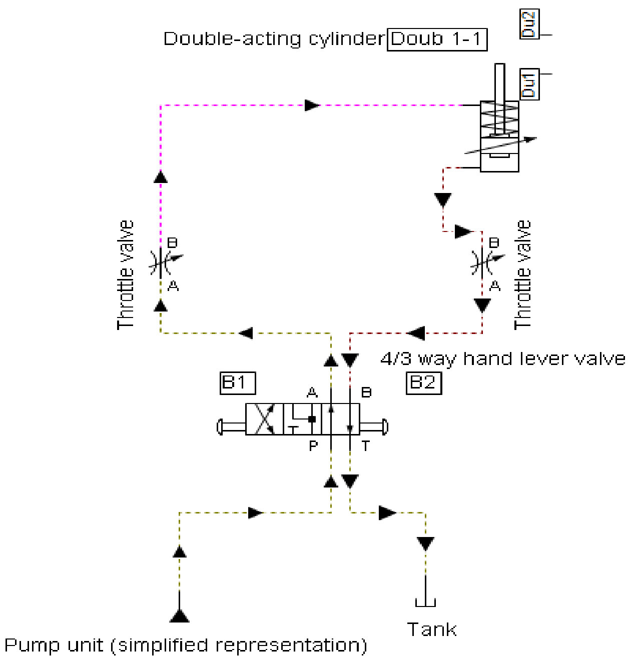


Fig. 6. Hydraulic circuit with double-acting cylinder (Doub 1-1). Simulation II.

The diagrams give show variation of the following functional parameters of the double-acting cylinder with return spring (Doub 1-1), Fig. 7.

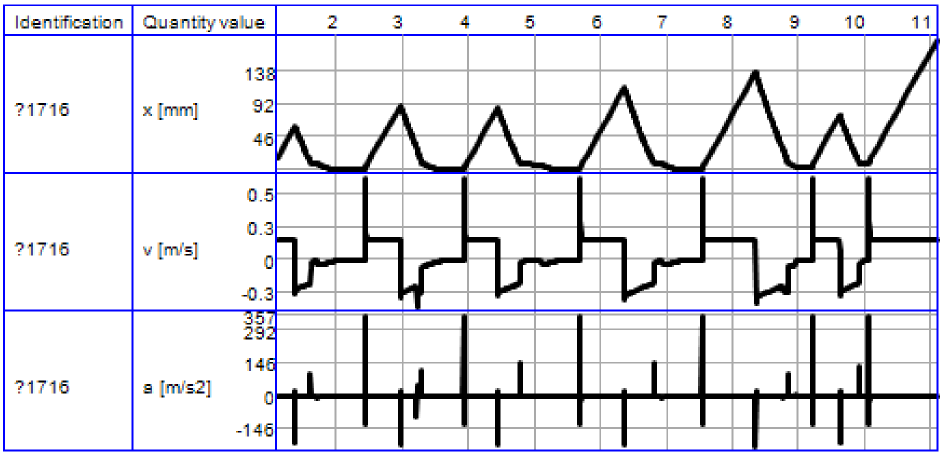


Fig. 7. Diagrams of parameters variations from the hydraulic cylinder (Doub 1-1)

Furthermore, an electro-hydraulic circuit has a double-acting pneumatic cylinder (Doub 2-1) with return spring [5].

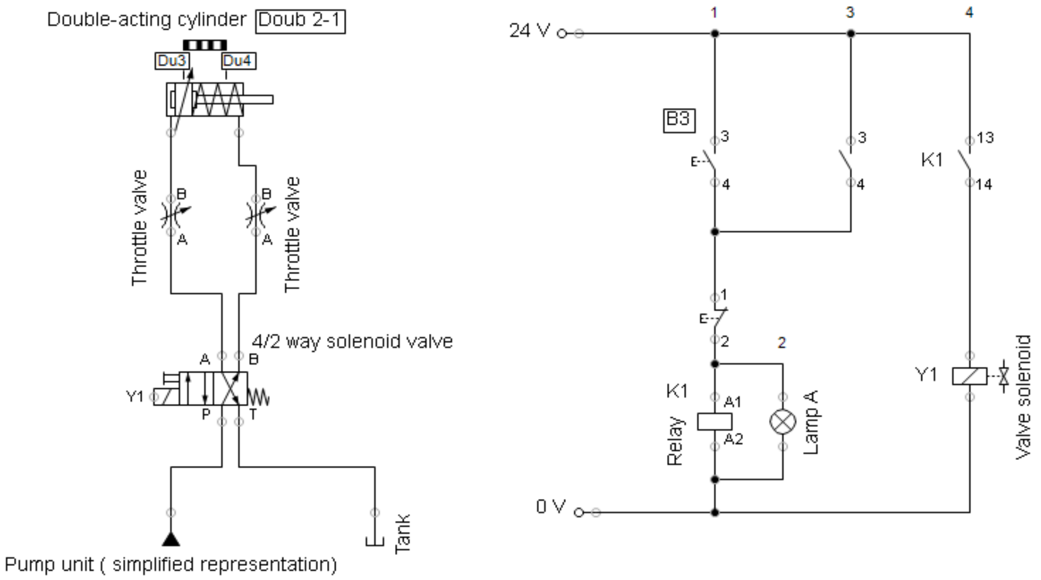


Fig. 8. Electro-hydraulic circuit using cylinder (Doub 2-1)

Table 3 below shows nine component devices used in the electro-pneumatic circuit [6].

Table 3: The devices of the electro-hydraulic circuit

Description	Number of components
Double-acting cylinder (Doub 2-1)	1
Throttle valve	2
4/2-way solenoid valve	1
Pump unit (simplified representation)	1
Tank	1
Lamp A	1
Relay	1
Solenoid valve	1

If operator presses B3 button, the piston rod of the double-acting cylinder (Doub 2-1), moves from point Du3 to point Du4, and a lamp shows a green signal. After that, the piston rod returns from point Du4 to point Du3, because the 4/2-way solenoid valve has a spring, Fig. 9.

