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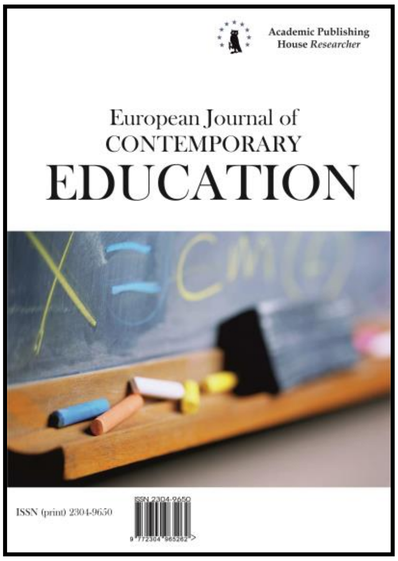

Hydraulic Analogy Method for Phenomenological Description of the Learning Processes of Technical University Students

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Abstract

A physical process analogy of the learning process was studied using a hydraulic method. Detailed educational guidance describing applied pedagogical concepts for technical instructors of the civil, mechanical, chemical and materials engineering disciplines was formulated. A unified engineering-friendly formulation of learning processes using a direct analogy of civil, mechanical, chemical and materials engineering physical processes was developed. Generalized expressions were proposed for an approximate description of learning processes in the educational curriculum in the form of hydraulic processes in civil, mechanical, chemical and materials engineering practice. It was shown that it is possible to intensify students' attention to the studied technical material through a step-by-step building of a proposed analogy between hydraulic and learning processes, which is based on the similarity between corresponding mathematical models for both processes. Hard-working students have the prime educational problem of managing the growing overload and holding in their memory a cumbersome quantity of studied material in technical, social and human sciences. The author-proposed educational approach provides a better simultaneous understanding of both hydraulics and didactics by acquiring new inter-disciplinary practical knowledge, which helps learners plan an optimal scientific-based mode for effective study and self-study of educational material. This educational research helps students to remember that it is impossible to learn the studied material at the required level of understanding with a single one-time acquaintance without multiple reviews and repetitions.

Keywords: engineering education, memorization, forgetting, hydraulic analogy.

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1. Background

1.1. Concerning the Culture of Student Memory

Pedagogical research into students' memories is very important for the philosophy of education because the learner's memory combines past and future with the current life-point of now, which is the present biological time of human life (Heersmink, Carter, 2017; Heersmink, 2018). Human memory certainly ensures our sentient existence but it also determines the accuracy, efficiency and quality of the educational process in schools and universities. It was well shown in the famous Johnny Mnemonic (1995) cyberpunk movie (Donner, 2005) that problems of human memory and/or memory impairments result in serious disturbances in a person's conscious life. Neuroscience, neurophysiology, psychiatry, numerous movies, popular fiction novels, and computer games like Sanitarium (1998), provide detailed descriptions of several mental disorders associated with amnesia when a person partially or completely forgets everything that has happened in their previous life. However, everyone forgets a lot of educational and general information and it is not due to age-related issues or the current state of individual mental health. And the following question presents itself: Why does the human brain have a strong tendency to forget incoming information on a regular basis?

Neurophysiologists suppose that our memory has a special structure, which is tailored and configured to manage a large volume of information without memory overloading and irreversible memory damage. It was well shown in the famous Tarja's song "The archive of lost dreams" (CD-album "What lies beneath", 2010) that we spontaneously and completely forget everything that we experienced a year or a month ago without additional retention and fixation of previous information in memory. All European culture was initially created as a culture of memory. Culture of memory is a special technique to work with oblivion. It is important to note that the purpose of civilization, instead of barbarism, is focused on memory preservation.

Psychologists point out an important consideration in educational process, which answers a question as to the conditions under which students better remember learning material (Figs. 1–4). Psychologists conclude that students better remember learning material when they see the sense and importance of the studied material, educational facts and occurrences. Pedagogically, it is possible to create a culture of student memory by the assignment a practical value to the studied material for students. It is impossible for students to successfully remember the mandatory volume of learning material without the assignment of educational values, and the creation of value-related interconnections and synergetic associations. A student's memory cannot accept and transform unrelated parts of complex learning material, which remains valueless for a student, and which results in a permanent failure to remember compulsory design schemes, numerous formulae, rules, theorems, corollaries etc. in a timely manner. Assignment of learning value should be a conscious permanent work for educators and students which distinguishes cultural people from barbarians.

Educators should understand that a student's memory is a very vulnerable thing which requires regular enhancement through systematic use of advanced learning tools and psychological techniques. Among memory-stimulating techniques, the simplest and most effective are narratives because written or pronounced narration is the first approach to creation of a memory culture when a person prepares detailed retrospective, informed, and critical essays, notes, blogs, and stories as well as relevant individual audio and video recordings about recently studied textbooks, video lectures, movies, and lived out days (Figs. 1–4). It is funny to note that MacLachlan's character, agent Cooper in Lynch's Twin Peaks (1990-1992) movie (O'Connor, 2004), was one of the first famous audio-blogger characters in a popular culture of the early 90s who clearly showed that detailed narration of diaries, descriptive paragraph writing (Fig. 2), and reading speeches and monologues (Fig. 4) are an integral part of people's common communicational tradition. Each time when people give retrospective monologues, speeches (Fig. 4) or written notes (Fig. 2) about the same topics, they find some additional new ways for reassessment and rethinking of their previous life and experience. When students start to tell aloud the complex learning material, they trying to understand it, the required information enters their memory and their mind becomes susceptible to understanding the bulk volume of new data. Information disclosure by speaking it aloud (Fig. 4) enables a person to be more intelligent and meaningful as well as explore multiple "corridors" and "corners" of his/her mind. Neurophysiologists suppose that speaking information aloud provides a human with the generation of new neural connections, networks and pathways between brain neurons. The principal differences between the two brains are grounded on different quantities and varying quality of existing neural networks. It is very important for students and teachers to work toward memory improvement by regularly speaking the studied material aloud (Fig. 4), by discussion of multiple high complexity textbooks, by constant generation of new narratives from physics, mathematics (1) – (63) and hydraulics (Figs. 5–6). This constant learning process (Figs. 1–4) has the two aspects. At the neurophysiologic level, students ensure complication and enhancement of existing neural connections as well as emergence and formation of novel neuronal networks and pathways within their brains. At the theoretical science-related level, students ensure intellectual complication and synergetic improvement of effectiveness of their rational life. A student usually iteratively memorizes and remembers the studied material (Fig. 5) by cyclic re-addressing of textbook information (Figs. 1–4). Sometimes the learning process reminds us of precision exercise of information cataloging, or pedantry with multiple repetitions of boring things (Fig. 5). However multiple repetitions and reiterations (Fig. 5) are mandatory procedures for concentrating a package of previously spoken material in the form of short concise phrases and laconic informative definitions within the learner's memory (Figs. 1–4). In fact, every scientific school is grounded on such brief axiomatic statements and assumptions, which are considered as scholarly dogmas or tenets. Ancient Greek philosopher Plato believed that any new knowledge is only remembering or recollection (Plato, 1892). According to Plato, the purpose of any dialog between teacher and student is based on imposition of certain influence on student's "spirit" to provide remembering or recollection of necessary knowledge (Plato, 1892). Plato supposed that it is principally impossible to teach a student any new knowledge "from the outside" and that any lecture must be a variation of his hypothesis of remembering or recollection (Plato, 1892). Quite often modern students attend lectures in an exploitative manner but Plato believed that it is impossible to behave as a mere user of a new knowledge. Plato noted that a lecture should provide motivating situations and stimulate different situations of understanding but only students can empower their mental and "spiritual" abilities and make their own internal decisions to teach themselves with new learning material. Plato assumed that a student can generate all knowledge based on internal principles of his/her spirit (Plato, 1892). Plato was assured that a memory, remembering and recollection are the roots of all available knowledge (Plato, 1892).

1.2. Concerning Memory Conceptions in Social Sciences

Information within human memory can be represented individually and simultaneously as semantic information and pattern (figural) information. Students should be able to use the benefits and possibilities of both data representations at every stage of the individual education process. The preferred way of person-centered data representation strongly depends on the student's individual characteristics. The quick and efficient way for proper solution of a complex educational problem is through the combined use of both data representations when unobvious and problematic relations and entities from the first representation become simpler and more student-friendly with further disclosure and practical applications with the second data representation.

In the beginning, social scientists considered human memory as a certain imprint or specific footprint, which ensures inactive conservation of human-found information because of the reproductive process. Hence, material review and repetition was considered as the main educational technique for footprint-based memory model. Considerable importance was also attributed to the frequencies and time frames for material repetition. The fourfold material repetition after the lapse of adequate definite time intervals was considered as an optimal mode for proper memorization of material with repetitions. Success in memorization of educational material was grounded on the enhancement of individual motivation, use of different mnemonics, mnemotechnics and association methods, which were specially designed for reduction of memorization-related issues and elimination of inabilities to memorize the studied material after repetition.

Starting approximately in mid-20th century, human memory was considered not as simple information storage but as human's activity, which was developed in human beings in the process of a social evolution. This novel memory interpretation was substantially enhanced and expanded by the inclusion of external means and tools for proper organization of learner's memory. This generalization of the memory concept led to more comprehensive research into cognitive processes, internal psychology, and such educational techniques as formalization, schematization (planning), and conciseness (meaningfulness), which determine the effectiveness of memory performance. This improved memory theory enabled a more sophisticated approach to memory as a substantive activity through the application of external tools. The main problem of memory activation during education has transformed into an administrative management problem, requiring reorganization of immersion educational activity. It was necessary to achieve a learning situation where the studied material has remained in the learner's memory since the learner is enthusiastic and engaged in the process of understanding the learning material. The process of retaining material in memory itself becomes a second-order problem and not a matter of principle in these learning situations. Practical realization of these theoretical results in education is a much more complex assignment than working with a footprint-based memory model. However, this approach is much more efficient than a simple mechanical memorization.

