За результатами промислових експериментів встановлено закономірності зміни тиску за перехідних процесів, викликаних запуском насосних агрегатів. Виявлено фактичну величину стрибкоподібної зміни тиску на вході і виході нафтоперекачувальної станції (НПС). Для дослідного нафтопроводу запропоновано аналітичні залежності для розрахунку коефіцієнта затухання хвилі тиску як функції витрати нафти та числа Рейнольдса

Ключові слова: неусталений гідродинамічний процес, стрибкоподібна зміна тиску, коефіцієнт затухання хвилі тиску

По результатам промышленных экспериментов установлены закономерности изменения давления при переходных процессах, вызванных запуском насосных агрегатов. Выявлена фактическая величина скачкообразного изменения давления на входе и выходе нефтеперекачивающей станции (НПС). Для опытного нефтепровода предложены аналитические зависимости для расчета коэффициента затухания волны давления как функции расхода нефти и числа Рейнольдса

Ключевые слова: неустановившийся гидродинамический процесс, скачкообразное изменение давления, коэффициент затухания волны давления

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EXPERIMENTAL STUDY OF TRANSIENT PROCESSES IN OIL PIPELINE CAUSED BY STARTUPS OF PUMPING UNITS

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1. Introduction

The system of main oil pipelines of Ukraine in recent years has operated at significant undercapacity with frequent changes of the volume flow of oil. In such conditions, the most energy efficient method of regulating the volumes of oil transportation by pipelines is the use of different combinations of working pumps at oil pumping stations (OPS). Any change in the number or combination of working at OPS pumps leads to disruption of the steady state of oil transportation, causes the transient process, which is characterized by fleeting changes in pressure and volume flow in each section of the pipeline [1].

One of the main parameters that determines the functionality and reliability of the main pipeline is the input and output value of the working pressure on each OPS, as well as anywhere in the section of pipeline. Excess pressure over the maximum permissible value can lead to an emergency, and unacceptable decrease in the inlet pressure of OPS causes dangerous cavitation in pumps.

Transient processes influence the mode of operation of the oil pipeline. They often lead to a violation of technological restrictions of pressure in the main oil pipelines, which can cause emergencies. In addition, the transient processes in the oil pipeline complicate determining the mass of oil in the cavity of pipe and commercial accounting of transported oil.

The above determines the relevance and importance of research on patterns of change of pressure in conditions of transients in oil pipelines caused by startups of pumping units.

2. Literature review and problem statement

In [2, 3], the differential equations that allow to calculate transient processes caused by sudden changes in pressure in any section of the pipeline are presented. To calculate the energy loss from friction along the length of the pipeline, a modified formula of Colebrook is used [4]. But it doesn't take into account the impact of pumping units on the OPS.

In [5], the authors considered modeling of starting modes of OPS by the startup of one or more consistently working pumping units. This paper determined the duration of the startup mode and the maximum fall of pressure before the OPS. However, the authors have not considered the way and amplitude of propagation of the pressure wave resulting from the start of pumps. There is no comparison of the theoretical results with actual data on the existing main oil pipelines.

In [6], an approximate method of analysis of patterns of transient processes in the pipeline caused by startups of pumping units is proposed. The downside is that the above calculation method gives overestimated results – more than 10 % of the experimental data. To implement this algorithm, it is necessary to know the law of change of input and output pressure over time in OPS when the start of pumping units, which in most cases is unknown.

The author of the paper [7], presented only an analytical method for calculating the law of change in pressure on the input and output of OPS when starting pumping units taking into account the operational parameters of the oil pipeline, built related graphic dependencies. But this work does not consider the patterns of change of oil pressure on the route of the pipeline caused by startups of pumping units. In addition, most theoretically derived calculated dependencies have not been confirmed by a sufficient amount of experimental data obtained at the existing main oil pipelines.

In [8, 9], the results of changes in pressure generated by a pump during startup are given. Researches relate only to head and flow characteristics of the pump and do not show how the fluid pressure changes at the inlet and outlet of the pumping unit during its start.

The paper [10] provides the results of theoretical and experimental studies of transient characteristics of a centrifugal pump during its launch. There are formulas that allow to calculate the change in pressure at the inlet and outlet of the pump with the accuracy of up to 10 %. Since the experimental installation isn't provided with a check valve (its impact isn't taken into account), the dependencies can't be used for calculation of transients in OPS of oil pipelines caused by starting the pump.

The impact of the inclusion of the pump during the transient process in the pipeline is considered in [11]. Mathematical modeling of the pump start is made using differential equations of torque of the pump rotor taking into account the check valve.

In [12–14], the authors thoroughly investigated the patterns of hydrodynamic transients in oil pipelines caused by stops of pumping units on OPS. Here are the results of industrial experiments performed on the existing main oil pipeline [12, 13], the results of theoretical researches of patterns of abrupt changes in input and output pressure of OPS, analytical expressions for high-pressure wave damping factor [14]. However, the laws of propagation of low-pressure waves caused by stops of pumping units are insufficiently studied.