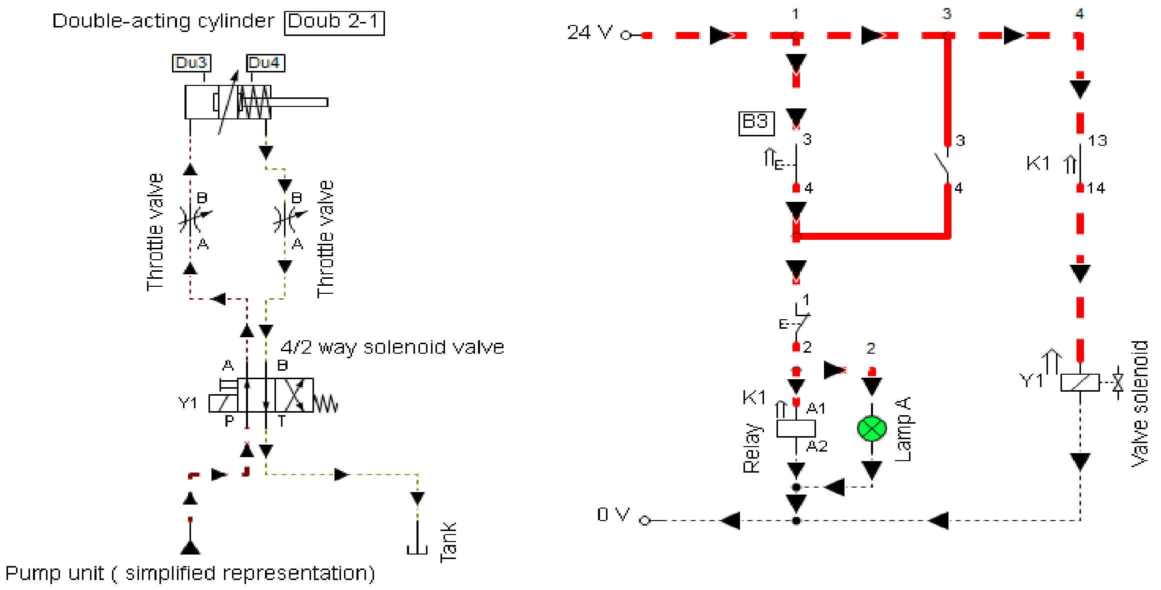


Fig. 9. Electro-hydraulic circuit using cylinder (Doub 2-1). Simulation.

Finally, the last electro-hydraulic circuit is equipped with two hydraulic cylinders, Fig. 10.

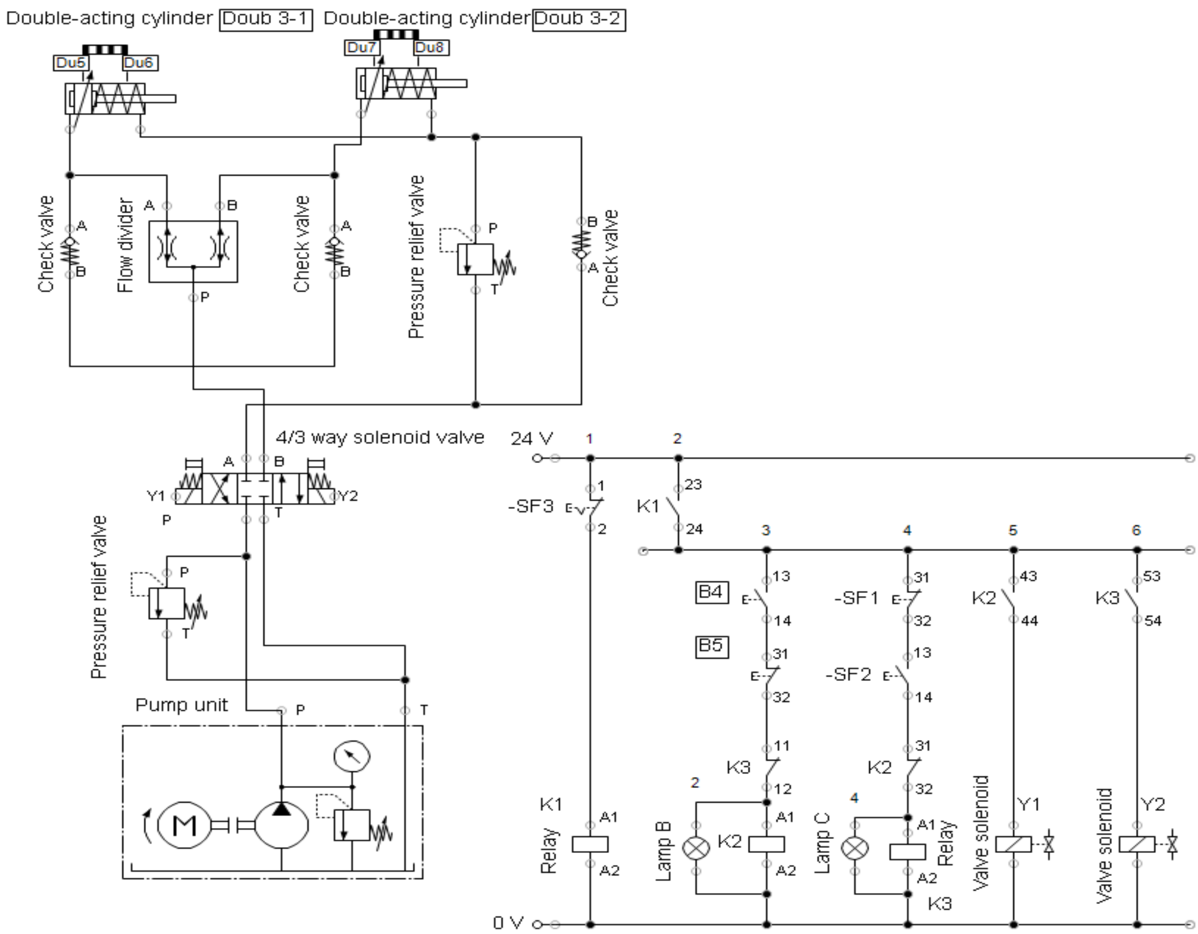


Fig. 10. Electro-hydraulic circuit using two hydraulic cylinders

Table 4 below shows ten component devices used in the electro-hydraulic circuit [7].