This second approach to a learner's memory shows us that the educational problem of memorization and forgetting has been overcome by the management problem of advanced organization of unified educational activity in each specific university.

Solution of the modern multidisciplinary problem of competitive development of an artificial intelligence has resulted in an actualization of the problem of human memory performance. It was found that several human memory-related issues remained unidentified and unresolved. The problems of memory system organization, accurate information retrieval, and information acquisition are some examples of these complex questions and issues, associated with the performance of multi-layered networks of artificial information-processing computer systems. Some examples of actual applied memory-related problems which have attracted research attention in the recent years include advanced human memory modeling for improvement of artificial intelligence memory capabilities, finding optimal strategies for education and considering the distinctive features of a person's individual experience and psychological preferences.

1.3. Concerning Memory Concepts in Didactic Transposition Theory

It is very important to address the concepts of a student's memory, which have been developed in modern constructivism philosophy (Piaget, 1950/1973; Vygotsky, 1986) and Chevallard's didactic transposition theory (Chevallard, 1985; Kang, Kilpatrick, 1992; Bosch, Gascón, 2006; Klisinska, 2009; Chevallard, Bosch, 2014), which arose from it. The change of educational paradigms in modern engineering didactics has shown that behaviorism philosophy should be replaced with constructivism philosophy. Today didactic transposition theory is often considered as an effective educational answer to contemporary anthropological challenges. The main purpose of Chevallard's didactic transposition theory (Chevallard, 1985; Kang, Kilpatrick, 1992; Bosch, Gascón, 2006; Klisinska, 2009; Chevallard, Bosch, 2014) is focused on accurate, effective and student-friendly transformation of highly theoretical scientific disciplines from modern engineering and physics research into the didactic sphere of educational and easily understandable STEM-disciplines. It is very complex and very important for didactic transposition theory to make a proper simplification of the studied material without undesirable distortion or misrepresentation of the original scientific concepts and facts. The educational idea of constructivism philosophy in applied didactics is grounded on the fact that it is impossible to transfer complete, comprehensive knowledge to a student. The only successful way for effective learning is to create favorable educational conditions, which will facilitate acquisition of new knowledge by students.

The basic ideas of constructivism philosophy in education are based on Piaget's (Piaget, 1950/1973) and Vygotsky's (Vygotsky, 1986) ideas in didactics. Piaget and Vygotsky have analyzed the emergence and formation of new knowledge in students, who are the subjects of the educational process (Piaget, 1950/1973; Vygotsky, 1986). Piaget and Vygotsky have noted that a student acquires some objective information from a lecture (Piaget, 1950/1973; Vygotsky, 1986). However, in most cases a student cannot acquire specific objective information from a lecture. The student develops a specific interpretation of the material presented in the lecture which is strongly dependent on the structure of the learner's mind and memory. As a result, in the student's recollection process he tends to reconstruct his interpretation of the lecture information as his own original knowledge with a peculiar synthesis of objective facts and his interpretations of these facts instead of simple mechanical mapping of objective facts. Piaget and Vygotsky have assumed that the generation of new knowledge within a student's mind is the result of successful resolution of the permanent contradiction between existing structure of the learning subject-learner and the reality of outward things (Piaget, 1950/1973; Vygotsky, 1986). Piaget and Vygotsky have assumed that it is impossible for a student to have a direct and comprehensive knowledge about the outside world (Piaget, 1950/1973; Vygotsky, 1986). They have noted that it is possible to achieve a successful embodiment of a student's knowledge about the outer world only through intensive activation of the subject's individual experience (Piaget, 1950/1973; Vygotsky, 1986). Piaget and Vygotsky have assumed that first-hand personal experience determines the overall performance of individual learning dynamics including the formation of individual cognitive perception, memorization, and forgetting of certain specific information (Piaget, 1950/1973; Vygotsky, 1986). They have supposed that student's knowledge is the process of construction of reality rather than discovery of reality (Piaget, 1950/1973; Vygotsky, 1986). It has been shown in constructivism that a student's knowledge is a set of the conceptual linkages, causality interconnections, preferable operations and successful principles, which helps the student achieve a competitive advantage (Piaget, 1950/1973; Vygotsky, 1986). Constructivism assumes that the educational purpose of cognition is a successful formation of constructs and virtual mind-based assemblies of surrounding reality, which are quite adequate for the phenomena of real life. Didactic transposition is focused on issues and problems of an accurate and efficient adaptation of students to the growing requirements of the educational environment. Successful educational adaptation ensures the formation of student's abilities toward effective and creative operation with new knowledge as well as successful knowledge application to the solution of applied engineering problems.

Every attentive student has some level of individual experience, associated with personal cognitive perception of learning material. An attentive teacher also does his/her best to ensure the proper visualization and specialty-related adaptation of the introduction of the learning problem to simplify the student's efforts to search for a solution of the technical problem. The motivated and ambitious students usually demonstrate a favorable and approving reaction in response to the lecturer's didactic efforts. Quite often a successful and effective student's memorization is based on efficient didactic encoding of learning information and student-friendly schematization of educational data. Modern educational science assumes that the effectiveness of the process of memorization is determined by a student's learning activity and initiative as well as the subject student's intentions toward achievement of individual educational goals. It follows, from the activity approach, to consider the process of forgetting as an expedient phenomenon. The process of forgetting ensures that only the things and facts which are strongly included in the process of subject's activity and are important for a learner remain within student's mind. It was empirically found in educational sciences that the strongest and the most effective connections and linkages in memory are formed only in the case where the object of memorization is the scope of an educational activity. The level of an engagement of the object of memorization to the further activity of the student determines the further productivity and period of existence of the correspondent newly-emerged connections and linkages within learner's memory. A conclusion may be made that success in memorization is mainly determined by the level of engagement of the memorized object in the student's educational activity and, in lesser degree, by the characteristics of memorized object. All technical knowledge in engineering sciences is based on human applied activity. So, it is easier to remember applied technical knowledge by showing the transposition of engineering knowledge from the original technical spheres to the representation of technical knowledge in didactics of engineering education. Modern engineering education shows that it is possible to enhance the didactics of numerous engineering disciplines through the application of the methodology of transposition of mathematical knowledge, which was originally developed by Yves Chevallard (Chevallard, 1985; Chevallard, Bosch, 2014), to instructional problems of technical knowledge transposition. Practical applications of didactic transposition theory to teaching of engineering disciplines require additional research of institutional educational practices which provide generation and further applications of certain specific knowledge. For example, emergence, formation and distribution of many elements of technical knowledge quite often take place beyond the academic communities. Therefore, new technical knowledge passes several practical adaptations before it finds applied educational use for academic community.

Moreover, it is important to understand that memorization is not individual educational action. Memorization is the dynamic process, which is mandatorily included in the practice of the community. New levels and novel stages of memory development are mainly associated with educational implementations of new socio-cultural tools and techniques as well as with new approaches to student educational activity and, in lesser degree, to the mental state of student's psychic functions (Kostikov et al., 2017; Perig et al., 2017; Perig, 2017).

Fig. 1. A student who tries to quickly remember the learning material only by reading

Fig. 2. A student who tries to quickly remember the learning material only by writing down his notes

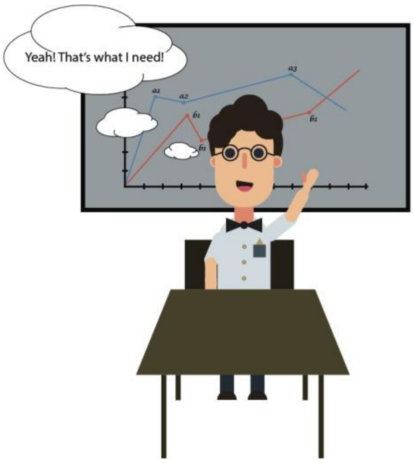


Fig. 3. A student who tries to quickly remember the learning material by making posters and wallpapers with the studied material

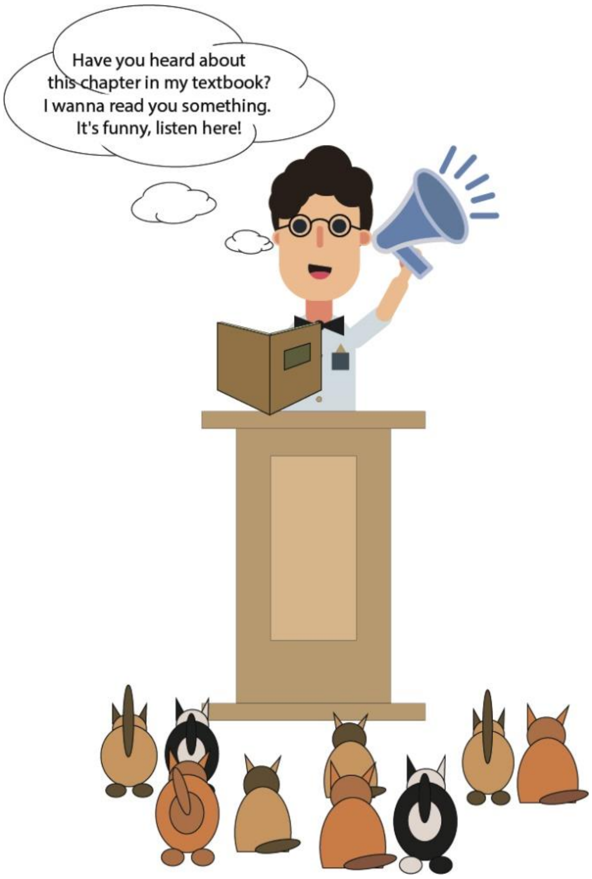


Fig. 4. A student who tries to quickly remember the learning material by reading aloud and by making a speech before available listeners