During the operation of main oil pipelines, the number of starts of pumping units isn't less than the number of stops. Each startup of the pumping unit provides no less problems than the stop. However, the patterns of hydrodynamic processes of starts of pumping units on OPS of main oil pipelines are not revealed fully in the works of many scientists.

That's why predicting the laws of hydrodynamic processes caused by startups of pumping units has serious theoretical and practical importance for the reliable operation of oil pipelines.

3. The purpose and tasks of the study

The purpose of the present study is processing the data of industrial experiments and establishing the patterns of change in pressure in the main oil pipeline in conditions of transients caused by starts of pumping units.

The goal is realized through the following tasks:

– identifying the relationship between the change in the parameters of the oil pumps in the process of starting and the dynamics of changes in pressure of oil on the inlet and outlet of OPS;

– identifying the patterns of change in pressure in any section of the pipeline during the transient process, caused by the launch of the pumping unit;

– identifying the factors that affect the pressure wave damping factor in the oil pipeline;

– developing regression models for the pressure wave damping factor in the pipeline, which was investigated.

4. Materials and methods of studying of transient processes in the existing oil pipeline caused by starts of pumping units

Industrial experiments were performed on the main oil pipeline "Druzhba" with a nominal diameter of 700 mm and a length of 400 km. On the route of the pipeline there are four OPS, equipped with oil pumps of OM series. On the route of the pipeline there are 14 checkpoints equipped with modern means of monitoring of operational parameters.

For measuring the pressure of the transported fluid, overpressure sensors Mikrotran F-R Fishers of MMG Automatika production (Hungary) with the accuracy class 0.075–0.1 were used.

Oil pressure measurement in conditions of fast transient processes in the oil pipeline was conducted with a frequency of 0.2 s. The design model of the operational section of the oil pipeline is given in [12].

During the industrial experiments, the density of the transported oil varied in the range of 864 to 878 kg/m^3. The coefficient of kinematic viscosity of oil ranged from 15 to 35 cSt.

When stopping one or more pumps operating in series at the input of the OPS there is an abrupt increase in pressure, and at the output of the OPS – an abrupt decrease of oil pressure. Studies [13] have shown the actual pressure changes on the inlet and outlet of OPS are by 3–23 % less than half the pressure created by the disabled pumps at the time of the stop.

When the pumping unit starts on OPS, by contrast, there should be an abrupt decrease in the inlet pressure of the OPS and the corresponding pressure increase on its output. This position is confirmed by the results of numerous industrial experiments [12–14].

5. The research results of transient processes arising from the start of pumping units

Let us consider the results of a study of the mode of operation of the oil pipeline, for which the volume flow of oil before the start of the pump was 1.460 m^3/h, after starting – 1.720 m^3/h. As an illustration, we show the pattern of changes in pressure at the input and output of OPS4 when starting the pumping unit on it (Fig. 1, 2, respectively).

Fig. 1 shows that for 30 seconds after starting the pumping unit, the pressure of the transported fluid on the inlet on the OPS4 abruptly decreased from 18.2 bar to 10.2 bar, then within two to three minutes with a much lower intensity the pressure continued to decline and reached a value of 8.2 bar. Then for 20 minutes inlet pressure on OPS4 continued to decline yet with lower intensity to a value corresponding to the new steady state mode of operation of the oil pipeline.

At the same time, on the output of the OPS4, as seen from Fig. 2, for 30 seconds after starting the pumping unit, the pressure of the transported fluid abruptly increased from 18.2 bar to 26.2 bar. Then within two to three minutes with a much lower intensity the pressure continued to increase, reaching a value of 28.0 bar, and then for 20 minutes pressure slowly decreased to a value corresponding to the new steady state mode of operation of the pipeline.

Industrial experiments have shown that the transient process at the input and output of the OPS, when starting the pumping unit can be divided into three stages that differ in the intensity of pressure changes over time:

– the first, up to 30 seconds, corresponds to an abrupt change in pressure;

– the second, for up to three minutes, corresponds to a slower change in pressure;

– the third, up to 20–25 minutes, even more slowly changes the pressure to a value corresponding to the new steady state mode of operation of the oil pipeline.