Table 4: The devices of the electro-hydraulic circuit

Description	Number of components
Double-acting cylinder (Doub 3-1)	1
Double-acting cylinder (Doub 3-2)	1
Pressure relief valve	1
4/3-way solenoid valve	1
Pump unit	1
Lamp B	1
Lamp C	1
Relay	1
Solenoid valve	2

Onwards, if operator presses B4 button, both piston rods of the double-acting cylinders (Doub 3-1 and Doub 3-2) move at the same time, that is, the piston rod of the double-acting cylinders (Doub 3-1) moves from point Du5 to point Du6, and respectively the piston rod of the double-acting cylinders (Doub 3-2) moves from point Du7 to point Du8. Further, a lamp B shows a red signal, Fig. 11.

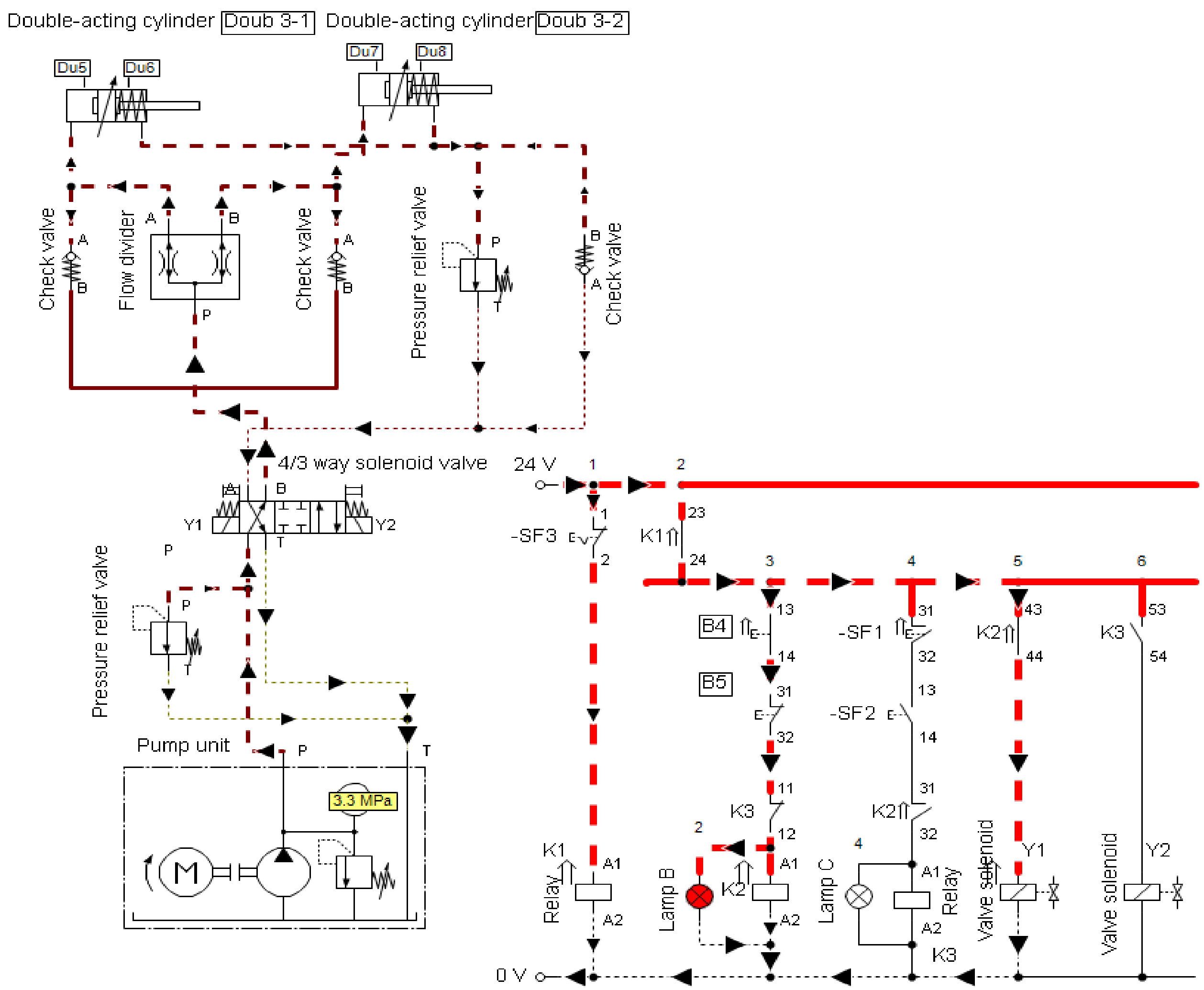


Fig. 11. Electro-hydraulic circuit using two hydraulic cylinders. Simulation I.

After that, if operator presses the B5 button, the piston rod of the double-acting cylinder (Doub 3-1) returns from point Do6 to point Do5, and the piston rod of the double-acting cylinder (Doub 3-2) returns from point Do8 to point Do7. In this case, the lamp C shows blue signal, Fig. 12.

