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Formation of soil pollution area by oil when there is break of airtightness of main pipeline

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Abstract
The process of oil filtering in the porous medium (soil) which is caused by sources of transported product in case of break of airtightness of long operated underground oil pipeline is researched in the article. Analysis of reasons of accident rate of oil pipelines is carried out and the nature of end-to-end defects of pipe body is considered. Modelling of formation of area of pollution of the soil by oil for creation of the field of filtering rate in the porous medium as the function of space coordinates and time is carried out.
Mathematical model based on the law of linear filtering in the form of Darci, continuity equation in two-dimensional form, where the leakage from the pipeline is modelled by function of Dirac source is developed. The results obtained allow to create non-stationary distribution of filtering rate in the soil, on the base of which, the conclusion about formation of area of environmental pollution by oil leakages is drawn.
Key words: EMERGENCY LOSSES, THROUGH FAULT, LEAKAGE FLOW, FILTERING RATE, SOIL POLLUTION AREA

Terms of oil pipelines operation in Ukraine are considerable and make from 15 to 52 years. One of the most serious problems of operation of such oil pipelines is their accident risk - unforeseen refusal of linear part that is followed by catastrophic influence on environment. At untimely and low-quality scheduled preventive maintenance of linear part of long operated oil pipelines, the risk of emergencies with depressurization of pipeline and oil spills increases significantly [1, 2, 3].

Authors fulfilled considerable scientific analysis of emergency situation connected with depressurization of the linear part of main pipelines of Ukraine and some other countries.

Great ecological disaster connected with accident at the oil pipeline of JSC "Komineft" happened in August, 1994 in Usinsk region of the Komi Republic, the Russian Federation. As a result of appearance of holes on the pipeline, there happened large-scale oil leakage. According to various data, losses made from 102 thousands to 576 thousands barrels of crude oil. There is no exact data on the area of polluted surface, but the numbers vary from 69 to 115 hectares.

On March 15, 2008 at 17:00 in Brodivsky district of the Lviv region (Ukraine) near the village of Yablunivka at Kilometer 649 of main oil pipeline "Odessa - Brody" with diameter of 1020 mm one of inspectors has found oil leakage - within the protected zone. Approximately one ton of raw materials was lost, the area of contamination was 50t sq.m.

On October 14, 2008 near the city of Budapest (Hungary) there was a break of oil pipeline "Druzhba" of the Hungarian oil and gas company MOL in the area connecting Hungary with Slovakia. As a result of this incident, there happened leakage of several hundred cubic meters of oil. The pipe was broken through as a result of territorial works, which were carried out by contractor in the private territory near the oil pipeline without coordination with Hungarian oil and gas company.

The gap on the main oil pipeline "Perm — Almetyevsk" in Perm Krai, Russian Federation happened on February 17, 2009 near the village of Klyuchiki. According to preliminary data, in result of failure of oil pipeline, about 10 tons of oil poured out [7].

On September 13, 2011 in three kilometers from the city of Petropavl, North Kazakhstan Region (Kazakhstan) on the Kilometer 1056 of the Taymis — Omsk — Novosibirsk oil pipeline (TON-2) of the North Kazakhstan oil pipeline management office of East branch of JSC "KazTransOil" during territorial

works on laying of fiber optic communication line in the protected zone, there happened a failure of the oil pipeline with a diameter of 720 millimeters. Accident caused the oil spill approximately on the area of 1000 square meters and volume - 200 cubic meters.

On July 19, 2012 at 10 a.m. during examination of oil pipeline "Druzhba" between villages Russkoe and Chopovtsy of Mukachevo district of Zakarpattia region (Ukraine), the workers of oil pipeline revealed the leak of oil into the soil reclamation canal. As it turned out, the oil leak is a result of break of rubber hose of high pressure, which was illegally fitted in the oil pipeline. Amount of the poured oil - up to 500 liters.