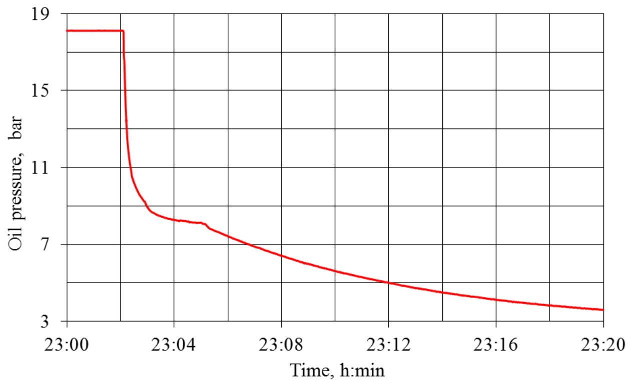

Fig. 1. Change in the oil pressure on the input of OPS4 over time when starting the pumping unit on the results of the experiment (volume flow of oil before the start 1.460 m^3/h)

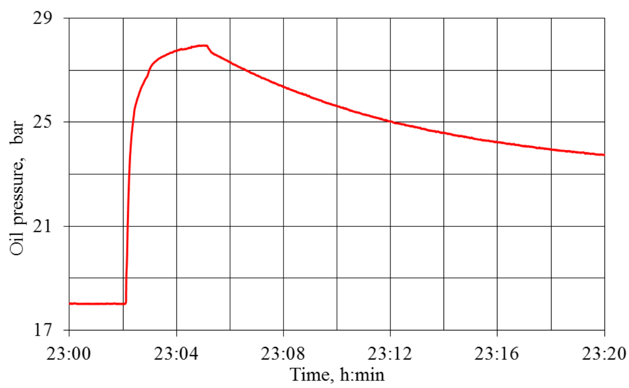

Fig. 2. Change in the oil pressure on the output of OPS4 over time when starting the pumping unit on the results of the experiment (volume flow of oil before the start 1.460 m^3/h)

For the entire set of experiments, it was found that regardless of which pump and on which OPS it starts, there is the same pattern of change in pressure in the first stage of the transient process, namely an abrupt decrease in the inlet pressure on OPS and an abrupt increase in pressure at its output. The pressure change amplitude never exceeds half the pressure created in the pump starting at an average volume flow during the implementation of the transient process. The specific value of the amplitude of pressure change depends on the hydraulic resistance of OPS communications; the type of the pump started, the mode of operation of the oil pipeline before and after startup.

As for the second phase of the transient process, caused by launching the pumping unit, for the entire set of experiments, it had a duration of two to three minutes and was characterized by a decrease in the inlet pressure of OPS and the corresponding increase in pressure on its output.

The most varied are the patterns of pressure changes on the input and output of OPS during the third final phase of the transient process, caused by the launch of the pumping unit. Besides the case shown in Fig. 1, characterized by further decrease in the pressure at the inlet of the OPS for twenty minutes, some experiments revealed cases of slow increase in the oil pressure at the inlet of the OPS (Fig. 3). Similarly, at the output of the OPS in the third stage of the transient process, for some experiments there was no reduction, as in Fig. 2, and the increase in oil pressure (Fig. 4).

To determine the cause of the unequal nature of the change in pressure in the third stage of the transient process, the values of the pressure of oil at the input and output of the OPS for steady state operation of the oil pipeline before and after starting the pumping unit were calculated using the developed software complex. The fragment of the data obtained is shown in Table 1.

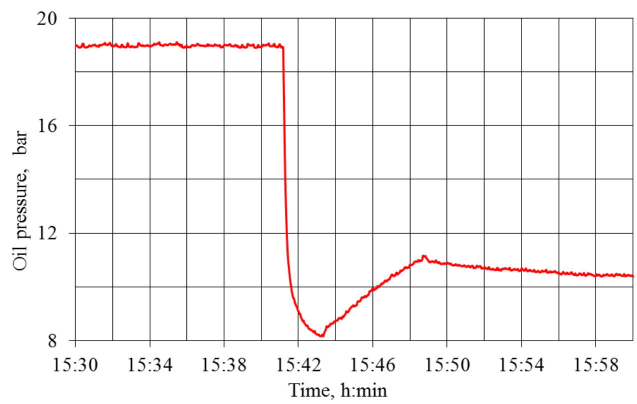

Fig. 3. Change in the oil pressure in the inlet of the OPS2 over time when starting the pumping unit on the results of the experiment (volume flow of oil before the start 1.130 m^3/h)

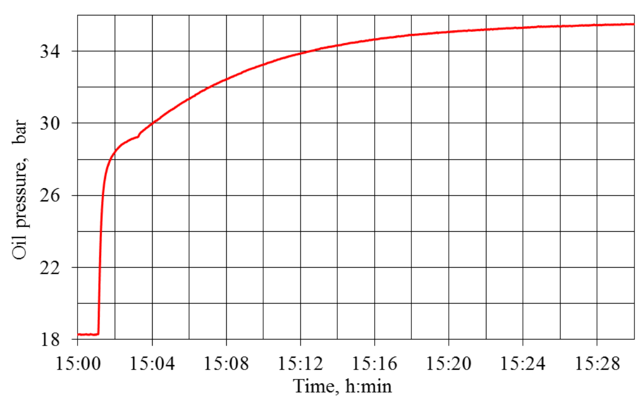

Fig. 4. Change in the oil pressure in the output of the OPS2 over time when starting the pumping unit on the results of the experiment (volume flow of oil before the start 1.120 m^3/h)

The analysis of these studies showed that in all industrial experiments, the nature of the change in pressure in the third stage of the transient process, caused by the launch of the pumping unit, is fully consistent with hydrodynamic patterns, that is, such a change of the pressure (increase or decrease), which provided the formation of values characteristic of the steady mode of operation of the oil pipeline with additional pumping unit.