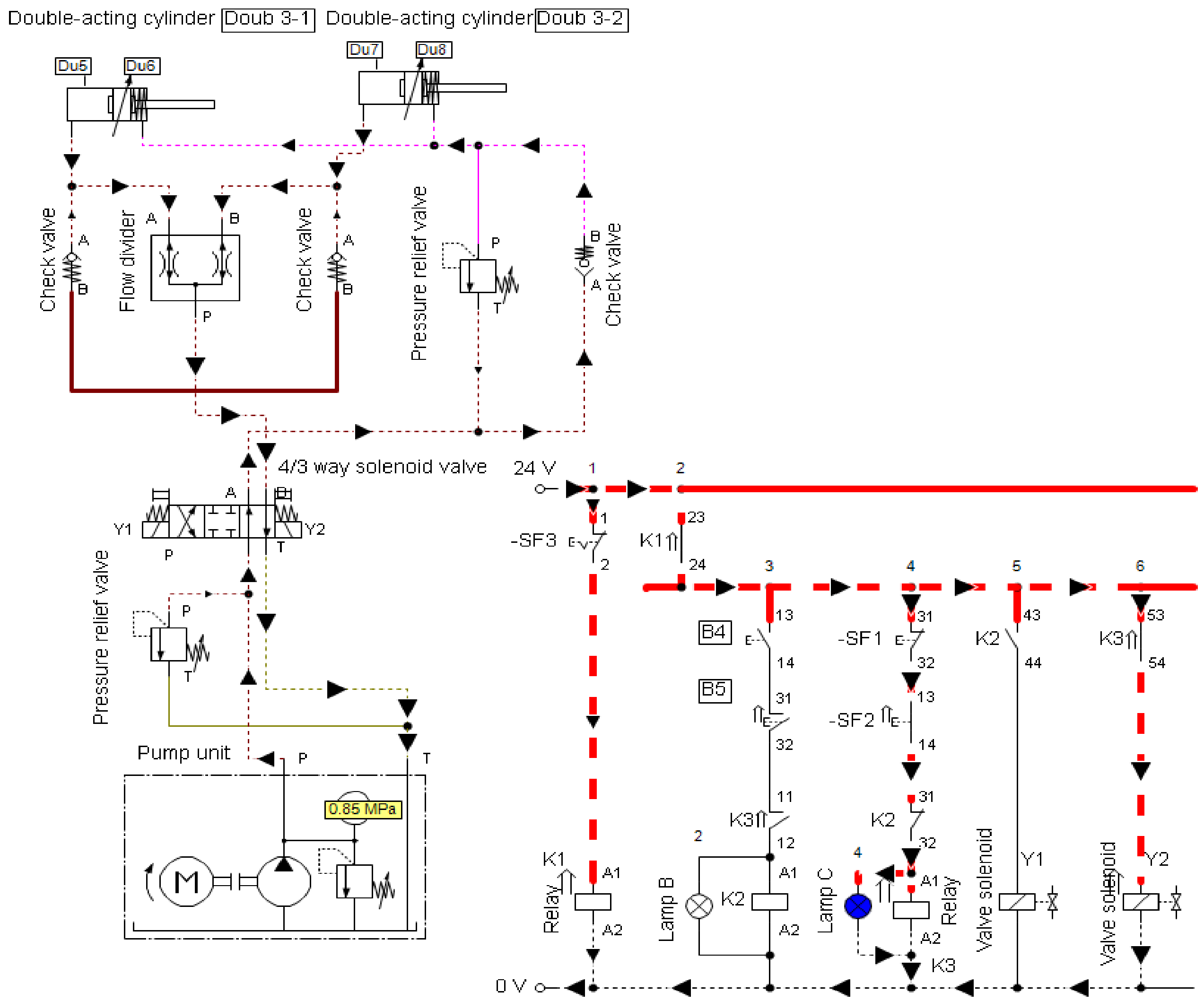


Fig. 12. Electro-hydraulic circuit using two hydraulic cylinders. Simulation II.

3. Conclusions

Hydraulic and electro-hydraulic circuits equipped with double-acting cylinders are used in many fields of industry.
Advantages of the double-acting cylinders with return springs in the hydraulic and electro-hydraulic circuits are:

- Accuracy
- Precision
- Energy-saving capability
- Push and pull motions.

The future papers on this topic will focus on the implementation in hydraulic circuits with double-acting cylinders together with several actuators (hydraulic motor, semi-rotary drive, loading unit, etc.).

Acknowledgements

We wish to thank Professor dr. eng. Nastasescu Vasile of the Military Technical Academy "Ferdinand I", for his unwavering guidance and support in the preparation of this manuscript.

References

[1] Dutu, I.C., and G. Matache. “Computer assisted electro-hydraulic stand for testing servovalves.” *Hidraulica Magazine*, no. 3-4 (2012): 73-77.
[2] Nastasescu, V., and G. Barsan. “SPH Method in Hydraulic Problems” / “Metoda SPH in probleme hidrotehnice.” Paper presented at the 16th International Multidisciplinary Conference - "Professor Dorin Pavel - the Founder of Romanian Hydropower Science" / A XVI-a Conferinta internationala – multidisciplinara “Profesorul Dorin Pavel – fondatorul hidroenergeticii romanesti”, Sebes, Romania, June 10-11, 2016.
[3] Nutu, C.S. “Utility Value Analysis method. Fractional analysis of quality characteristics.” / “Metoda analizei valorii de utilitate. Analiza fractoriala a caracteristicilor de calitate.” Das 6te Internationale Workshop - “Stochastische Modelle in der Technik und Wirtschaft”/ “Stochastic models in the technology and economy”, FILS-UPB, Bucharest, Romania, May 30, 2013.
[4] Popa. T., M. Cotrumba, and O.S. Cupsa. “Industrial Requirements – Challenges for Academic Sector.” Paper presented at the 12th International Technology, Education and Development Conference INTED 2018, Valencia, Spain, March 5-7, 2018.
[5] Degeratu M., A. Petru, Șt. Georgescu, and S. Ioniță. *Hyperbaric technologies for unitary and saturation diving / Tehnologii hiperbare pentru scufundări unitare și în saturație*. Bucharest, Matrix Rom Publishing House, 2008.
[6] Francalanza, E., A. Bonnello, E. Rauch, C. Amza, M. Lundgren, and G. Putnik. *An industry 4.0 digital training toolbox*. Bucharest, Printech Publishing House, 2022.
[7] Francalanza, E., J. Borg, and C. Constantinescu. “Deriving a systematic approach to changeable manufacturing design”. *Procedia CIRP* 17 (2014): 166-171.

