railroad tank; hydrodynamic brake; viscous oil; viscous oil products; rheology

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EN-ROUTE MECHANICAL ACTIVATION OF VISCOUS OIL AND OIL PRODUCTS TRANSPORTED IN RAILROAD TANK CARS

Summary. The authors of this document are aiming to substantiate the advantages of en-route mechanical activation technology as aids for railroad transportation of viscous oil and oil products in tank cars. The conceptual design implies the use of momentum generated by brake action. This document also contains preliminary data of laboratory research confirming the validity of the developed concept.

МЕХАНОАКТИВАЦИЯ ВЯЗКОЙ НЕФТИ И НЕФТЕПРОДУКТОВ В ПУТИ СЛЕДОВАНИЯ ЖЕЛЕЗНОДОРОЖНОГО СОСТАВА

Аннотация. В статье авторами обосновывается способ транспортировки вязкой нефти и нефтепродуктов железнодорожными цистернами с механоактивацией в пути следования состава путем использования кинетической энергии торможения и приведены предварительные результаты лабораторных исследований, подтверждающие работоспособность идеи.

The high viscosity of crude oil seriously complicates its transportation. A number of papers by various authors consider the reasons for this and how to resolve it [1-3]. With poorly developed pipeline transmission systems in some of the regions of Kazakhstan the share of rail shipment of oil and its products remains quite significant. The other factors supporting the use of railway transportations are relatively advanced railway network, low density of population and long distances that products have to travel from manufacturers to consumers. The situation has improved recently with the start of rapid development of oil pipeline systems, but the problem is yet to be resolved.

Under the aforesaid circumstances one has to improve the marketability and enhance the competitive power of railway services through carrier costs reduction that among other things such as direct transportation costs also include expenses on preliminary heating of viscous oils to ensure swift unloading of railcar tanks at their discharge terminals. This is especially important in winter time when preliminary heating requires more energy and time to empty the tanks hence the costs and terminal time increase negatively affecting route turnover rates and causing shortage of cars.

The problems arising during transportation of highly paraffinic crude are mainly related to formation of solid wax crystals due to low temperature environment. They completely dissolve in oil and oil products with the increase of temperature to a sufficient level. But sometimes the temperature level drops low enough to allow wax crystals form a space lattice across the system thus immobilizing the fluid phase [4]. The higher the paraffin content and asphalt pitch are – the harder the space lattice is. This increases oil viscosity, oil chilling temperature and gel strength.

Thus, oils from Mangyshlak oil fields that have wax concentration of up to 25% as well as asphalt pitch at 17% or greater are qualified as high pour-point oil type and when subjected to high temperatures (close to 313 K) display thixotropic behavior of viscoplastic fluids. That is why before filling the tanks with this type of oil and prior to unloading the oil has to be preheated to reach temperature level of 340-350 K. All efforts to resolve the problem up to present time were limited to devising various stationary preheating systems at product destination points. However, the energy efficiency of existing heating methods applied nowadays is quite low. For instance, heating railcars with superheated vapor requires up to 5000 kg of vapor per each tank containing fuel oil [4].

Depending on viscous oil freight turnover (the figure in Kazakhstan exceeds two million tons per year) the overall volume of heat energy used for heating purposes may be colossal. To produce that much of energy we have to use huge amounts of valuable hydrocarbons, a process that creates noxious emissions. Even partial reduction of these costs will have appreciably positive impact on productivity and environment.

The authors of this document made an effort to substantiate the viscous oil railway transportation method that employs conversion of railway car brake action energy to ensure rheological properties of oil, such as viscosity and fluidness are maintained at appropriate level.

It is a known fact that trains on their way to their destination stations have to use their brake systems quite often to keep up with the schedule and for intermediate stops. At that a huge amount of kinetic energy generated by moving train is uselessly wasted due to friction in clasp blocks. This not only results in wear of clasp blocks made from highly expensive composite materials, but also contributes to intensive wear in wheel treads.

One of the well-known devices engineered for direct conversion of mechanical power to heat energy that has high energy conversion efficiency is the hydrodynamic brake [5, 6].