2. The State of the Art. Introduction and the Background

Pedagogical processes of learning and forgetting are complex internal and often implicit psychological processes, which attract a lot of research efforts of such researchers as Aberšek et al. (Aberšek et al., 2014), Barry et al. (Barry et al., 2017), Bosch et al. (Bosch, Gascón, 2006), Champagne et al. (Champagne et al., 1980), Chen (Chen, 2017), Chevallard et al. (Chevallard, 1985; Chevallard, Bosch, 2014), Coolen et al. (Coolen et al., 2005), Davidovitch et al. (Davidovitch et al., 2008), Doi et al. (Doi et al., 2010), Donner (Donner, 2005), Enelund et al. (Enelund et al., 2013), Finch et al. (Finch et al., 2018), Foster et al. (Foster et al., 2018), Fox et al. (Fox et al., 2015), Gerstner et al. (Gerstner et al., 2014), Gibbons et al. (Gibbons, Langton, 2016), Heersmink et al. (Heersmink, Carter, 2017; Heersmink, 2018), Jaber et al. (Jaber, Bonney, 1996; Jaber, Bonney, 1997; Jaber et al., 2013), Kang et al. (Kang, Kilpatrick, 1992), Kangas et al. (Kangas et al., 2017), Klisinska (Klisinska, 2009), Kostikov et al. (Kostikov et al., 2017), Mallot (Mallot, 2013), Mayer (Mayer, 2014; Mayer, 2015; Mayer, 2016; Mayer, 2017), Murre et al. (Murre, Chessa, 2011), Nelson et al. (Nelson et al., 2015), Nomura et al. (Nomura, Asai, 2011), O'Connor (O'Connor, 2004), Omar (Omar, 2014), Perig et al. (Perig et al., 2017; Perig, 2017), Piaget (Piaget, 1950/1973), Plato (Plato, 1892), Rahmandad et al. (Rahmandad et al., 2009), Salameh et al. (Salameh et al., 1993), Sayre et al. (Sayre et al., 2012), Sun et al. (Sun et al., 2014), Vygotsky (Vygotsky, 1986), Wilson et al. (Wilson et al., 2012), and others.

Existing and emerging modern trends have comprehensively showed the actual necessity of the basic expansion of memory concepts and a change of horizons for rethinking memory. Modern scientific research into human memory-related problems has given a priority to memory technology.

Heersmink and Carter (2017) have studied metaphysical, epistemic, and ethical dimensions of memory technologies (Heersmink, Carter, 2017). Progress in metaphysical aspects of memory technologies require advanced research into the nature, information properties and functions of memory technologies, the means of classification and the ontological status of memory technologies (Heersmink, Carter, 2017). Research into the epistemological aspects of memory focuses attention on the integrity and reliability of external memory, on conditions when external memory is considered as knowledge, and on metacognitive monitoring of external memory processes (Heersmink, Carter, 2017). An ethical slice was focused on consideration of the desirability of the influence of different technologies on biological memory and on the estimation of technological influences on the human subject (Heersmink, Carter, 2017).

Heersmink (2018) has analyzed the different ways, routes and modes, which are available for interlacing artifacts with autobiographical memory systems (Heersmink, 2018). Heersmink (2018) has proposed the narrative approach to a human being (Heersmink, 2018). Heersmink (2018) has assumed that it is possible to consider people as unraveling stories of their lives (Heersmink, 2018). It was shown that unfolding the story of human life not only determines the current individual convictions and desires but also directs our further aims and actions in a future (Heersmink, 2018). Heersmink (2018) has supposed that human autobiographical memory is partially associated with his embodied interactions with such artifacts as photos, videos, diaries, souvenirs, artworks, jewellery etc, which initiate the activation of individual autobiographical memories (Heersmink, 2018). Heersmink (2018) has concluded that it is impossible to characterize the human being as brain-determined multiple psychological states or as organism-realized biological states (Heersmink, 2018). Heersmink (2018) has supposed that it is necessary to consider the human being as a relational and distributed assembly (Heersmink, 2018).

However, the further enhancement of modern educational process in technical universities requires additional research of learning and forgetting processes (Figs. 1–4) in context of existing analogies of educational (Figs. 1–4) and physical (Figs. 5–6) processes.

3. Aims and Scopes of the Article. Novelty

The subject of the research is the relationship between learning (Figs. 1–4) and physical processes (Figs. 5–6) in hydraulics.

The object of the research is the description of an analogy between educational (Figs. 1–4) and hydraulic (Figs. 5–6) processes.

The scope of the research is the formulation of detailed educational guidance in applied pedagogical concepts (Figs. 1–4) for technical instructors of civil, hydraulic, mechanical, chemical and materials engineering disciplines (Figs. 5–6).

The prime novelty of the research is a unified engineering-friendly formulation of learning processes (Figs. 1–4) through a direct analogy with physical processes in civil, hydraulic, mechanical, chemical and materials engineering (Figs. 5–6).

4. The Processes of Learning and Forgetting

The formation of sustainable knowledge (Figs. 1–4) requires a student to regularly overcome some forgetting processes as shown in Fig. 5. Curve AB corresponds to the learning process and curve BCD corresponds to the process of forgetting. Curve CE corresponds to the process of a faster than normal recovery of knowledge. A steeply sloping curve CE is associated with an increase in the amount of knowledge in random access memory due to the transition from long-term memory into random access memory, whenever the knowledge is needed again. Curve EF corresponds to reduced forgetting after recollection or repetition.

Forgotten material does not disappear from memory but is transferred from a student's random access memory to long-term memory. When this material is needed again, it is recalled from the student's long-term memory. The success and speed of the recall process is directly proportional to the number of times the studied material has been recalled (Figs. 1–4).

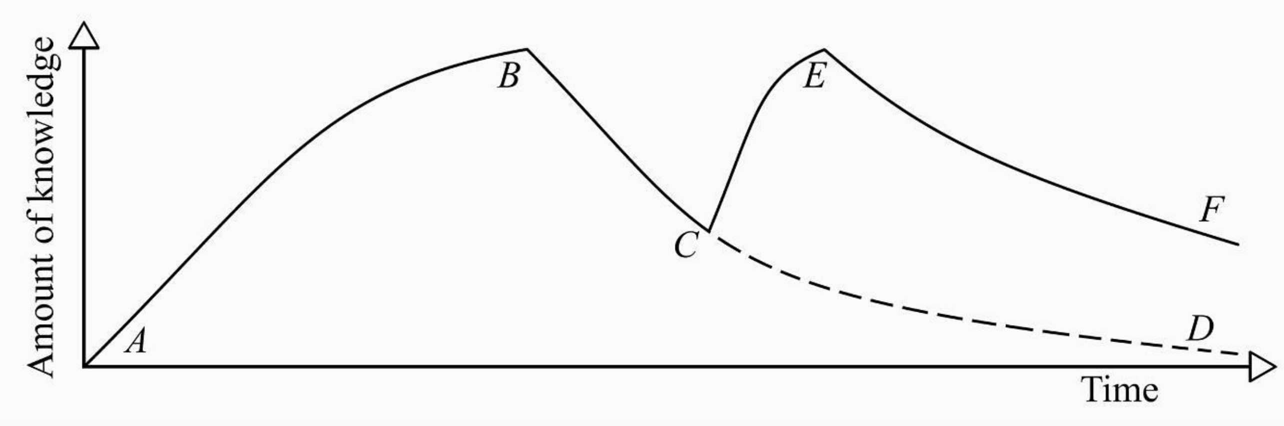


Fig. 5. Change in the level of knowledge in a student's random access memory

When a technical university trains teachers and instructors of technical disciplines, it is very important to explain these applied pedagogic ideas and concepts (Figs. 1–4) with a close connection to proper examples from applied technical disciplines (Figs. 5–6). Proper association of pedagogical concepts (Figs. 1–4) with a student's major (Figs. 5–6) is especially important when the lecturer explains the laws of knowledge accumulation in the process of education, the partial forgetting of knowledge, and knowledge recovery in memory. When the lecturer explains the pedagogic processes (Figs. 1–4) to students majoring in civil, hydraulic, mechanical, chemical and materials engineering and fluid mechanics, then it is more suitable to use the hydraulic model of the process of education (Figs. 5–6).

5. Hydraulic Technical Analogy for Description of Learning Processes

Comparison of human memory work with flowing fluid (Perig et al., 2010; Perig, Golodenko, 2014a; Perig, Golodenko, 2014b; Perig, Golodenko, 2015; Perig, Golodenko, 2016a; Perig, Golodenko, 2016b; Perig, Golodenko, 2017a; Perig, Golodenko, 2017b) is very popular in people language. The pedagogical ideas of Figs. 1–5 for civil, mechanical, chemical and materials engineering students majoring in fluid mechanics (Perig et al., 2010; Perig, Golodenko, 2014a; Perig, Golodenko, 2014b; Perig, Golodenko, 2015; Perig, Golodenko, 2016a; Perig, Golodenko, 2016b; Perig, Golodenko, 2017a; Perig, Golodenko, 2017b) can be described by using the design scheme of a hydraulic system, shown in Fig. 6.