Analysis of the Behavior of Fluids Specific to Electrohydraulic Systems and the Performance of Industrial Machine Tools

PhD. Chem. **Adriana Mariana BORȘ[1]**, Dipl. Eng. **Liliana DUMITRESCU[1,*]**,
MSc. Eng. **Ștefan-Mihai ȘEFU[1]**, Dr. **Marin ȘENILĂ[2]**

[1] National Institute of Research & Development for Optoelectronics / INOE 2000 – Subsidiary Hydraulics and Pneumatics Research Institute / IHP, Bucharest, Romania

[2] INCDO-INOE 2000, Research Institute for Analytical Instrumentation ICIA Cluj-Napoca

* lilianad.ihp@fluidas.ro

Abstract: *Hydraulic oils play a major role in the performance of high-precision industrial machine tools. The share of hydraulic oils on the market is significant and constitutes an important group within lubricants. The decision to use a certain type of hydraulic oil from a certain range can sometimes be very difficult. The difference in use and operation is the main reason why great attention must be paid to identifying that hydraulic oil formulation with specific additives for each type of machine-tool or equipment in the targeted industrial segment. The main properties of state-of-the-art hydraulic lubricating fluids are aimed at the reliability and performance of the drive system. The big companies especially dedicate all the technology and research in obtaining the ranges for professional use, therefore, the study of modern and innovative lubricating fluids, specially dedicated, with synergies that give life to products with extraordinary qualities, able to offer and satisfy the best performance in the most difficult situations of using hydraulic drive systems.*

Keywords: *Austenitic steels, CNC, depassivation, hydraulic oil*

1. Introduction

The performance of properly used lubricating oils has led to the solution of some technically demanding problems in the field of hydraulic actuation. The specialized literature provides important data regarding the constant development of hydraulic fluids, taking into account oils or hydraulic fluids such as:

- ✓hydraulic fluids based on mineral oil;
- ✓fluids under synthetic pressure;
- ✓biodegradable hydraulic fluids;
- ✓fire-resistant hydraulic fluids.

New hydraulic oil technologies aim at environmentally friendly formulations as an alternative to hydraulic oils containing zinc and ash, biodegradable hydraulic fluids. Emphasis is placed on the development of food-grade hydraulic oils, synthetic base fluids for multi-grade hydraulic oils, and new fire-resistant water-glycol hydraulic oils. Advances are being made in the area of hydraulic fluids with a special anti-wear capability, but also for the compatibility of hydraulic oils and oil filter sockets, as well as cooling lubricants of machine tools, low viscosity fluids. These types of high-efficiency and energy-enhancing hydraulic fluids offer solutions that take into account new requirements for thermal, oxidative and shear stability, with a quick response for smooth operation.

The special operating conditions for industrial machines raise particularly severe restrictions and require a rigorous selection of fluid categories that meet most of the requirements imposed on them. Among the most important requirements that are imposed and based on which these working fluids are chosen, the following are worth mentioning:

- excellent lubricating properties and high mechanical resistance of the liquid film;
- high chemical and thermal resistance and stability to prevent its oxidation, decomposition and degradation;
- minimal variation of viscosity with temperature;
- not to release vapors at normal operating temperatures and not to contain impurities that facilitate the release of vapors;

- not to contain, not to absorb and not to release air beyond the amount allowed by the technical prescriptions;
- not to cause corrosion and damage to the sealing elements;
- have a high flash point and a freezing point as low as possible;
- minimum content of mechanical and technical impurities.

2. Case Study - Performance of industrial CNC machine tools with the selected hydraulic fluid

The study consists of analyzing the behavior of an industrial CNC numerical control machine tool, EMCO/MCX-600, a lathe used for mechanical splintering processes.

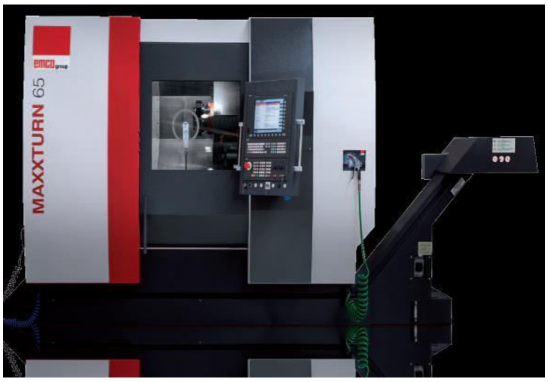


Fig. 1. Machine tool EMCO/MCX600

The hydraulic actuation system used to manufacture the parts of some assemblies and subassemblies is from the category of special purpose steels that differ from tool steels for the splintering process of technological flow. The choice of steel for exploitation in optimal conditions is an important stage that currently applies both to the material and to the technology used. Alloys of non-ferrous metals have chemical, physical, mechanical and technological properties superior to pure metals. Compared to iron alloys, non-ferrous alloys show a much higher resistance to the corrosive agents' action. Due to the high corrosion resistance and cold deformability, stainless steels are used in various fields, being found in the chemical, food, construction, household industries, etc. The concern regarding the environment protection imposes a new perspective on the use of stainless steels, such as protective coatings, corrosion-resistant semi-finished and/or finished products, pharmaceutical or medical applications. According to their chemical composition or crystal structure, stainless steels can be grouped [1] as follows:

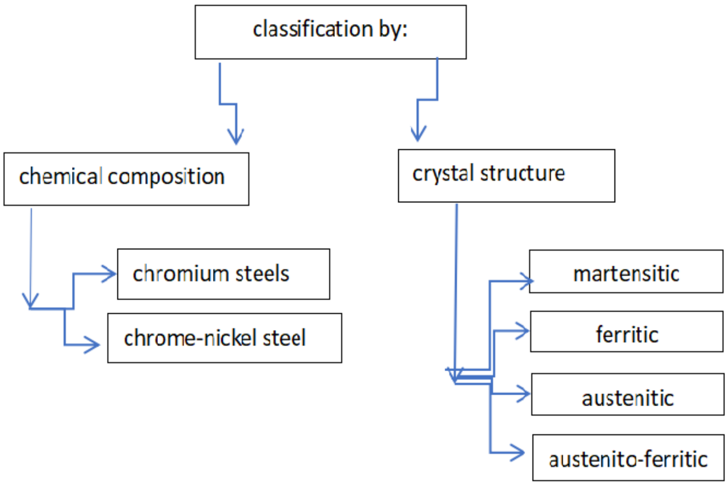


Fig. 2. Classification of stainless steels [2,3]