On August 14, 2012 at about 6 o'clock in the evening near the village of Krivets of Bogorodchansky district of Ivano-Frankivsk region (Ukraine) as a result of depressurization of underground oil pipeline with diameter of 159 mm which belongs to NGDU "Nadvirnaneftegaz" of JSC "Ukrnafta" there was a leak of about 4 m^3 of oil onto the ground surface with further transfer to local water body. In result of investigation it was established that accident had happened because of corrosion damage of the pipeline.

Accident at the main oil pipeline "Unecha - Mozyr" of the republican unitary enterprise "Gomeltransneft Druzhba" of "Belneftekhim" concern has happened on November 4, 2012 at about 11 a.m. in the village of Igovka of Dobrushsky district of Gomel region (Belarus). In result of drop scattering of oil by the wind, pollution of ground surface at the area of 70 × 200 meters took place. The area of oil spill has covered about 100 sq.m.

50 tons of oil have spread as a result of the failure of "Nizhny Novgorod— Yaroslavl" oil pipeline, which happened on December 20, 2012 near the village of Zhovtnevoe, Vyaznikivsky district, Vladimirskiy region (Russian Federation). The khor that passes through the village was flooded with oil.

On May 21, 2014 Zakarpattia section of the branch "Main oil pipelines "Druzhba" of JSC "Ukrtransnafta" revealed pollution of the soil by oil on the outskirts of Kaydanovo village of Mukachevsky district of Zakarpattia region (Ukraine). In result of accident about 42 m^2 of soil was polluted by oil.

On December 26, 2014 on the territory of the Rakoshino village of Mukachevsky district, Zakarpattia region (Ukraine) locals revealed slick oil spot. After arrival of emergency response group, there were revealed two more spots 50 and 5 m^2 in area. Oil leak happened due to violation of tightness of the linear part of main oil pipeline "Druzhba".

One of the largest accidents of 2014 happened on December 5 on the "Ashkelon — Eilat" oil pipeline in the south of Israel. 21.9 thousand barrels of oil poured out into the Arabah desert from faulted out pipe. Ecologists marked that it was the largest accident in memory of Israel. Investigation showed that oil leak turned out to be the consequence of imprudence during repair works, when the pipeline was damaged.

Because of damage of "Druzhba" oil pipeline that occurred on April 27, 2015 near the agrotown Bobovichi of the Gomel region (Belarus), oil supply to Europe was temporary stopped. Incident happened in the territory of oil pumping station "Gomel" as a result of break of airtightness of technological oil pipeline "Unecha — Mozyr" with diameter of 530 mm and working pressure of 4.5 MPa and a depth 1,7 m which is under supervision of JSC "Gomeltransneft Druzhba" of concern "Belneftekhim". The area of oil spill was 0,06 hectares. The amount of leak is unknown.

On June 23, 2015 suburb of Nefteiugansk, Khanty-Mansi Autonomous District of the Russian Federation was flooded by oil pipeline after the accident in the area of Ust-Balykskyi deposits of subsidiary JSC "Rosneft". Diameter of damaged oil pipeline is about 40 cm. The volume of the spilled oil is unknown.

Breakdown of the oil main pipeline of Buguruslanskyi region of oil control of JSC "Transneft — Privolga" happened on December 15, 2015 in six kilometers from the village Ponykla of Buguruslanskyi district of the Orenburg region (Russian Federation). The area of oil spill was 500 sq.m., amount of the spilled oil is unknown.

On January 25, 2016 break of the pipeline Peruvian state company Petroperu caused spillage of 3.0 thousand barrels of oil and pollution of two rivers in the northwest of the country. According to preliminary data, two breaks took place and the landslide became the reason of one of them.