To implement this method the steam-heating tank cars are required to have undercar hydrodynamic brakes that will act as vortex heat generator (Fig. 1 and 2) [7, 8]. The system is powered up through main trainline pipe by airclutch installed on wheel pair shaft 4 and is designed to activate during service brake application at downward slopes and intermediate station stops. In doing so the kinetic energy of the train is simultaneously converted into heat and hydromechanical energy in hydrodynamic brake 1 which are then used for heating and breaking down of structure of transported product thus increasing the time for recovery of its thixotropic properties.

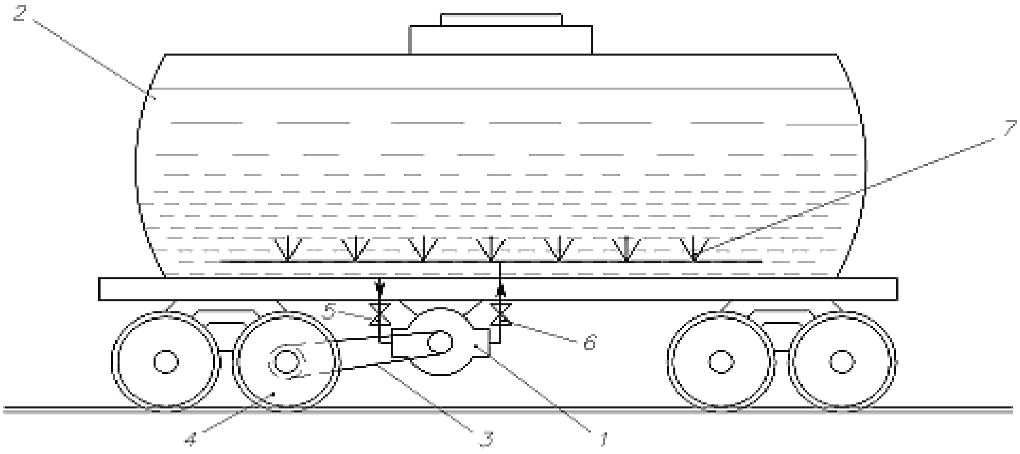

Fig. 1. Undercar hydrodynamic brakes layout drawing: 1-Undercar hydrodynamic brake (vortex heat generator); 2-Tank; 3-V-belt drive; 4-Wheel pair; 5, 6-Tempreature controlled valves; 7- Mixing devices

Рис. 1. Схема компоновки цистерны подвагонным гидродинамическим тормозом: 1-подвагонный гидродинамический тормоз (кавитационный теплогенератор); 2-цистерна; 3-клиноременная передача; 4-колесная пара; 5,6-терморегулируемые задвижки; 7- смесительные устройства

It has been found that up to 95% of hydrodynamic brake stopping power is converted into heat energy. In view of the fact that discharge of hydraulic fluid from brake system is carried out under excessive pressure through low pressure jet pump installed in transportation tank (and acting as mixing device 7), the discharge process leads to additional rapid mixing of heated oil products and increases the convective heat transfer.

It is known that control of hydrodynamic brake capacity (i.e. applied load conversion into heat) can be implemented by changing the fluid level in its working cavity through fluid supply or fluid discharge.

Temperature controlled valves 5, 6 automatically adjust the hydrodynamic brakes for optimum performance to sustain the required temperature level of transported oil products.

Besides, operational capability of the standard brake system is never disabled. Simultaneous application of both systems may help significantly reduce the stopping distance and improve the maneuverability of the train.

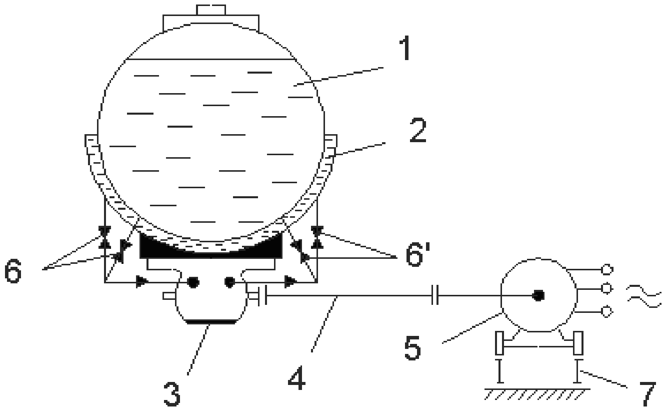

Fig. 2. Viscous oil and oil products transportation tank layout drawing: 1-Oil product (oil); 2-Low-freezing liquid in steam jacket; 3-Hydraulic brake; 4-Driveline (Cardan joint); 5-External drive (electric motor); 6-Thermally controlled valves; 7- Track for external drive at discharge terminals