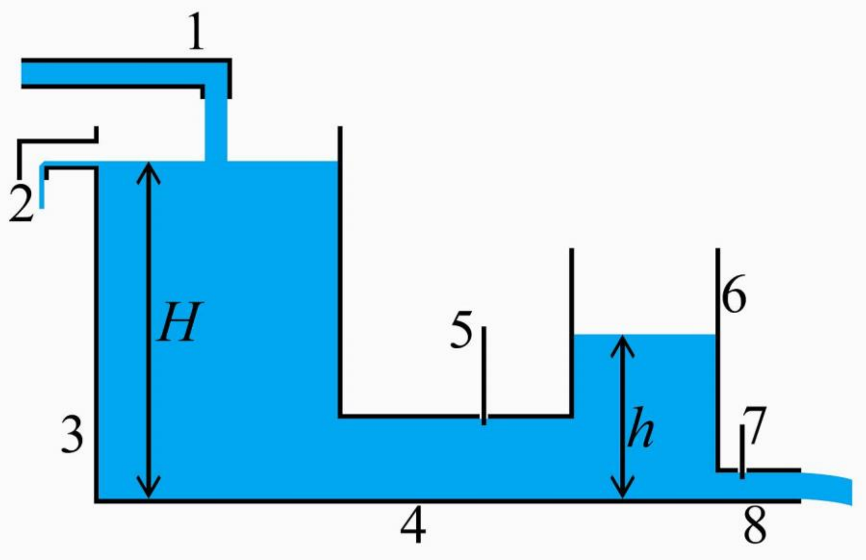


Fig. 6. Hydraulic model for description of the learning and forgetting processes

Digital numbers in Fig. 6 are used to denote the following machine parts and elements of the hydraulic system:

1 – fluid supply conduit into the head tank;
2 – discharge tube to maintain a constant level of fluid *H* in the head tank;
3 – head tank;
4 – fluid supply conduit from the head tank into the receiving tank, (i.e. the inlet of knowledge flow and memory reconstruction of previously studied material);
5 – gate valve, which regulates inflow into the receiving tank, (i.e. information flow into random access memory);
6 – receiving tank, where the fluid level *h* simulates the amount of knowledge of a certain specific discipline within the random access (working) memory;
7 – gate valve, which regulates outflow from the receiving tank representing the flow of forgotten information, (i.e. the flow of information which is transferred from the student's random access memory into the long-term memory);
8 – discharge tube, providing fluid outflow from the receiving tank, representing the flow of forgotten information, which is transferred to a student's long-term memory.

6. Analytical Approach to Laminar Hydraulic Modeling of Learning Processes

In the beginning, it is useful for a lecturer to address the first case of a slow laminar fluid flow through a hydraulic system in Fig. 6. It is possible to derive an analytical estimation for the laminar flow problem in Fig. 6 by neglecting the local hydraulic resistances.

6.1. Laminar-Flow based Analytical Solution of a Hydraulic Analogy for the expansion or learning phase

It is necessary to note that according to the Bernoulli equation for forced flow of fluid within conduit 4 in the process of filling (tanking up) the receiving tank 6 we have

$$H - h = h_{12}, \tag{1}$$

where H ([m], [mm]) and h ([m], [mm]) are the marks of free liquid surfaces or the fluid level marks in the head and receiving tanks (Fig. 6).

Loss of pressure head (height loss) can be estimated with the Darcy-Weisbach equation as

$$h_{12} = \left(\frac{1}{(2 \cdot g)}\right) \cdot \lambda \cdot \left(\frac{L_1}{D_1}\right) \cdot \left(V_1^2\right), \tag{2}$$

where λ is the flow friction coefficient, L_1 ([m], [mm]) and D_1 ([m], [mm]) are the length and diameter of conduit 4, $V_1 = V$ ([m/s], [mm/s]) is the fluid velocity in this tube 4, and g ([m/s^2], [mm/s^2]) is gravity acceleration.

The Poiseuille formula yields the following expression for the laminar flow friction coefficient

$$\lambda = \frac{64}{\mathbf{R}} = \left(\frac{(64 \cdot \nu)}{(V_1 \cdot D_1)} \right), \tag{3}$$

where **R** is Reynolds number and ν ([m^2/s], [mm^2/s]) is the kinematic viscosity coefficient.

Substitution of the Poiseuille formula (3) into the Darcy-Weisbach equation (2) and (2) into (1) results in expression

$$H - h = \left(\frac{1}{(2 \cdot g)} \right) \cdot \left(\frac{(64 \cdot \nu)}{(V_1 \cdot D_1)} \right) \cdot \left(\frac{L_1}{D_1} \right) \cdot \left(V_1^2 \right) = \frac{(32 \cdot \nu \cdot V_1 \cdot L_1)}{(g \cdot D_1^2)} = \frac{V_1}{\left(\frac{(g \cdot D_1^2)}{(32 \cdot \nu \cdot L_1)} \right)} = \frac{V_1}{A_1}, \tag{4}$$

where

$$A_1 = \left(\frac{(g \cdot D_1^2)}{(32 \cdot \nu \cdot L_1)} \right). \tag{5}$$

It is obvious from the previous expression (4) that

$$V_1 = V = A_1 \cdot (H - h). \tag{6}$$

According to the continuity equation

$$V_1 \cdot \omega_1 = V_t \cdot \omega_t, \tag{7}$$

we can estimate the rise rate (the rate of lifting) of the fluid level mark in the receiving tank 6 as

$$V_t = \frac{V_1 \cdot \omega_1}{\omega_t} \tag{8}$$

or

$$V_t = A_1 \cdot (H - h) \cdot \left(\frac{\omega_1}{\omega_t} \right) \tag{9}$$

where ω_1 ([m^2], [mm^2]) is the cross-sectional area of conduit 4, and ω_t ([m^2], [mm^2]) is the cross-sectional area of the receiving tank 6.

The increment of the fluid level mark in the receiving tank 6, which simulates the amount of student's knowledge within working memory, can be estimated as

$$dh = V_t \cdot dt \tag{10}$$

or

$$dh = A_1 \cdot (H - h) \cdot \left(\frac{\omega_1}{\omega_t} \right) \cdot dt. \tag{11}$$

Separation of variables in the last differential equation (11) results in the expression

$$\frac{dh}{(H - h)} = \left(A_1 \cdot \left(\frac{\omega_1}{\omega_t} \right) \right) dt. \tag{12}$$

This equation (12) can be integrated by considering that

$$d(H - h) = -dh \tag{13}$$

and

$$\frac{d(H - h)}{(H - h)} = -\left(A_1 \cdot \left(\frac{\omega_1}{\omega_t} \right) \right) dt. \tag{14}$$

The first integral of this expression (14) yields

$$\ln(H - h) = -\left(A_1 \cdot \left(\frac{\omega_1}{\omega_t} \right) \right) \cdot t + \ln(H) \tag{15}$$

because

$$(H-h)\big|_{t=0}=H. \tag{16}$$

Exponentiation of this integral (15) results in

$$\frac{(H-h)}{H}=e^{-\beta_1\cdot t}, \tag{17}$$

where

$$\beta_1=\left(A_1\cdot\left(\frac{\omega_1}{\omega_t}\right)\right) \tag{18}$$

is the time constant [1/s] for the process of filling (tanking up) the receiving tank 6.

The solution of the last expression yields that the fluid level mark in the receiving tank in the process of filling is $h = H\cdot[1 - \exp(-\beta_1\cdot t)]$ ([m], [mm]) or $h = H\cdot(1 - e^{-\ln 2\cdot t/\tau})$ ([m], [mm]), where $\tau = \ln 2/\beta_1$ [s] is the time interval for which the fluid level mark in the receiving tank in the process of filling the tank reaches a value of $h = (1 - e^{-\ln 2})\cdot H = H/2$ ([m], [mm]).

The solution of the last expression (17) yields that the fluid level mark in the receiving tank in the process of filling is

$$h=H\cdot\left(1-e^{-\beta_1\cdot t}\right) \tag{19}$$

or

$$h=H\cdot\left(1-\exp\left(-(\ln 2)\cdot\left(\frac{t}{\tau}\right)\right)\right), \tag{20}$$

where

$$\beta_1=\frac{\ln 2}{\tau} \tag{21}$$

and

$$\tau=\frac{\ln 2}{\beta_1} \tag{22}$$

is the time interval [s] for which the fluid level mark in the receiving tank in the process of filling (tanking up) the receiving tank reaches a value of

$$h^*=H\cdot\left(1-e^{-(\ln 2)}\right)=\frac{H}{2}. \tag{23}$$

Pedagogically, these derived formulae (19) – (20) for h ([m], [mm]) simulate the increase in the amount of knowledge in the student's random access memory in the process of education, where time τ [s] (22) is the time interval for which the student's random access memory receives half of all information to be memorized.

Therefore, the level of fluid in the receiving tank in Fig. 6 simulates the amount of knowledge of a specific discipline within the student's random access memory. It is possible to derive curves AB and BD in Fig. 5 with the concepts of Fig. 6. If gate valve 5 is open and gate valve 7 is closed, then the fluid level mark in the receiving tank is determined as

$$h=H\cdot\left(1-e^{\left(-(\ln 2)\cdot\left(\frac{t}{\tau}\right)\right)}\right), \tag{24}$$

which corresponds to the curve AB in Fig. 5, where h ([m], [mm]) is the fluid level mark in the receiving tank at time t [s]; H ([m], [mm]) is the fluid level mark in the head tank at time t [s]; and τ [s] is the time for which the fluid level mark in the receiving tank achieves the value of $H/2$ ([m], [mm]).