On April 25, 2016 in the Mediterranean Sea at coast of Genoa (Italy), big oil spill was formed. The reason of it was accident happened on April 18, 2016 in the pipeline of the Ligurian company Iplom. At first, oil rushed into one of the local rivers, and in several days a spot of 2 kilometres in length and about 500 meters in width emerged in the waters between the cities of Genoa, Savona and Imperia. Amount of the spilled oil is unknown.

Having analysed emergency situations on the linear part of oil main pipelines, it is possible to select five basic reasons leading to depressurization (Figure 1):

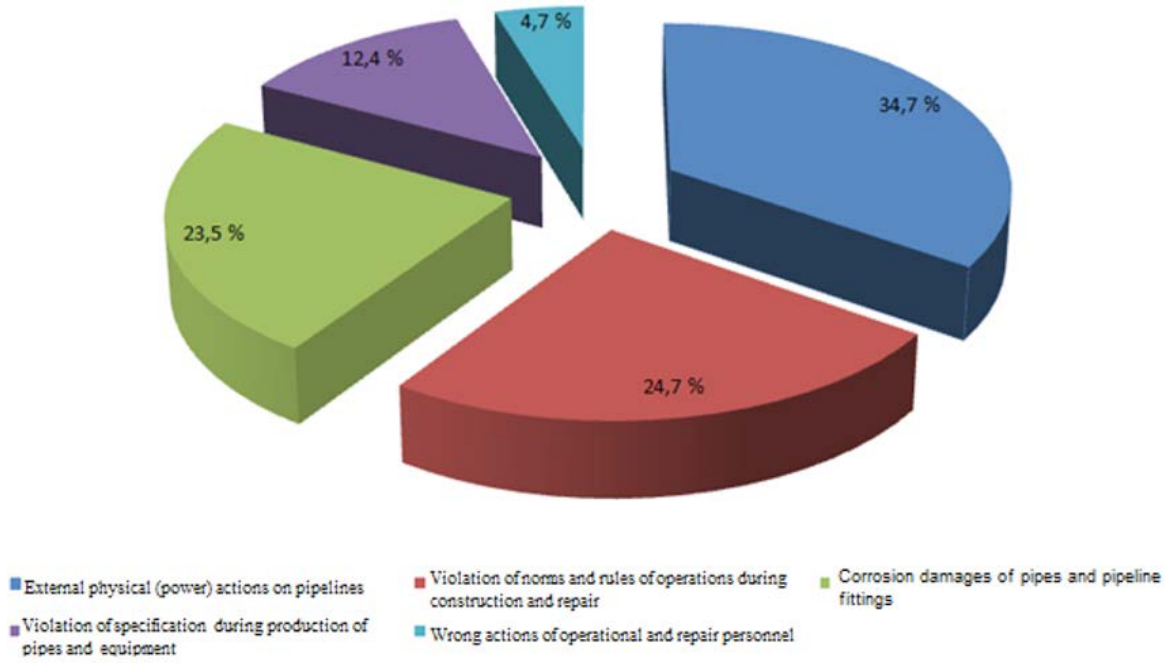

Figure 1. Origins of emergency situations connected with depressurization of linear part of main pipelines

- external physical (power) influences on pipelines, including criminal inserts which have led to leakages – 34.7%;
- violation of norms and rules of works during construction and repair, deviations from design decisions – 24.7%;
- corrosion damages of pipes, locking and control valves - 23,5%
- violation of specifications at production of pipes and equipment - 12,4%;
- wrong actions of operating and maintenance staff - 4,7%.

Let us consider the character of defects of pipeline body during emergency oil spills. These are through faults of various forms and sizes that can be both in base metal and in welded seams of pipes – fig.2.

a) b)

c) d)

e)

Figure 2. Characteristic defects of pipe body leading to emergency losses of transported environments

The greatest damage is caused by accidents on pipelines where breaks took place in base metal of pipes or in zone of welded joints. The basic factor determining the extent of damage in case of failures of oil main pipelines is the amount of the spilled oil and the area of the polluted territory.