The properties of stainless steels vary with Cr, Ni and carbon content. The average base composition of stainless steels is: 18% Cr and 9% Ni. The carbon content is less than 1.2%, for those steels that show properties of resistance to aggressive environments, resistant to corrosion. The corrosion resistance is based on the formation of a passive film on the surface, the stability of which increases with the chromium content and can be further increased by alloying with molybdenum. The passivity is ensured by the thin film of hydrate metal oxide, in which an enrichment of chromium is produced compared to the base metal.
The formed film is able to maintain a state of equilibrium with the working environment, and becomes difficult or not at all penetrable for other environments. Once the steady state is reached the corrosion will be of negligible magnitude.
The following types of steel with maximum corrosion resistance are distinguished:
- 18-10 type steels with 0.02 - 0.15 % C;
- steels with improved corrosion resistance by adding molybdenum and copper;
- steels resistant to hot oxidation by adding silicon;
- steels whose wear is improved by adding sulphur, selenium, copper, etc.

The more homogeneous the crystalline structure of stainless steels, the more favorable their properties.
An important role in achieving the homogeneous crystalline structure belongs to the applied heat treatment process.
Thus, stainless steels can undergo structural changes under the action of:
• a thermal treatment (imposed by the manufacturing process);
• cold plastic deformation (austenitic steels);
• a thermomechanical treatment at high temperature (subject to mechanical stress at high temperature).

3. Corrosion resistance of austenitic stainless steels

Destruction by corrosion is a very complex phenomenon, in many cases it causes a change in their properties, which leads to a sudden decrease in mechanical strength. Depending on the steel nature, the aggressive environment, as well as the working conditions, the corrosion rate may remain constant, increase or decrease over time. A metal or an even "stainless" alloy can be very resistant under certain conditions, but can become unstable under others, corroding heavily.
This explains the large number and variety of methods for testing and measuring corrosion resistance, taking into account the changes caused by corrosion in the physical and chemical properties of metals and alloys. The plastic deformation of stainless steels produces important changes in their structure and properties, which influence corrosion resistance [4]. This, in some conditions, can lead to the breaking of the passive film (mechanical depassivation), which can cause the appearance of local or even generalized corrosion. To remedy this phenomenon, a chemical repassivation can be resorted to, using appropriate technologies. The passive film stability, which protects stainless steels against corrosion, is conditioned by a large number of factors: physical-chemical, metallurgical, mechanical, geometric and microbiological. Breaks that can occur in this protective film can lead to various forms of localized corrosion, such as stress corrosion cracking or to the formation of peaks. More significant depassivation can cause cavitation or even the appearance of generalized corrosion. In the case of austenitic stainless steels, the presence of chromium (over 12-13%) ensures the formation of the protective passive film. At the same time, the presence of carbon can also be a factor that contributes to the passive film destabilization, since this element tends, when hot, to form chromium carbides with good stability and chromium is thus no longer available to participate in the passivation of the material (its concentration falls below the allowed limit of 12-13%). Under the action of a superficially applied mechanical deformation, two independent phenomena can occur: a mechanical depassivation and a change in the microstructure. The mechanical depassivation is due to the breaking of the passive film caused by the appearance of important stresses during the manufacturing process of the part, and generalized corrosion may occur. To remedy this phenomenon, a chemical repassivation is often resorted to after alloy deformation, using appropriate treatments and baths. 8 types of hydraulic oil with relatively similar properties and

contents were tested. 5 of these, from the same range (RENOLIN) [5] intended for the technological flow for the processing of steel, alloy and metal parts have recorded close performances. For the 5 types of hydraulic oil, the tests were repeated by increasing the number of operation hours for the same operating conditions (same type of machined part in size and shape and the same material) with each of these oils.

Table 1. Presentation of the 8 types of hydraulic oils tested

FLUID CODE	Hydraulic oils/Industrial lubricants
HYDROTHERM 46 M	Fire-resistant hydraulic fluid from the HFC group
RENOLIN AR-SERIES	General lubricating oils based on mineral oils, lubricating oils according to DIN 51501: L-AN
RENOLIN B 46 CP	AW high-quality hydraulic oil for highly stressed hydraulic circuits
RENOLIN B HP PLUS-SERIES	High-quality AW/EP hydraulic fluids and hydraulic oils based on special base oils of the latest generation in combination with new additive technology
RENOLIN MR3 VG10	HLPD special hydraulic and lubricating fluids, according to DIN 51502, with outstanding corrosion protection and strong cleaning and dirt-carrying capacity, Excellent oxidation stability based on high-quality hydrated base oils; ISO 6743-4: HM with DD performance
RENOLIN CLP PLUS-SERIES	Specially approved, long-term gear oils with very high aging stability and excellent detergent characteristics (DD) – self-cleaning oils
RENOLIN MR 310/520/1030	Multi-application oils for bearings, transmissions and hydraulic systems with excellent viscosity-temperature behavior for low temperature applications, detergent / dispersant
RENOLIN ZAF D HT-SERIES	Universal zinc and ash free hydraulic fluids and industrial gear oils with very high aging stability and excellent wear protection, detergent / dispersant

With all these aspects in mind, RENOLIN MR3 VG10 hydraulic oil was chosen after the test period was completed. The analysis of hydraulic oil samples was carried out after the manufacture of the same type of part (in number of 190 pcs) and the number of hours of operation (3-4 part/h, 6h/day, 10 days of tests, approximately 60 hours of operation) of the EMCO/MCX-600 machine tool.