Table 1

The values of oil pressure on the inlet and outlet of the OPS for steady mode before and after starting the pumping unit

Location of determination of oil pressure	The pressure under the steady mode, bar				The scheme of pumping units on the OPS	The number of the OPS, where the pump was started
	OPS1	OPS2	OPS3	OPS4		
Mode 1						
OPS input	6.7	15.4	2.9	13.4	2-TR-3-TR	–
OPS output	26.4	15.4	25.9	13.4		
OPS input	6.7	8.6	14.2	18.1	2-3-3-TR	OPS2
OPS output	25.9	32.6	36.6	18.1		
OPS input	6.6	3.3	4.0	2.9	2-3-3-3	OPS4
OPS output	25.5	26.9	26.0	26.6		
Mode 2						
OPS input	6.7	8.6	14.2	18.1	2-3-3-TR	–
OPS output	25.9	32.6	36.6	18.1		
OPS input	6.6	3.3	4.0	2.9	2-3-3-4	OPS4
OPS output	25.5	26.9	26.0	26.6		
OPS input	6.6	18.4	13.0	5.6	1,2-3-3-4	OPS1
OPS output	46.6	41.6	34.4	28.8		
OPS input	6.5	12.9	2.9	11.3	1,2-2-2,3-4	OPS3
OPS output	45.8	35.8	44.3	34.1		

The next stage of research was to identify the patterns of the pressure change wave propagation in the pipeline after starting the pumping unit.

Fig. 5, 6 show the dynamics of changes in oil pressure at the control points located at a distance of 54 and 96 km to the OPS4 where the launch of the pumping unit was performed.

Fig. 5, 6 show that the wave of reduced pressure formed at the OPS input, where the launch of the pumping unit was performed with the speed of sound is distributed to the previous OPS (oil flow) and then before the start of the operating section of the pipeline. The amplitude of the abrupt decrease in pressure along the length of the oil pipeline is reduced by hydraulic energy loss.

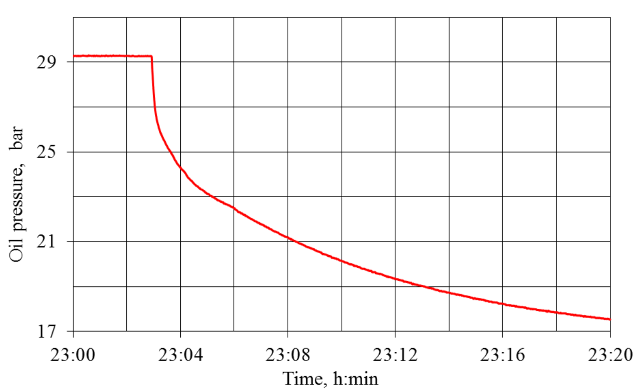

Fig. 5. Change in the oil pressure over time at a distance of 54 km to the OPS4 when starting the pumping unit on the results of the experiment (volume flow of oil before the start 1.460 m^3/h)

Fig. 7, 8 show the dynamics of changes in oil pressure at the control points located at a distance of 48 and 100 km after OPS4 where the launch of the pumping unit was performed.

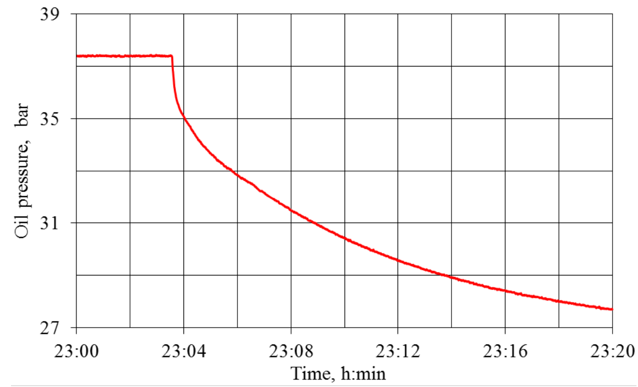

Fig. 6. Change in the oil pressure over time at a distance of 96 km to the OPS4 (OPS3 output) when starting the pumping unit on the results of the experiment (volume flow of oil before the start 1.460 m^3/h)

Fig. 7, 8 show that the high-pressure wave formed at the outlet of the OPS, where the pumping unit was launched with the speed of sound is distributed to the next OPS (the movement of oil) and then by the end of the operational section of the oil pipeline. The amplitude of the abrupt increase in pressure along the length of the pipeline is also reduced through the hydraulic energy loss.