6.2. Laminar-Flow based Analytical Solution of a Hydraulic Analogy for the recession or forgetting phase

It is noted that according to the Bernoulli equation for forced flow of fluid within conduit 8 in the discharge process of receiving tank 6 we have

$$h = h_{12}, \tag{25}$$

where h ([m], [mm]) is the level mark of the free liquid surface in the receiving tank (Fig. 6).

Loss of pressure head (height loss) can be estimated with the Darcy-Weisbach equation as

$$h_{12} = \left(\frac{1}{(2 \cdot g)}\right) \cdot \lambda \cdot \left(\frac{L_2}{D_2}\right) \cdot \left(V_2^2\right), \tag{26}$$

where λ is flow friction coefficient, L_2 ([m], [mm]) and D_2 ([m], [mm]) are length and diameter of conduit 8, $V_2 = V$ ([m/s], [mm/s]) is the fluid velocity in this tube 8, and g ([m/s^2], [mm/s^2]) is gravity acceleration.

The Poiseuille formula yields the following expression for laminar flow friction coefficient

$$\lambda = \frac{64}{\mathbf{R}} = \left(\frac{(64 \cdot \nu)}{(V_2 \cdot D_2)}\right), \tag{27}$$

where **R** is Reynolds number and ν ([m^2/s], [mm^2/s]) is the kinematic viscosity coefficient.

Substitution of the Poiseuille formula (27) into the Darcy-Weisbach equation (26) and (26) into (25) results in the expression

$$h = \left(\frac{1}{(2 \cdot g)}\right) \cdot \left(\frac{(64 \cdot \nu)}{(V_2 \cdot D_{21})}\right) \cdot \left(\frac{L_2}{D_2}\right) \cdot \left(V_2^2\right) = \frac{(32 \cdot \nu \cdot V_2 \cdot L_2)}{(g \cdot D_2^2)} = \frac{V_2}{\left(\frac{(g \cdot D_2^2)}{(32 \cdot \nu \cdot L_2)}\right)} = \frac{V_2}{A_2}, \tag{28}$$

where

$$A_2 = \left(\frac{(g \cdot D_2^2)}{(32 \cdot \nu \cdot L_2)}\right). \tag{29}$$

It is obvious from the previous expression that

$$V_2 = V = A_2 \cdot h. \tag{30}$$

According to the continuity equation

$$V_2 \cdot \omega_2 = V_t \cdot \omega_t \tag{31}$$

we can estimate the rate of lowering of the fluid level mark in the receiving tank as

$$V_t = \frac{V_2 \cdot \omega_2}{\omega_t} \tag{32}$$

or

$$V_t = A_2 \cdot h \cdot \left(\frac{\omega_2}{\omega_t}\right), \tag{33}$$

where ω_2 ([m^2], [mm^2]) is the cross-sectional area of conduit 8, and ω_t ([m^2], [mm^2]) is the cross-sectional area of the receiving tank 6.

We estimate the negative increment of fluid level mark in the discharging of receiving tank as

$$dh = -V_t \cdot dt \tag{34}$$

or

$$dh = -A_2 \cdot h \cdot \left(\frac{\omega_2}{\omega_t}\right) \cdot dt. \tag{35}$$

Separation of variables in the last differential equation (35) results in the expression

$$\frac{dh}{h} = -A_2 \cdot \left(\frac{\omega_2}{\omega_t}\right) \cdot dt. \tag{36}$$

The first integral of this expression (36) yields

$$\ln(h) = -\left(A_2 \cdot \left(\frac{\omega_2}{\omega_t}\right)\right) \cdot t + \ln(h_0) \tag{37}$$

because

$$(h)\big|_{t=0} = h_0 \,. \tag{38}$$

Exponentiation of this integral (37) results in

$$\frac{h}{h_0} = e^{-\beta_2 \cdot t} \,, \tag{39}$$

where

$$\beta_2 = \left(A_2 \cdot \left(\frac{\omega_2}{\omega_t} \right) \right) \tag{40}$$

is the receiving tank 6 discharging process time constant [1/s].

The solution of the last expression yields that the fluid level mark in the receiving tank in the process of discharging is

$$h = h_0 \cdot e^{-\beta_2 \cdot t} \tag{41}$$

or

$$h = h_0 \cdot \left(\exp\left(-(\ln 2) \cdot \left(\frac{t}{T} \right) \right) \right), \tag{42}$$

where

$$\beta_2 = \frac{\ln 2}{T} \tag{43}$$

and

$$T = \frac{\ln 2}{\beta_2} \tag{44}$$

is the time interval [s] for which the fluid level mark in the discharging receiving tank reaches the value of

$$h^{**} = h_0 \cdot \left(e^{-(\ln 2)} \right) = \frac{h_0}{2} \,. \tag{45}$$

Pedagogically, these derived formulae (41) – (42) for *h* ([m], [mm]) simulate decrease in the knowledge in the student's random access memory in the process of education, where time *T* [s] is the time interval for which student's random access memory still contains half of the information memorized earlier.

Pedagogically, gate valve 5 can regulate the memory rate (the memory rate is higher in every successive process of recall than during initial training), and gate valve 7 can regulate the forgetting rate (the forgetting rate is slower in every successive process of recall).

Therefore, if gate valve 5 is closed and gate valve 7 is open, then the fluid level mark in the receiving tank is

$$h = h_0 \cdot \left(e^{\left(-(\ln 2) \cdot \left(\frac{t}{T} \right) \right)} \right), \tag{46}$$

which corresponds to the curve BD in Fig. 5, where h_0 ([m], [mm]) is the fluid level mark in the receiving tank at the time of opening of gate valve 5; *T* [s] is time for which the fluid level mark in the receiving tank is reduced to the value of $h_0/2$ ([m], [mm]).

However, this first "laminar case" (1) – (46) with available analytical solution (Figs. 5–6) is quite "slow" and requires a long running time as a computational or physical classroom demonstration experiment for engineering students.

7. Numerical Approach to Turbulent Hydraulic Modeling of Learning Processes

In further explanation, it is important for a lecturer to address the second case of a fast, turbulent fluid flow through a hydraulic system in Fig. 6. It is possible to derive a numerical estimation for the turbulent flow problem in Fig. 6 for the "turbulent case" accounting for the local hydraulic resistances. This second "turbulent case" with the absence of an analytical solution is relatively fast and has an acceptable running time to be considered as suitable for a computational or physical classroom demonstration experiment for engineering students.

The lecturer notes that previous formulae (2) and (26) for the Darcy-Weisbach equation are also valid for turbulent modes of fluid flow in the second "turbulent case" but the friction coefficient λ for turbulent flow should be determined with formula (47) instead of the previous "laminar λ-expressions" (3) and (27).

Flow friction coefficient λ (Darcy's constant (3), (27)) in formulae (2) and (26) for hydraulically rough pipes in a square resistance law zone (with Reynolds numbers **R** > ((500▪D)/Δ_{eq})) can be estimated with the Shifrinson formula as

$$\lambda = 0.11 \cdot \left(\frac{\Delta_{eq}}{D} \right)^{0.25}, \tag{47}$$

where Δ_{eq} [mm] is an equivalent pipe roughness and D [mm] is an internal pipe diameter.

It is necessary to consider that the head (height) loss of a local resistance can be estimated with Weisbach formula as

$$h_{loc} = \zeta \cdot \left(\frac{V^2}{2 \cdot g} \right), \tag{48}$$

where ζ is the drag coefficient of a local resistance.

For the inlet into the conduit from the tank we have a value of a local resistance $\zeta_{entry} = 0.5$. For the outlet from the conduit into the tank we have a value of a local resistance $\zeta_{exit} = 1.0$.

It is possible to estimate the rate of opening of gate valve (or valve opening position) by the following expression:

$$n = \frac{\omega_0}{\omega}, \tag{49}$$

where ω ([m^2], [mm^2]) is the cross-sectional area of the conduit, and ω_0 ([m^2], [mm^2]) is the area of the open cross-section of gate valve. It is possible to list the values of coefficient of a local resistance of gate valve ζ_{latch} in the following Table 1:

Table 1. The numerical values of coefficient of a local resistance of a gate valve ζ_{latch}

n	ζ_{latch}
1.00	0.15
0.75	0.20
0.50	2.00
0.25	20.0

7.1. Turbulent-Flow based Numerical Solution of a Hydraulic Analogy for the expansion or learning phase

In the beginning of the "turbulent modeling" we will analyze the filling stage of the receiving tank 6 in Fig. 6. This turbulent mode of the hydraulic stage (Fig. 6) simulates the learning stages for memorization and repetition of the studied material (Figs. 1–5). It is also possible to neglect the velocities of displacements of fluid levels in tanks 3 and 6. We write the following Bernoulli equation for this turbulent hydraulic stage (Fig. 6), which generalizes the previous idealized expression (1):

$$H - h = \left(\lambda_1 \cdot \left(\frac{L_1}{D_1} \right) + \zeta_1 \right) \cdot \left(\frac{\left(V_1^2 \right)}{\left(2 \cdot g \right)} \right), \tag{50}$$

where H ([m], [mm]) and h ([m], [mm]) are the level marks of the free liquid surfaces or the fluid level marks in the head 3 and receiving 6 tanks (Fig. 6). Index one "1" in (50) corresponds to fluid supply conduit 4, which connects tanks 3 and 6. The total (resultant) drag coefficient of a local resistance ζ_1 in (50) is as follows:

$$\zeta_1 = \zeta_{entry} + \zeta_{exit} + \zeta_{latch} . \tag{51}$$

We will assume the value of the coefficient of local resistance of the gate valve 5 in (51) is equal to $\zeta_{latch} = 20$ for the rate of opening of the gate valve $n = 0.25$ (Table 1) in further turbulent modeling (Fig. 6) of the educational stage of memorization of the studied material (Figs. 1–5).