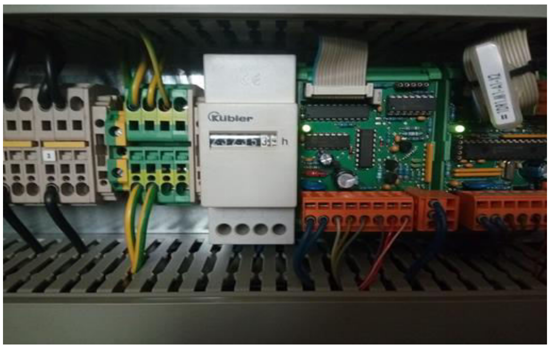


Fig. 3. Counter for the operating hours number

Fig. 4. Hydraulic oil samples analyzed

This type of hydraulic oil identified and tested confirmed the characteristics given by the technical data sheet [6] and the guide for understanding the DIN 51502 codes on the designation of lubricants, namely:
- excellent oxidation stability;
- HLPD according to DIN 51502 [7];
- protection against corrosion;

- strong cleaning capacity;
- meets and exceeds the requirements according to DIN 51524-2 HLPD;
- ISO 6743-4 HM[1] with DD performance [8]

RENOLIN-MR-3-VG-10 is a hydraulic lubricating fluid that:
- contains: detergent, dispersant, refined oils and additives
- has the following physico-chemical properties:
  - density (15 °C) = 0.84 g/cm^3;
  - kinematic viscosity at (40 °C) = 10 mm^2/s and at (100 °C) = 2.7 mm^2/s;
  - ignition temperature 160 °C;
  - insoluble in water;
  - characteristic smell;
  - translucent yellow;
- does not present risks for human health (operator) through handling and exposure with appropriate equipment.

The lubrication capacity of the selected fluid is based on the ability to form a resistant film, a fact that determines the performance of the process carried out with a reduced energy consumption, determined in principle by the reduction in a significant proportion of the frictional forces. Different additives or surface-active chemical compounds in the composition of hydraulic oil are substances with low surface tension with a double hydrolytic function (they change the surface tension of the fluid in which they are introduced in small concentrations) and adhere to the metal surface with which the fluid comes into contact, forming a capillary-active film. These agents in different concentrations, in relation to the HLB (hydrophilic-lipophilic balance) value, can provide the lubricant film with a high breaking resistance by acting as an extreme pressure (EP) agent.

In contact with the cylinder surface, it adheres due to adhesive forces, forming physical adsorption or even chemosorption films resistant to very high surface tensions. This phenomenon is also due to the fact that the active substances form pseudo-stable compounds on the metal surface that compose a continuous fine film that covers the surface in contact, substantially reducing friction, thus ensuring smooth sliding.

Due to the physico-chemical affinity determined by the surfactants, the additive fluid achieves important effects, namely:
- improves the sliding coefficient (good resistance to high pressures);
- causes a lubrication of the sliding surfaces that reduces the internal friction force (releases potential centers preventing the formation of micro agglomerations with various impurities).

Through all these cumulative effects, hydraulic fluids contribute to the reduction of frictional resistance and implicitly to the reduction of energy consumption in the processes used. Therefore, an effective lubricated system must provide a balance between lubrication and cooling. Theory has shown that at a lower coefficient of friction lower rolling forces are required. Implicitly, in this situation wear phenomena are reduced and the amount of heat generated by the friction that occurs at the working contact on the technological flow is reduced. In such conditions, it is allowed to increase the speed and as a consequence energy and material consumptions are reduced, especially of the cylinders whose wear is slower. Friction and lubrication are influenced by a number of parameters such as fluid properties, temperature, sliding speed, contact pressure. From the point of lubricant view, parameters that affect friction and lubrication, respectively parameters depending on which the performance of a lubricant and the coefficient of friction vary, are: viscosity, thickness of the lubricant film, pressure stability, temperature stability, additives used in a special regime of work (pressure and temperature). The oil film thickness is directly proportional to the viscosity. Research has shown that an increase in the degree of long-term wear of hydraulic oils can lead to an amount of carbonic residues of 0.9 - 2 mg/L. Carbon residues could be limited by choosing an improved waste oil filtration system. Their presence leads to a strongly favourable environment for the oil oxidation process to take place. During the heat treatment, the residual products formed react with the gaseous products, and cause the formation of areas with carbon concentrations on the surface of cylinders of the drive systems. The knowledge and control of the phenomena that occur due to the poor quality of the hydraulic fluids used, correlated with the other

[1] *HM: with active substances to increase anti-corrosion protection, resistance to aging as well as to reduce frictional wear in the contact region*

process parameters, allow the establishment of optimal characteristics that lead to the realization of high-performance products from a qualitative point of view [4]. Considering the aspects mentioned above and the recommendations from the specialized literature, we can consider that the selected oil RENOLIN-MR-3-VG-10 use is indicated. The equipment and machine tools used for various manufacturing processes imply a high degree of increase in demands in establishing the hydraulic fluid and the parameters of the manufacturing technological flow. Thus, in the case of the EMCO machine tool, the demand for a very good viscosity stability and chemical inertness was taken into account, characteristics that are met by the selected oil that is part of the range of those recommended for these requirements such as: synthetic fluids from silicon oxide polymers, compounds based on ethers or other synthetic fluids.
It should be noted that at ultra-high pressures of over 30 kbar and not too high temperatures all liquids solidify. In these conditions, it is recommended to use media such as: polyfluoroethylene, silver chloride, etc.

4. Wear and repair of hydraulic equipment used in the manufacture of parts and subassemblies

In order to prevent excessive wear of the EMCO/ MCX-600 type hydraulic equipment used in the technical machining processes, the following aspects are taken into account, namely:
- use according to the conditions specified in the technical book/user manual;
- the use of hydraulic oils and emulsifiable oils according to the specified indications (time, concentration, temperature), for each type of operation performed;
- verification and maintenance according to the maintenance plan developed in accordance with the imposed rules;
- current repairs and specialized capital repairs;
- measures to carry out the repair of the machine safely.