Today, especially important scientific task is prediction of nature of formation of pollution area of the soil by oil from the pipeline. A series of papers [4, 5, 6] are devoted to the problem of formation of areas of pollution. In these papers, physical phenomenon (physical sense) of process is considered, results of physical modelling and their analysis are provided, methodical bases of the acceptable risk are developed. However, necessary attention was not provided to the problem of formation of pollution areas. Therefore, process modelling of formation of pollution area, that is creation of field of speeds of filtering in the porous medium as functions of spatial coordinates and time, is the relevant task.

Authors have obtained the equation allowing prediction of change of pressure in the porous medium in time due to growth of the filtration resistance caused by spillage of oil from the pipeline

$$P(x,y,t)=\frac{æqa}{2\pi F}\int_0^\infty \frac{\sin\lambda y_0 \sin\lambda y}{\lambda}\left\{\left[\sigma(x-x_0)-1\right]\left[e^{-\lambda(x_0-x)}erfc\left(\frac{x_0-x}{2\sqrt{æt}}-\lambda\sqrt{æt}\right)-\right.\right.$$
$$-e^{\lambda(x_0-x)}erfc\left(\frac{x_0-x}{2\sqrt{æt}}+\lambda\sqrt{æt}\right)\Big]-\sigma(x-x_0)\left[e^{-\lambda(x-x_0)}erfc\left(\frac{x-x_0}{2\sqrt{æt}}-\lambda\sqrt{æt}\right)-\right. \quad (1)$$
$$\left.\left.-e^{\lambda(x-x_0)}erfc\left(\frac{x-x_0}{2\sqrt{æt}}+\lambda\sqrt{æt}\right)\right]\right\}d\lambda.$$

For establishment of nature of formation of pollution area of the soil by oil from the pipeline, it is necessary to determine consistent pattern of speed change of filtering in time [4, 5]. The superposition principle of movements, according to which the velocity vector of filtering of product in the soil is presented in the form of the vector sum of its projections to coordinate axes, is used for this purpose

$$\overline{w}=\overline{w}_x+\overline{w}_y. \quad (2)$$

Values of projections of velocity vector of filtration are defined basing on the Darcy's law using the dependence (1)

$$w_y(x,y,t)=-\frac{k}{\eta}\frac{\partial P(x,y,t)}{\partial y}=\frac{q}{2\pi F}\int_0^\infty \sin\lambda y_0\cos\lambda y\left\{\left[\sigma(x-x_0)-1\right]\left[e^{-\lambda(x_0-x)}erfc\left(\frac{x_0-x}{2\sqrt{æt}}-\lambda\sqrt{æt}\right)-\right.\right.$$
$$-e^{\lambda(x_0-x)}erfc\left(\frac{x_0-x}{2\sqrt{æt}}+\lambda\sqrt{æt}\right)\Big]-\sigma(x-x_0)\left[e^{-\lambda(x-x_0)}erfc\left(\frac{x-x_0}{2\sqrt{æt}}-\lambda\sqrt{æt}\right)-\right. \quad (3)$$
$$\left.\left.-e^{\lambda(x-x_0)}erfc\left(\frac{x-x_0}{2\sqrt{æt}}+\lambda\sqrt{æt}\right)\right]\right\}d\lambda;$$