To practice operation of the oil pipeline, the most interesting is prediction of the amplitude of abrupt changes in pressure in arbitrary points of the route. For the mode of operation of the pipeline, which was analyzed above, such dependence of the magnitude of an abrupt decrease in pressure ΔP (bar) on the distance to the OPS x (km), where the pumping unit was started, was obtained (Fig. 9).

For the same mode of operation of the oil pipeline, the dependence of the magnitude of an abrupt increase in pressure ΔP (bar) on the distance after the OPS x (km), where the pumping unit was started, is shown in Fig. 10.

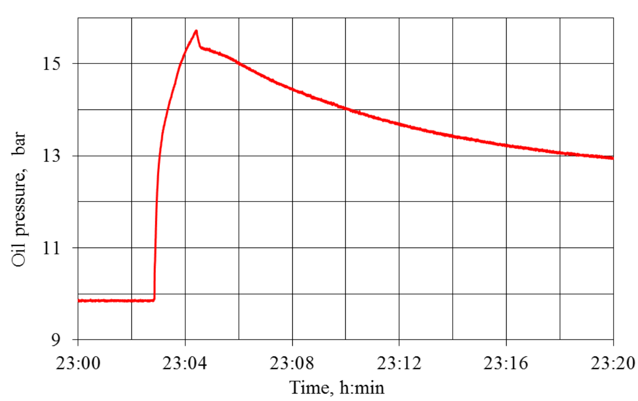

Fig. 7. Change in the oil pressure over time at a distance of 48 km from the OPS4 when starting the pumping unit on the results of the experiment (volume flow of oil before the start 1.460 m^3/h)

Fig. 9, 10 show that for the mode of operation of the oil pipeline the amplitudes of the waves of increased and reduced pressure significantly declined along the length of the linear part of the pipeline on both sides of the OPS, where the pumping unit was launched. At a distance of 50 km from the OPS, the pressure wave amplitude decreased by 2.2 times, and at a distance of 100 km – by 4.5 times compared with the initial amplitude.

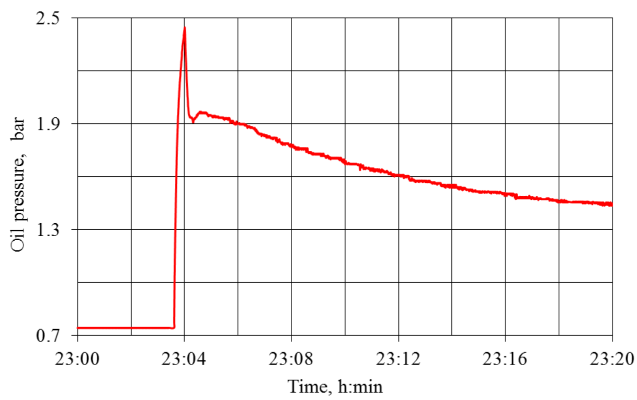

Fig. 8. Change in the oil pressure over time at a distance of 100 km from the OPS4 when starting the pumping unit on the results of the experiment (volume flow of oil before the start 1.460 m^3/h)

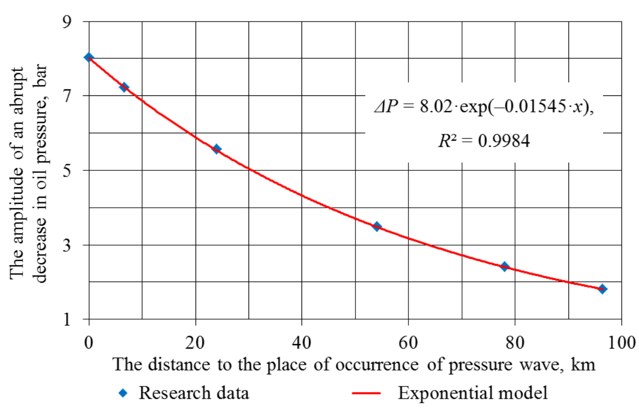

Fig. 9. The dependence of an abrupt decrease of oil pressure on the distance to the OPS4 where the pumping unit was started on the results of the experiment (volume flow of oil before the start 1.460 m^3/h)

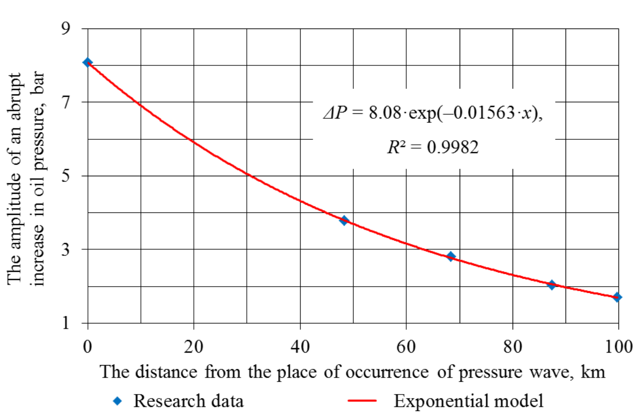

Fig. 10. The dependence of an abrupt increase of oil pressure on the distance to the OPS4 where the pumping unit was started on the results of the experiment (volume flow of oil before the start 1.460 m^3/h)