Drawing up the maintenance schedule requires taking into account all the factors that influence the safety of the machine's operation, namely: the load and volume of work, the work pace, the operator, hand carrying out the repair by specialists, corresponding to the machine complexity and the type of repair. The introduction of advanced technologies ensures the repairs quality, the increase of work productivity and the cost price reduction by accurately determining the defects, wear areas and their size on the parts in operation. The actual conditions in which parts work are a function of physical properties (coefficient of thermal expansion, coefficient of linear expansion, temperature coefficient of resistivity), mechanical properties (mechanical strength, toughness, hardness, stress and wear resistance) and the appropriate technological flow. Depending on the condition of the oil film formed, the parts surfaces in friction are completely separated, the external pressure being taken up and transmitted through the moving oil layer. Although the oil layer thickness is very small, the lubricant movement occurs by neglecting the inertia forces and the weight of the fluid, the effect of viscosity being predominant. To reduce friction, fluid friction and the use of quality lubricants are necessary. In this way, boundary friction can be combated, a phenomenon that occurs when the load increases a lot, the relative speed decreases, and the lubricant layer between the surfaces is very thin. The boundary layer avoids erosion wear. Also, the semi-fluid friction that occurs between surfaces with a continuous oil film but of variable thickness, a phenomenon that frequently occurs during overstressed mechanical operations or worn parts and is unavoidable in long-term processes, can also be dimmed. Thus, it is necessary to apply the appropriate technical operation measures such as: greasing the mechanisms, supplying with good quality hydraulic oil, proper adjustment but also observing the operating rules of the used equipment.

5. Conclusions

The quality of the selected and used lubricating fluid refers to good chemical stability, appropriate viscosity, an adequate content of refined oils and additives with anti-corrosive effect, good cleaning ability and oxidation stability. From the analysis of RENOLIN-MR-3-VG-10 type hydraulic oil samples after several cycles of operating hours, it is found that the use of this fluid allows the

formation of resistant films, which eliminate boundary or semi-fluid friction. In high temperature conditions, the addition of detergent, dispersant and additives improves the functionality of the mechano-hydraulic drive system for the performed chipping operation. The hydraulic oil reduces the wear of the EMCO/MCX-600 industrial CNC machine tool by maintaining the parameters (pressure, temperature, viscosity, etc.) within limits that do not affect the physical-chemical properties of the fluid and the adherent film in the hydraulic contact area. The functionality of the hydraulic machine is closely related to the wear uniformity of the main component elements and to the change over time in the structure and physico-chemical properties of the materials. The use of lubrication with a quality hydraulic fluid to form a film of hydraulic oil between the friction surfaces of the cylinder aims to:
- reducing the friction effect;
- preventing and reducing machine wear and temperature;
- increasing the tightness of cylinders;
- anti-corrosion effect on the parts.

Acknowledgments

This work was carried out through the Core Program within the National Research Development and Innovation Plan 2022-2027, carried out with the support of the Romanian Ministry of Research, Innovation and Digitalization (MCID), project no. PN 23 05. The research was financially supported by a project funded by MCID through Programme 1 – Development of the national research & development system, Sub-programme 1.2–Institutional performance–Projects financing the R&D&I excellence, Financial Agreement no. 18PFE/30.12.2021.

References

[1] Truşculescu, Marin, and Aurel Ieremia. *Stainless and refractory steels / Oțeluri inoxidabile și refractare*. Timişoara, Facla Publishing House, 1983.
[2] Vermeşan, Horațiu. *Research on the corrosion behavior of stainless steels subjected to plastic deformation and ionic nitriding / Cercetari privind comportarea la coroziune a otelurilor inoxidabile supuse deformarii plastice si nitrurarii ionice*. PhD thesis. Technical University of Cluj-Napoca, 1998. *Chapter I. The current state of research on the corrosion behavior of stainless steels subjected to plastic deformation and ionic nitriding / Stadiul actual al cercetarilor privind comportarea la coroziune a otelurilor inoxidabile supuse deformarii plastice si nitrurarii ionice*. Accessed August 29, 2023. http://users.utcluj.ro/~hvermesan/doctorat/cap1-1.html.
[3] Vermeşan, Horațiu. *Surface engineering technologies applied to stainless steels / Tehnologii de ingineria suprafețelor aplicate oțelurilor inoxidabile*. Intensive course: *Advanced processes in surface engineering* / Curs intensiv: *Procedee avansate în ingineria suprafețelor*. Câmpia Turzii, June 8-11, 1998.
[4] ASSOFLUID. *Hydraulics in Industrial and Mobile Applications.* Brugherio (Milano), Grafiche Parole Nuove, 2007.
[5] Fuchs Lubricants Romania S.R.L. "Hydraulic oils." / "Uleiuri hidraulice." Accessed August 28, 2023. https://www.fuchs.com/ro/ro/produse/program-produs/lubrifianti-industriali/uleiuri-hidraulice/.
[6] Fuchs Lubricants Germany GmbH. "RENOLIN MR 3 VG 10." Accessed August 28, 2023. https://www.fuchs.com/de/en/product/product/149273-RENOLIN-MR-3-VG-10/.
[7] ***. "Lubrication Guide Applicable DIN Standards. Codes for Lubricants according to DIN 51502." Accessed August 29, 2023. https://dokumen.tips/documents/codes-for-lubricants-acc-din-51502.html?page=1.
[8] ExxonMobil. "Hydraulic Oil: ISO 6743-4 and/or DIN 51524." *Mobil™ lubricants*. Accessed August 28, 2023. https://www.mobil.com/en/lubricants/for-businesses/industrial/lubricants/equipments/hydraulic-oil-i_a1t41000004osoxea0.

FLUIDAS

NATIONAL PROFESSIONAL ASSOCIATION OF HYDRAULICS AND PNEUMATICS IN ROMANIA

fluidas@fluidas.ro