$$w_x(x,y,t) = -\frac{k}{\eta}\frac{\partial P(x,y,t)}{\partial x} = \frac{q}{2\pi F}\int_0^\infty \frac{2}{\sqrt{\pi æt}}\sin\lambda y_0 \sin\lambda y\{\left[\sigma(x-x_0)-1\right][e^{-\lambda(x_0-x)}erfc\left(\frac{x_0-x}{2\sqrt{æt}}-\lambda\sqrt{æt}\right)+$$
$$+\exp[-\lambda(x_0-x)-\left(\frac{x_0-x}{2\sqrt{æt}}-\lambda\sqrt{æt}\right)^2]+e^{\lambda(x_0-x)}erfc\left(\frac{x_0-x}{2\sqrt{æt}}+\lambda\sqrt{æt}\right)-$$
$$-\exp[\lambda(x_0-x\ -\left(\frac{x-x_0}{2\sqrt{æt}}+\lambda\sqrt{æt}\right)^2]]-\sigma(x-x_0)[e^{-\lambda(x-x_0)}erfc\left(\frac{x-x_0}{2\sqrt{æt}}-\lambda\sqrt{æt}\right)+ \quad (4)$$
$$+\exp[-\lambda(x-x_0)-\left(\frac{x-x_0}{2\sqrt{æt}}-\lambda\sqrt{æt}\right)^2]+e^{\lambda(x_0-x)}erfc\left(\frac{x-x_0}{2\sqrt{æt}}+\lambda\sqrt{æt}\right)-$$
$$-\exp[\lambda(x-x_0)-\left(\frac{x-x_0}{2\sqrt{æt}}+\lambda\sqrt{æt}\right)^2]]\}d\pi.$$

Dependences (3) and (4) allow to calculate value of projections of velocity vector of filtration in each point of the plane and time. For creation of formation of pollution area, entire process breaks into discrete periods Δt, on the beginning of each of which according to (3) and (4) projections of velocity vector of filtration are defined. Based on projections of velocity vector the vector itself is being built. Growth of pollution area in the direction of each velocity vector of filtration for the specified period is defined by product $w\Delta t$.

According to this algorithm calculations are carried out and graphs reflecting the nature of formation of pollution area of the soil by leak from the oil pipeline are built and shown in figure 3.

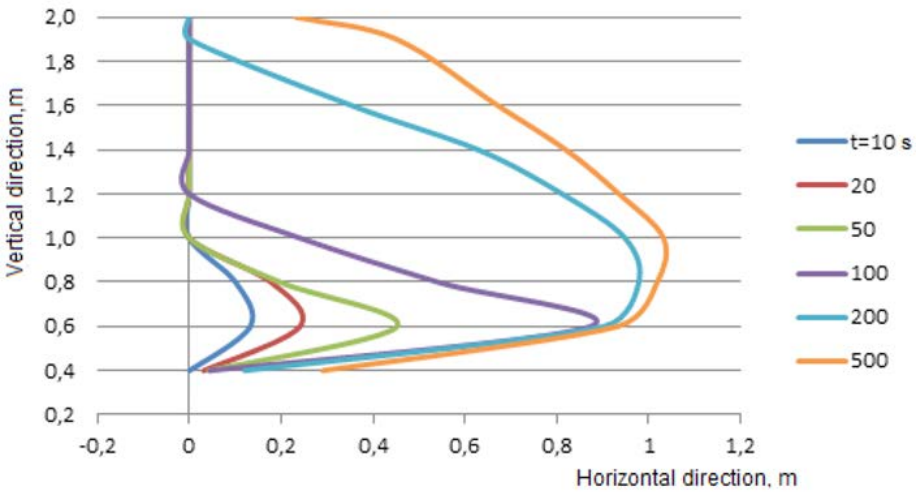

Figure 3. Nature of formation of pollution area of the soil by leak from the oil pipeline

The analysis of obtained graphic dependences shows that non-stationary process of formation of pollution area by leak from the oil pipeline can be divided into three phases respectively. The first phase starts with the moment of leak and is characterized by distribution of liquid in the vertical direction and downwards due to action of gravitational forces, at the same time pressure filtrational counteraction gradually grows till the moment when the size of filtrational resistance becomes equal to the size of gravitation force. From this point the second phase, which is characterized by distribution of liquid in the horizontal direction starts, at the same time filtrational resistance continues growing that causes a liquid filtation in the vertical direction up and is the beginning of the third phase of non-stationary filtration, which comes to the end by liquid achievement of soil surface.

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