6. Discussion of results of studies of patterns of change in pressure on OPS and in the linear part of the pipeline at the start of pumping units

Almost instantaneous (abrupt) change in the pressure created by the pump, causes, according to the law of conservation of energy, a sudden change in pressure on the inlet and outlet of the respective OPS. Processing of the results of a large number of industrial experiments showed that when starting the pumping unit, transient changes in pressure are observed at the input and output of the respective OPS, namely the pressure at the inlet of the OPS decreases, at the output – increases. To determine the actual value of changes in the oil pressure in the first stage of the transient process, we introduce the concept of the coefficient of reducing the amplitude of an abrupt pressure change at the inlet and outlet of the OPS

$$k_{in} = \frac{\Delta P_{in_{act}}}{\Delta P_{in}}, \quad (1)$$

$$k_{out} = \frac{\Delta P_{out_{act}}}{\Delta P_{out}}, \quad (2)$$

where $\Delta P_{in_{act}}$, $\Delta P_{out_{act}}$ – actual value of an abrupt change in pressure at the inlet and outlet of the OPS, respectively; ΔP_{in}, ΔP_{out} – theoretically expected value of an abrupt change in pressure at the inlet and outlet of the OPS, respectively.

Table 2 contains comparison results of experimental and theoretically expected values of an abrupt change in pressure at the inlet and outlet of the OPS when the start of the pumping unit.

Analysis of the data of Table 2 shows that the actual value of an abrupt change in pressure at the input and output of the OPS is by 15–23 % less than the theoretically expected value, that is half the pressure created in starting the pump. For the forecast calculation of parameters of transients when the start of pumping units in the oil pipeline, on which industrial experiments were carried out, it is advisable to take the maximum value of coefficients $k_{in} = k_{out} = 0{,}85$.

Thus, the results of industrial experiments in the existing oil pipeline set the value of an abrupt decrease and increase in pressure of the transported oil at the input and output of the OPS when the start of the pumping unit on it.

Analysis of the graphical dependencies and exponential mathematical models showed that in a particular transient mode of operation of the oil pipeline, the values of the wave damping coefficients of higher and lower pressure almost coincide. The actual values of an abrupt decrease in pressure at the inlet and increase in pressure at the outlet of the OPS when the start of the pumping unit may be different due to the uneven hydraulic resistance of inbound and outbound communications.

Thus, the value of an abrupt decrease in pressure in any section of the oil pipeline, located at the distance x to the place of the start of the pump (the movement of oil), takes the form

$$\Delta P = \Delta P_{in} \cdot \exp(-K_d \cdot x), \quad (3)$$

where ΔP_{in} – the actual value of an abrupt decrease in pressure at the inlet of the OPS where the pumping unit was launched; K_d – pressure wave damping factor.

Table 2

Comparison of experimental and theoretically expected values of an abrupt change in pressure at the inlet and outlet of the OPS when the start of the pumping unit

Number of mode	The pressure created by the pump after starting, bar	Pressure increase at the outlet of the OPS, bar		The value of the empirical coefficient (for the output line of the OPS)	Pressure decrease at the inlet of the OPS, bar		The value of the empirical coefficient (for the input line of the OPS)
		theoretical value	experiential value		theoretical value	experimental value	
1	20.15	10.08	8.08	0.802	10.08	8.02	0.796
2	22.50	11.25	8.89	0.790	11.25	8.98	0.798
3	15.05	7.53	5.92	0.787	7.53	5.83	0.775
4	19.21	9.61	7.84	0.816	9.61	7.96	0.829
5	15.45	7.73	6.07	0.786	7.73	5.97	0.773
6	17.31	8.66	6.96	0.804	8.66	7.06	0.816
7	11.48	5.74	4.58	0.798	5.74	4.45	0.775
8	22.31	11.16	9.38	0.841	11.16	9.20	0.825
9	14.61	7.31	6.44	0.882	7.31	5.94	0.813
10	20.83	10.42	8.37	0.804	10.42	8.03	0.771
11	13.94	6.97	5.91	0.848	6.97	5.77	0.828
12	12.27	6.14	5.26	0.857	6.14	4.84	0.789
13	21.01	10.51	8.48	0.807	10.51	8.43	0.802
14	19.64	9.82	8.09	0.824	9.82	8.23	0.838
15	13.79	6.90	6.08	0.882	6.90	5.71	0.828
16	15.03	7.52	5.86	0.780	7.52	5.95	0.792
17	15.05	7.53	5.82	0.773	7.53	5.80	0.771
18	21.01	10.51	8.88	0.845	10.51	8.77	0.835
19	16.05	8.03	6.74	0.840	8.03	6.65	0.829
20	22.54	11.27	9.24	0.820	11.27	9.16	0.813
21	22.14	11.07	9.28	0.838	11.07	9.34	0.844

Similarly, the value of an abrupt increase in any section of the oil pipeline, located after the OPS, where the pumping unit was started

$$\Delta P = \Delta P_{out} \cdot \exp(-K_d \cdot x), \quad (4)$$

where ΔP_{out} – the actual value of an abrupt increase in pressure at the outlet of the OPS, where the pumping unit was launched.