We will also assume the value of local resistance coefficient of gate valve 5 in (51) equal to $\zeta_{latch} = 0.15$ for the rate of gate valve opening $n = 1.00$ (Table 1). This allows further hydraulic-based turbulent modeling (Fig. 6) of the educational stage of repetition and review of the studied material (Figs. 1–5) with a quicker completion (restocking) of the student's working memory.

Equation (50) yields the following expression for the average fluid velocity through the section of the conduit 4:

$$V_1 = \sqrt{\left(\frac{((2 \cdot g) \cdot (H - h))}{\left(\lambda_1 \cdot \left(\frac{L_1}{D_1} \right) + \zeta_1 \right)} \right)} . \tag{52}$$

Use of the previous expressions (7) and (8) yields the following generalized formula for the velocity of displacement of the fluid level mark in receiving tank 6 as

$$V_t = \left(\frac{\omega_1}{\omega_t} \right) \cdot \sqrt{\left(\frac{((2 \cdot g) \cdot (H - h))}{\left(\lambda_1 \cdot \left(\frac{L_1}{D_1} \right) + \zeta_1 \right)} \right)} , \tag{53}$$

where ω_1 ([m^2], [mm^2]) is the cross-sectional area of conduit 4, and ω_t ([m^2], [mm^2]) is the cross-sectional area of the receiving tank 6.

The increment of the turbulent fluid level mark in receiving tank 6, which simulates the amount of student's knowledge within working memory, can be estimated by the following generalization of the previous expression (10) as

$$dh = \left(\left(\frac{\omega_1}{\omega_t} \right) \cdot \sqrt{\left(\frac{((2 \cdot g) \cdot (H - h))}{\left(\lambda_1 \cdot \left(\frac{L_1}{D_1} \right) + \zeta_1 \right)} \right)} \right) \cdot dt . \tag{54}$$

The total fluid level mark in the receiving tank 6 we will estimate as

$$h_i = h_{i-1} + dh \tag{55}$$

or

$$h_i = h_{i-1} + \left(\left(\left(\frac{\omega_1}{\omega_t} \right) \cdot \sqrt{\left(\frac{((2 \cdot g) \cdot (H - h))}{\left(\lambda_1 \cdot \left(\frac{L_1}{D_1} \right) + \zeta_1 \right)} \right)} \right) \cdot dt \right) . \tag{56}$$

7.2. Turbulent-Flow based Numerical Solution of a Hydraulic Analogy for the recession or forgetting phase

At the second stage of the "turbulent modeling" we will analyze the stage of discharge of the receiving tank 6 in Fig. 6. This turbulent mode of hydraulic stage (Fig. 6) simulates the educational stages for forgetting and recession of the studied material (Figs. 1–5). The displacement velocities of fluid levels in the tanks 3 and 6 may be neglected. It is possible to write the following Bernoulli equation for this turbulent hydraulic stage (Fig. 6), which generalizes the previous idealized expression (25):

$$h=\left(\lambda_2\cdot\left(\frac{L_2}{D_2}\right)+\zeta_2\right)\cdot\left(\frac{\left(V_2^2\right)}{(2\cdot g)}\right), \tag{57}$$

where h ([m], [mm]) is the level mark of the free liquid surface or the fluid level mark in the receiving tank 6 (Fig. 6). Index two "2" in (57) corresponds to fluid discharge conduit 8, which provides fluid outflow from the receiving tank 6. The total (resultant) drag coefficient of a local resistance ζ_2 in (57) is as follows:

$$\zeta_2=\zeta_{entry}+\zeta_{latch}. \tag{58}$$

We will assume the value of local resistance coefficient of gate valve 7 in (58) equal to $\zeta_{latch}=0.15$ for the rate of gate valve opening $n=1.00$ (Table 1) in further hydraulic-based turbulent modeling (Fig. 6) for educational stage of forgetting of the previously studied material (Figs. 1–5). We will also assume the value of coefficient of a local resistance of gate valve 7 in (58) equal to $\zeta_{latch}=20.0$ for the rate of gate valve opening $n=0.25$ (Table 1) in further hydraulic-based turbulent modeling (Fig. 6) of the educational stage of reduced forgetting after recollection or repetition (review) of the studied material (Figs. 1–5) with much slower discharge (recession) of the student's working memory.

Equation (57) yields the following expression for the average fluid velocity through the section of the discharge conduit 8:

$$V_2=\sqrt{\left(\frac{(2\cdot g\cdot h)}{\left(\lambda_2\cdot\left(\frac{L_2}{D_2}\right)+\zeta_2\right)}\right)}. \tag{59}$$

Use of the previous expressions (31) and (32) yields the following generalized formula for the displacement velocity of the fluid level mark in the receiving tank 6 as

$$V_t=\left(\frac{\omega_2}{\omega_t}\right)\cdot\sqrt{\left(\frac{(2\cdot g\cdot h)}{\left(\lambda_2\cdot\left(\frac{L_2}{D_2}\right)+\zeta_2\right)}\right)}, \tag{60}$$

where ω_2 ([m^2], [mm^2]) is the cross-sectional area of conduit 8, and ω_t ([m^2], [mm^2]) is the cross-sectional area of the receiving tank 6.

The negative increment of the turbulent fluid level mark in the receiving tank 6, which simulates the amount of student's knowledge within working memory, can be estimated by the following generalization of the previous expression (34) as

$$dh=\left(\left(\frac{\omega_2}{\omega_t}\right)\cdot\sqrt{\left(\frac{(2\cdot g\cdot h)}{\left(\lambda_2\cdot\left(\frac{L_2}{D_2}\right)+\zeta_2\right)}\right)}\right)\cdot dt. \tag{61}$$

The total fluid level mark in the receiving tank 6 we will estimate as

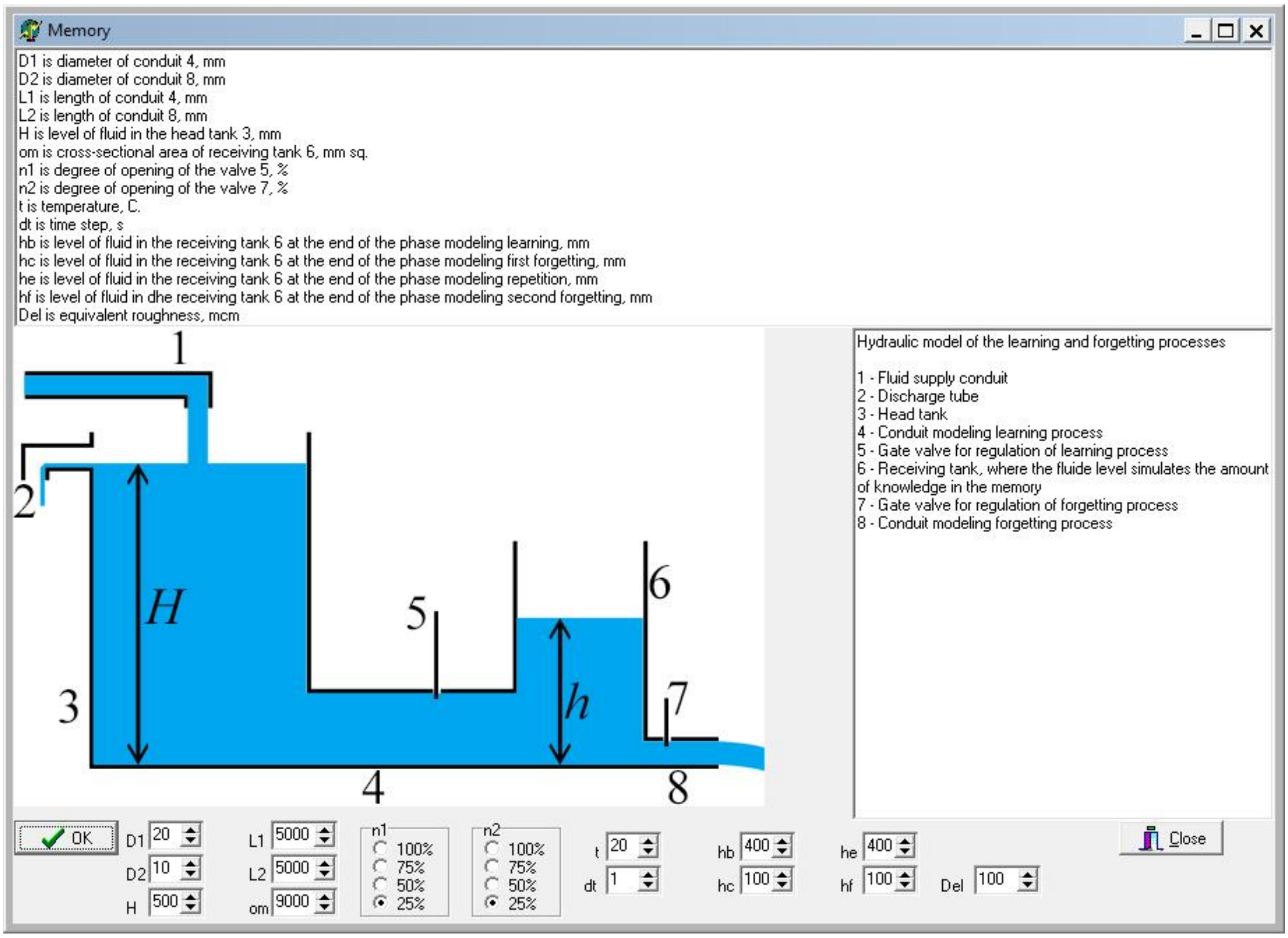
$$h_i = h_{i-1} - dh \tag{62}$$

or

$$h_i = h_{i-1} - \left(\left(\left(\frac{\omega_2}{\omega_t} \right) \cdot \sqrt{ \left(\frac{(2 \cdot g \cdot h)}{\left(\lambda_2 \cdot \left(\frac{L_2}{D_2} \right) + \zeta_2 \right)} \right) } \right) \cdot dt \right). \tag{63}$$

7.3. Graphical Results of a Numerical Solution for Turbulent-Flow based Hydraulic Model of a Student's Learning Process

A computer implementation of a turbulent hydraulic model (47) – (63) resulted in the development of an author-proposed educational computer code (Figs. 7–8), designed for numerical simulation of operating modes of a hydraulic design scheme in Fig. 6 and graphical hydraulic-based visualization of learning processes in Fig. 5.