To practice the operation of the main oil pipeline, adequate forecasting of the value of the abrupt increase and decrease of pressure in any point of the pipeline in case of start of the pumping unit at any OPS is important.

According to the results of experimental studies for a particular pipeline system, on which industrial experiments were carried out, regression models for the pressure wave damping factor were developed. Processing of experimental studies of the patterns of transients caused by launches of pumping units made it possible to confirm the results obtained earlier in [12]. For the oil pipeline, which was the object of research, the actual speed of propagation of the pressure wave is about 1110 m/s, which is 12 % higher than the value calculated by the standard formula.

With the known wave propagation speed c=1110 m/s and the internal diameter of the pipeline D=0.702 m, the pressure wave damping factor in the oil pipeline was represented by a power function of hourly oil flow rate Q_h and the Reynolds number Re before the beginning of the transient

$$K_d = a \cdot Q_h^b \cdot Re^c, \quad (5)$$

where a, b, c – coefficients of the regression model.

The regression coefficients were determined by the least squares method with the developed computer software. In order to improve the adequacy of mathematical models, the computational algorithm provided for checking each point of the experimental sample for the performance of Student's t-test.

A mathematical model of the damping coefficients of increased and reduced pressure waves caused by starting the pumping unit on the OPS has the form

$$K_d = 2.505 \cdot 10^{-4} \cdot Q_h^{0.457} \cdot Re^{0.072}. \quad (6)$$

The dependence (6) is valid for the range of changes of the hourly volume flow of oil in the experimental pipeline from 1100 to 2400 m^3/h and Reynolds numbers from 18000 to 120000.

Table 3 contains a piece of the results of comparison of the calculated and experimental values of the pressure wave damping factor when the pumping unit is started on the OPS of the oil pipeline, which was the subject of research.

Table 3

The results of comparison of the calculated and experimental values of the pressure wave damping factor in case of start of the pumping unit on the OPS of the oil pipeline, which was the subject of studies

Number of mode	The density of oil, kg/m³	Kinematic viscosity of oil, cSt	Hourly volume flow of oil (before-start), m³/h	Reynolds number	Pressure wave damping factor, km⁻¹		The relative difference, %
					calculated using the formula (6)	experimental values	
1	876.0	25.11	1930	38724	0.01701	0.01708	–0.42
2	877.0	25.37	1130	22440	0.01280	0.01308	–2.11
3	877.0	25.37	1257	24962	0.01355	0.01344	0.79
4	877.5	26.92	1124	21036	0.01271	0.01254	1.38
5	877.4	27.65	1160	21137	0.01290	0.01267	1.83
6	877.4	27.65	1400	25510	0.01425	0.01404	1.51
7	877.8	28.63	1500	26396	0.01474	0.01473	0.10
8	877.8	28.63	1710	30092	0.01580	0.01588	–0.49
9	876.9	26.25	1447	27772	0.01456	0.01469	–0.90
10	877.5	26.50	1140	21674	0.01282	0.01274	0.65
11	876.9	27.73	2022	36737	0.01731	0.01723	0.45
12	876.9	27.73	2022	36737	0.01731	0.01737	–0.36
13	876.9	27.73	2012	36555	0.01726	0.01742	–0.91
14	876.9	27.73	2012	36555	0.01726	0.01733	–0.39
15	877.0	27.70	1516	27573	0.01486	0.01445	2.86
16	868.6	17.87	2350	66254	0.01934	0.01891	2.29
17	869.5	17.22	1730	50615	0.01649	0.01607	2.63
18	870.7	19.17	1170	30749	0.01331	0.01363	–2.37
19	867.3	16.94	2150	63943	0.01852	0.01902	–2.60
20	867.1	15.25	2170	71690	0.01876	0.01852	1.28

As can be seen from Table 3, the results of the calculation of the pressure wave damping factor in the oil pipeline using the regression formula correlate well with the results of processing of industrial experiments. The maximum deviation of the absolute value doesn't exceed 3 %. These dependencies can be used to calculate the abrupt changes in pressure during transients caused by launches of pumping units on the OPS of the oil pipeline that was investigated.

7. Conclusions

1. Industrial experiments have shown that the transition process, caused by starting the pumping unit, on the inlet as well as on the outlet of the oil pumping station, can be divided into three stages that vary in intensity of pressure change over time. The first stage lasts up to 30 seconds and corresponds to an abrupt change in pressure. The second stage may last up to three minutes and has much slower pressure change. During the third stage, lasting for 20–25 minutes, pressure changes much more slowly to a value, which corresponds to a new steady state operation mode of the pipeline. The variation of pressure in the third stage of the transition process when starting the pumping unit is fully consistent with the pressure change (increase or decrease), which ensures the formation of values characteristic of a new steady state mode of the pipeline operation.