D1 is diameter of conduit 4, mm
D2 is diameter of conduit 8, mm
L1 is length of conduit 4, mm
L2 is length of conduit 8, mm
H is level of fluid in the head tank 3, mm
om is cross-sectional area of receiving tank 6, mm sq.
n1 is degree of opening of the valve 5, %
n2 is degree of opening of the valve 7, %
t is temperature, C.
dt is time step, s
hb is level of fluid in the receiving tank 6 at the end of the phase modeling learning, mm
hc is level of fluid in the receiving tank 6 at the end of the phase modeling first forgetting, mm
he is level of fluid in the receiving tank 6 at the end of the phase modeling repetition, mm
hf is level of fluid in dhe receiving tank 6 at the end of the phase modeling second forgetting, mm
Del is equivalent roughness, mcm

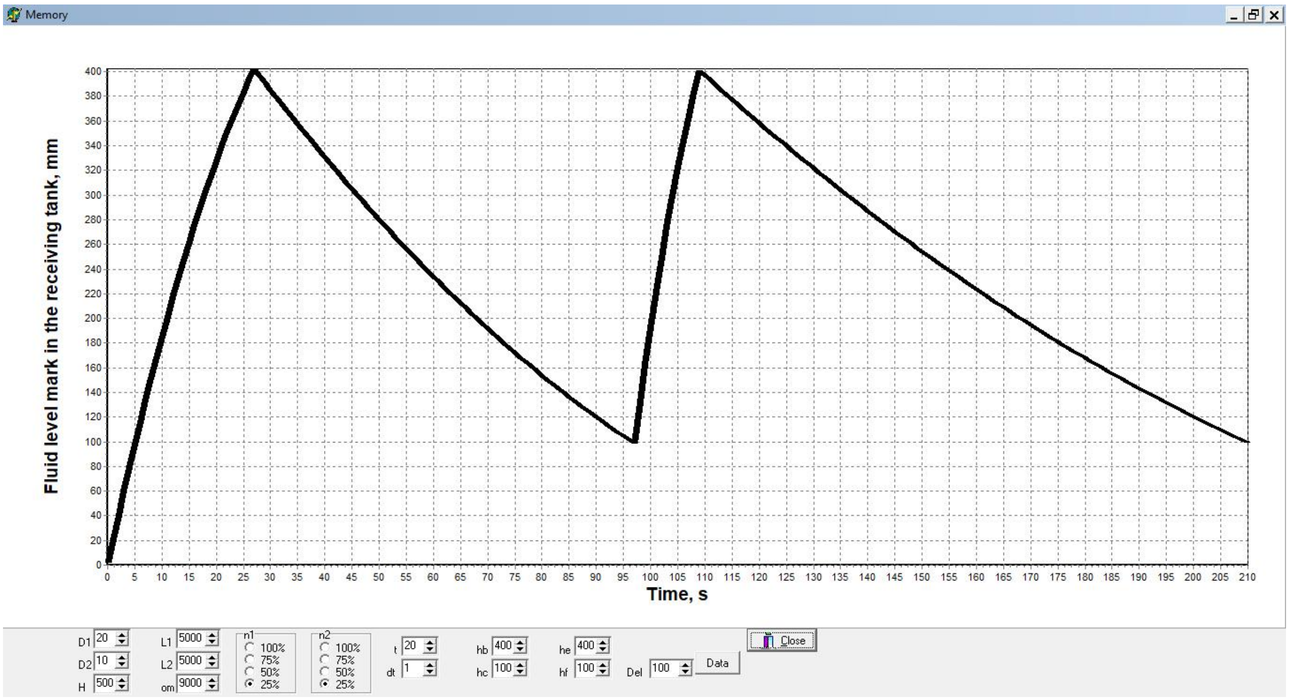
Hydraulic model of the learning and forgetting processes

1 - Fluid supply conduit
2 - Discharge tube
3 - Head tank
4 - Conduit modeling learning process
5 - Gate valve for regulation of learning process
6 - Receiving tank, where the fluide level simulates the amount of knowledge in the memory
7 - Gate valve for regulation of forgetting process
8 - Conduit modeling forgetting process

D1 20
D2 10
H 500
L1 5000
L2 5000
om 9000
n1 ○ 100% ○ 75% ○ 50% ● 25%
n2 ○ 100% ○ 75% ○ 50% ● 25%
t 20
dt 1
hb 400
hc 100
he 400
hf 100
Del 100

Fig. 7. Interface of author-developed computer code for numerical modeling of the learning and forgetting processes through implementation of turbulent hydraulic model (47) – (63)

Computer-derived results of numerical simulation of turbulent flows of fluid (47) – (63) in Figs. 7–8 essentially broaden and supplement previous analytical results (1) – (46) for laminar fluid flows.



D1 20
D2 10
H 500
L1 5000
L2 5000
om 9000
n1 ○ 100% ○ 75% ○ 50% ● 25%
n2 ○ 100% ○ 75% ○ 50% ● 25%
t 20
dt 1
hb 400
hc 100
he 400
hf 100
Del 100

Fig. 8. Graphical visualization of author-developed results for numerical modeling of the learning and forgetting processes through implementation of a turbulent hydraulic model (47) – (63)

8. Discussion

Knowledge of educational psychology (Figs. 1–4) with an emphasis on the mechanisms of memorization and forgetting (Fig. 5) is especially important for instructors of technical disciplines (Figs. 5–8). Moreover, an instructor must share this knowledge with his students to help them properly organize their individual work with the material covered during the semester (Figs. 1–4). The student needs to know that strong knowledge retention (Figs. 1–4) requires several cycles of recollection or repetition (Figs. 5, 8). This means that students are strongly encouraged to prepare themselves for examinations not on the night before the examination but throughout the entire semester (Figs. 1–4). It is preferable not to study and recollect all the bulk volume of required course material (Fig. 1), but in small doses (Figs. 2–4) because the efficiency of the learning process decreases to the end of the phase of study or recollection (Figs. 5, 8).

A lecturer must explain the elements of educational psychology and technical pedagogy (Figs. 1–4) for instructors of technical disciplines using relevant examples, originating from the corresponding engineering disciplines (Figs. 5–8) to make the pedagogical truth more attractive and understandable for technical university students (Figs. 5–8). For this approach to stimulate students' interest, the proposed practical examples must be natural and easy to follow for technical university students, resulting in the studied educational material remaining in the students' memories. It is useful to address technical analogies (Figs. 5–8) and provide examples of periodicity in dynamic processes in nature and technology, which correspond to the technical instructors' major, when the lecturer speaks about periodicity in the educational processes of learning-forgetting-recollection (Figs. 5, 8). It is very important to provide graphical image-bearing ideas (Figs. 1–5) about cross-disciplinary analogies of these periodical processes (Figs. 5, 8) in real complex systems (Figs. 6–7).

The acquaintance of technical university students (Figs. 1–4) with different periodical processes in technology, nature, society, economics, education, and humanities (Figs. 5, 8) provides a broadening of students' ideas and enables the humanization of the technical university educational curriculum (Figs. 1–4). Development and use of simple mathematical models (Figs. 6–7) of periodical processes (Figs. 5, 8) enables the introduction of information technologies to teaching educational psychology and technical pedagogy (Figs. 1–4). When a hydraulics specialist or a fluid power engineer sees communicating vessels before him (Figs. 6–7), they will unwittingly recall the psychological law that memorization accelerates with every new recollection and forgetting decreases with every new repetition (Figs. 1–8).

It is possible to make an analogy with the highest wave (the tenth wave or wreck (decuman) billow) in a stormy sea and the mechanism of student's memory (Figs. 1–8). It is well known that the tenth sea wave, which is very long, appears because of interference of shorter sea waves. A learner's memory mechanism (Figs. 1–8) also involves a peculiar kind of interference of information obtained via human sensory organs, and information which is stored in the student's long-term memory. This communication of information flows may result in the constructive interference of information with the appearance of a flash of dawned inspiration in a student with a deeper understanding of the studied material. Sometimes this superposition of the flows of information results in destructive interference when a student's random access memory erases and is cleared of upsetting unpleasant memories to protect human's mind.

It is very important to "fix" previously studied material in a student's memory through regular organization of refresher control works (Fig. 2), repetitive competitions (Fig. 4), reiterative thematic Olympiads, and display posters repetitively with basic formulae and regularly update these posters (Fig. 3) because with time students may lose awareness of old poster inscriptions (Figs. 2–3). It is also useful to make regular supporting conspectuses and workbooks for memory stimulation (Figs. 2–3).

Humanizing the educational process (Figs. 1–4) while learning mathematical and technical disciplines (Figs. 5–8) attracts students' attention, generates a keen interest, and leads to synergetic cross-disciplinary student understanding. A lecturer describes to students that ideas, models and techniques of hydraulics and continuum mechanics (Figs. 6–7) have the widest applications in technology, natural sciences, medicine, and economics. Why not apply these concepts to learning theory, educational psychology and time management (Figs. 1–4)?