When the pumping unit is being started, an abrupt decrease in pressure on the inlet and an abrupt increase in pressure on the outlet of the OPS can be observed. It was found out, that the actual value of abruptly changing pressure both on the inlet and outlet of OPS is 15–23 % less than the theoretically expected value, in particular, half the pressure of the pump started.

2. The same trends of pressure change were observed in the linear part of oil pipeline as well as at the OPS during the transition process, caused by running the pumping unit. It was determined that the amplitude of abrupt pressure change decreases exponentially along the length of the linear section of the pipeline on both sides (upstream and downstream of oil pumping direction) of the oil pumping station, where the pumping unit was started.

3. For the oil pipeline, on which the experiments were conducted with known values of the diameter and speed of sound, a coefficient of pressure wave damping can be expressed as a power function of oil flow rate and the Reynolds number as a characteristic of the flow mode. The damping coefficients of increased and decreased pressure waves are almost the same for a specific transition mode of operation of the pipeline. The actual values of abrupt pressure decrease on the inlet and pressure increase on the outlet of the oil pumping station in case of the pumping unit start may differ due to different hydraulic resistance of inlet and outlet pipelines with fittings.

4. The results of calculations of the pressure wave damping factor in the oil pipeline with the help of the regression model correlate well with the results of processed industrial experiments. The maximum deviation of the results doesn't exceed ±3 %. These dependencies can be used to calculate abrupt pressure changes during transients caused by running the pumping units at oil pumping stations of the pipeline that was investigated.

Subsequently, based on the results of theoretical studies and industrial experiments, it is planned to develop generalized models of the pressure wave damping factor in case of start of pumping units at OPS of the pipelines with any diameter.

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PRINCIPLES OF CYBERNETIC SYSTEMS INTERACTION, THEIR DEFINITION AND CLASSIFICATION

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Предметом дослідження є об'єкти, які визначаються поняттям «система», а саме той клас систем, об'єкти якого забезпечують виконання певної функції. Такий клас систем визначено поняттям «кібернетичні системи» (КС). Об'єктом дослідження є процеси взаємодії КС. В результаті дослідження було встановлено властивості КС, особливості їх архітектурного взаємодії і дано визначення КС. Отримані результати можуть використовуватися при проектуванні автоматичних ліній у вигляді адаптивних, оптимальних об'єктів інтерактивної взаємодії

Ключові слова: статична система, кібернетична система, динамічна система, система перетворення, система буферізації

Предметом исследования являются объекты, которые определяются понятием «система», а именно тот класс систем, объекты которого обеспечивают выполнение определенной функции. Такой класс систем определен понятием «кибернетические системы» (КС). Объектом исследования являются процессы взаимодействия КС. В результате исследования были установлены свойства КС, особенности их архитектурного взаимодействия и дано определение КС. Полученные результаты могут использоваться при проектировании автоматических линий в виде адаптивних, оптимальних объектов интерактивного взаимодействия

Ключевые слова: статическая система, кибернетическая система, динамическая система, система преобразования, система буферизации

1. Introduction

One of the main issues of modern business is connected with a problem of efficiency increase. And it's really a problem, because the practitioners' efforts are aimed at efficiency improving of such enterprise structural divisions as: the departments, sites, shops, etc. However, the enterprise consists of systems and the functions of each one are performed in many different structural divisions. There is a question: "If the system is an integrity, what are the consequences of an attempt to optimize a separate process in different structural entity divisions?".

The automation of technological processes to some extent solves the problem of increasing the efficiency. However, the automation of technological processes doesn`t solve the issue of increasing efficiency completely. It is connected with the fact that a search of an optimum is defined in control process. But also control won't execute the assigned to it optimization functions if technological operations are rigidly connected among themselves. That is, the optimization efforts, in general, are vain if the automatic transfer line isn't designed as dynamic systems interaction process. Therefore, the existing practice of creating automatic and automated production processes excludes a possibility of full optimization.

The "system" category is one of the fundamental concepts associated with the world around models in the course of thinking. And the models determined by the concept "system" are understood and defined as a certain integrity.

The complexity of the situation is that the concept "system" is used for some integrity identification in defining of interconnected objects complete set and of holistic objects that perform a certain function. Also, the objects are defined by the "system" concept if they are able to perform or perform a certain function in the interaction process with other similar objects by the products variety exchange.

For example, the concept "system of movement" can be used for definition of numerous mechanisms and the relations between them. The functional orientation of an object is the sign by which the structural elements of the movement object are defined as movement system.

We are talking about object's cybernetic representation when the system of movement is defined as the object, performing movement function.

Thus, the movement system can be used for definition of objects (models) of two classes. On the one hand, it is a set of