The proposed educational approach for teaching students about learning theory (Figs. 1–4) using technical analogies (Figs. 5–8) is effective because it implicitly uses ideas of didactic transposition theory (Chevallard, 1985; Kang, Kilpatrick, 1992; Bosch, Gascón, 2006; Klisinska, 2009; Chevallard, Bosch, 2014). The authors have provided a student-friendly didactic transposition-based (Chevallard, 1985; Kang, Kilpatrick, 1992; Bosch, Gascón, 2006; Klisinska, 2009; Chevallard, Bosch, 2014) translation of hydraulics laws of laminar fluid flows (1) – (46) for describing knowledge flow in learning theory (Figs. 1–4). Students admitted that our approach helped them to see the "bridges" between hydraulics and human behavior (Figs. 1–4). Curious students sometimes rhetorically argued that our laminar flow-based model (1) – (46) can't describe the quick acquisition of new knowledge by movie superheroes and often refer to the Neo-superhero in the Matrix movie trilogy who managed to "load" new skills and knowledge into his brain in a few minutes. A lecturer encourages the most ambitious and curious students to learn the elements of turbulent flows (47) – (63), which helps them get some engineering ideas about the dynamics of high-velocity fluid flows, and which should help them better understand processes like quick knowledge flow during movie superhero cognition.

The proposed analogy (Figs. 5–8) was regularly described to undergraduate students majoring in civil, mechanical, industrial and control engineering in hydraulics-related disciplines taught by the authors for the last four years. An applied engineering problem of fluid outflow from one water tank to another (Figs. 6–7) is a sound hydraulic-based student-friendly model of the psychological laws of learning and forgetting (Figs. 1–5). Teaching the proposed analogy provides a reduction in student learning time, which was required for student self-study of the fundamentals of hydraulics theory and hydro-mechanics (Figs. 6–7). It was found with targeted students that the study of technical analogies (Figs. 5–8) with learning processes (Figs. 1–5) essentially improves the student's knowledge about laminar ((1) – (46)) and turbulent ((47) – (63)) fluid flow and provides better student understanding of the Darcy-Welsbach equation, the Poiseuille formula, the continuity equation, the Bernoulli equation, and techniques for the solution of differential equations. Examination results showed better student understanding of the above-mentioned topics (1) – (63). Running an accurate, rigorous pedagogical experiment concerning the quantitative measurement of the effectiveness of learning theory teaching using hydraulic analogies (Figs. 5–8) is rather complex now because our hydraulics courses are very limited in classroom hours. We work with small student groups for getting statistically-valid data, while, now, authors have no teaching hours for engineering pedagogy and psychology. Running a pedagogical experiment for estimation of analogy effectiveness will be a matter of further research studies in industrial pedagogy for civil, mechanical, chemical and materials engineering students (Figs. 1–4).

9. Conclusion

The authors have taught two voluntary engineering undergraduate classes in Biofluid mechanics (Rubenstein et al., 2016) using the basic ideas of the present didactic research through wide discussion of Figs. 1–8 and detailed explanation of formulae (1) – (63). These classes involved 4 students in the spring of 2017 and 3 students in the spring of 2018. In addition, the authors taught two other classes using these ideas using Figs. 1 – 6 and practical implementation of an author-proposed numerical computer code in Figs. 7 – 8. One of these was a voluntary undergraduate engineering course in "Information Processing Systems" (Coolen et al., 2005) involving 5 students in the spring of 2018 and the other was "Mathematical Modeling in Biomedical Engineering" (Gerstner et al., 2014; Coolen et al., 2005; Doi et al., 2010; Mallot, 2013; Nomura, Asai, 2011) with 6 students in the spring of 2018.

The authors have also outlined the fundamentals of this approach in Figs. 1–8 in a formulae-free explanation in a voluntary humanitarian-focused graduate course "Subject in philosophical-clinical discourse" with 5 students in the spring of 2018.

It is obvious that the number of students involved in these courses was insufficient for a statistically-valid and statistically-significant educational experiment.

All engineering students who were experienced with differential equations could easily follow through all the hydraulics formulae (1) – (63). Both mathematically-weak technical students and mathematically-free humanitarian students were encouraged to use the author-proposed computer code, which implicitly utilizes hydraulic "turbulent" formulae (47) – (63). The main message, which students should remember, is the simple fact that a student's "learning/forgetting cycle" is a naturally-oscillating educational process which can be easily described with a simple two-vessel hydraulic analogy through analytical "laminar" equations (1) – (46) or numerical "turbulent" expressions (47) – (63).

The explanation of learning dynamics in the present didactic article is not complicated for anyone who has ever looked through modern computational textbooks on learning dynamics (Gerstner et al., 2014; Coolen et al., 2005; Doi et al., 2010; Mallot, 2013; Nomura, Asai, 2011) of biologically-inspired artificial neuronal- and perception-based information-processing systems. Authors of the present educational research strongly believe that students who understand our didactic approach, will be more successful and consistent in the study of extra-complex and mathematically-saturated modern guides (Gerstner et al., 2014; Coolen et al., 2005; Doi et al., 2010; Mallot, 2013; Nomura, Asai, 2011), where they will see the same oscillations in learning systems as we studied in our Figs. 6, 8 but the level of their correspondent mathematical efforts will increase by several times due to the complex nature of Hodgkin–Huxley-like models (Gerstner et al., 2014; Coolen et al., 2005; Doi et al., 2010; Mallot, 2013; Nomura, Asai, 2011) of Bonhoeffer–van der Pol and FitzHugh–Nagumo.

People usually have the greatest practical interest in issues regarding their persons. This simple fact is the basic idea for humanization of the educational process. It is possible to intensify students' attention to the studied technical material through a step-by-step building of a proposed analogy between hydraulic and learning processes, which is based on the similarity between corresponding mathematical models for both processes. Hard-working students have the prime educational problem of managing the growing overload and holding in their memory a cumbersome quantity of studied material in technical, social and human sciences. The author-proposed educational approach provides a better simultaneous understanding of both hydraulics and didactics by acquiring new inter-disciplinary practical knowledge, which helps learners plan an optimal scientific-based mode for effective study and self-study of educational material. This educational research helps students to remember that it is impossible to learn the studied material at the required level of understanding with a single one-time acquaintance without multiple reviews and repetitions.

Analysis of such quasi-periodical processes in education, society, economics, nature, and engineering as learning and forgetting, exemplified in physical systems by such as a hydraulic tank system, economic systems in an overproduction crisis, Kondratviev waves in economic systems, predator-prey ecological systems, respiratory cycles in animals, solar cycles in astronomy, etc. has shown that there are objective analogies between oscillations in these complex systems.

All the above-mentioned processes, like many other complex oscillating systems in nature and society, allow simple approximate descriptions by functions $N = N_0 \cdot (1 - \exp(-\beta \cdot t))$ in the expansion or learning phase and $N = N_0 \cdot \exp(-\beta \cdot t)$ in the recession or forgetting phase.

Detailed educational guidance and a unified engineering-friendly formulation of applied pedagogical concepts and learning processes with a direct analogy with physical processes in civil, mechanical, chemical and materials engineering were proposed and developed for technical university students.

Notation

The following symbols are used in this paper:

A_1 = first time constant for the process of tanking up of the receiving tank 6 [1/s];
A_2 = first time constant for the process of discharging of the receiving tank 6 [1/s];
D_1 = diameter of conduit (tube) 4 ([m], [mm]);
D_2 = diameter of conduit (tube) 8 ([m], [mm]);
e = exp = 2.718281828;
g = gravity acceleration ([m/s^2], [mm/s^2]);
H = level of fluid in the head tank ([m], [mm]);
h = level of fluid in the receiving tank ([m], [mm]);
h_{12} = loss of pressure head (height loss) ([m], [mm]);
L_1 = length of conduit (tube) 4 ([m], [mm]);
L_2 = length of conduit (tube) 8 ([m], [mm]);
R = Reynolds number;
T = time interval for which the fluid level mark in the receiving tank in the process of discharging of the receiving tank reaches the value of ($h^{**} = h_0/2$) [s];
V_1 = fluid velocity in conduit (tube) 4 ([m/s], [mm/s]);
V_2 = fluid velocity in conduit (tube) 8 ([m/s], [mm/s]);
β_1 = second time constant for the process of tanking up of the receiving tank 6 [1/s];
β_2 = second time constant for the process of discharging of the receiving tank 6 [1/s];
λ = flow friction coefficient;
ν = kinematic viscosity coefficient ([m^2/s], [mm^2/s]);
τ =time interval for which the fluid level mark in the receiving tank in the process of tanking up of the receiving tank reaches the value of ($h^* = H/2$) [s];
ω_1 = cross-sectional area of conduit (tube) 4 ([m^2], [mm^2]);
ω_2 = cross-sectional area of conduit (tube) 8 ([m^2], [mm^2]);
ω_t = cross-sectional area of the receiving tank 6 ([m^2], [mm^2]).

Disclosure

The submission of the authors' paper implies that it has not been previously published, that it is not under consideration for publication elsewhere, and that it will not be published elsewhere in the same form without the written permission of the editors.

Conflict of Interests

The authors Alexander V. Perig, Nikolai N. Golodenko, Violetta M. Skyrtach, and Alexander G. Kaikatsishvili declare that there is no conflict of interests regarding the publication of this paper.

Authors' contributions

All authors participated in the design of this work and performed equally. All authors read and approved the final manuscript.

Compliance with ethical guidelines

Competing interests. The authors declare that they have no competing interests.

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