Рис. 2. Схема компоновки железнодорожной цистерны для перевозки вязкой нефти и нефтепродуктов: 1-нефтепродукт (нефть); 2-низкозамерзающая жидкость в паровой рубашке; 3-гидротормозное устройство; 4-передача (кардан); 5-внешний привод (электродвигатель); 6-терморегулируемые вентили; 7-рельсовая колея для перемещения привода в пунктах слива

The technology for en-route preservation of rheological properties of viscous oil products transported in rail car tanks will help significantly reduce (and in some cases completely exclude) energy expenditures on preheating process that has to be applied prior to unloading of tanks at discharge terminals.

Hydrodynamic brake system has the following advantages:

- Small size while high efficiency rates of conversion of mechanical energy into heat (up to 95%);
- Easy control and performance adjustment;
- Adaptability for stationary use at tank receiving racks prior to product discharge;
- Hydrodynamic impact on oils moving through impeller combined with cavitation and thermal effect should significantly increase the amount of time needed for thixotropic recovery;
- High pressure jet of hot oil at hydrodynamic brake discharge end hitting the fluids in tank causes intensive bubbling of fluids which in turn forces the intensity of convective heat transfer to increase;
- Maintainability, high reliability, fire and explosion safety.

Nevertheless, there is still a high chance of system failure in case transported fluids lose their flow state. That is the reason why the en-route system disconnection intervals should not exceed the time required for thixotropic properties of transported fluids to recover. In case of high risk of transported fluids losing their fluidness the tank cars with steam jackets are required to have this system installed.

The steam jacket can be filled with low-freezing liquid which will act as hydraulic fluid in hydrodynamic brake system when it’s connected. The brake spindle can be connected to external power source (electric motor) for heating of fluid stored in tanks in stationary conditions upon arrival of tank cars to the discharge terminal receiving platform. This heating method will result in penetration of heat into tank walls reducing the viscosity of oil layers adjacent to the walls and causing the layers to slip down into the drain valve or oil-handling facility.

If heating of transported fluids has to be avoided whenever possible or for some reason is undesirable at all (for instance to avoid losses in low boiling fluids) the hydrodynamic brake can be replaced with mechanical activation system – a high speed stirring device designed to break down wax crystals turning them into highly dispersed structure.

To confirm the validity of these statements we have done a series of lab tests and are now ready to present the preliminary results as follows below.

Equipment used and test procedure

The test unit assembly included radially finned disk type hydrodynamic brake system 1 (refer to fig. 3) driven by DC electric motor 2 for rpm control monitored through type TE-10 electronic tachometer to an accuracy of up to 1 min^{-1}. The number of radial fins in impeller design was based on the peak value of dissipative heating on water. The liquid supply and discharge pipelines were thermally insulated.

The flow rate of working fluid (oil product) was measured with tachometer 3. The impeller inlet and outlet fluid temperature as well as temperature level in pressure tank were measured with chromel-copel thermocouples t1, t2 and t3 followed by measurement data registration in 6-channel logger Combined recorder (accuracy rating 0,5; scale range 0-150 ^{0}C).

The impeller inlet and outlet pressure level was measured with pressure gages 4 and 5 having instrument range of -1 to 1 and 0 to 5 bar accordingly with upper range value accuracy of 1%.

In order to control the heat loss process (simulating the low temperature environment of wintertime) tank 6 was enclosed in thermally insulated shroud furnished with built-in tube coil 7 to facilitate circulation of cooling fluid fed from low temperature liquid thermostat 8.

The rheological properties of tested fluids were measured and rated for viscosity, setting points and thixotropic properties recovery time. The selection of the aforementioned parameters for analysis was justified by the fact that these parameters were found to be essential for determination of performance characteristics and operational capabilities of the suggested transportation system since viscosity defines the flow behavior of fluids as well as tank discharge time; thixotropic properties recovery time tells us how much slack time we have before we need to reactivate the system whereas the setting point helps assess the likelihood of system failure.

The viscosity and fluidness were estimated indirectly based on measured effusion time required to completely drain the tank from fluids through metering hole 9. Dripping from free end of tube was recognized as indication of discharge completion.

Samples of fluids were taken from tank 6 while in service for follow up observation and analysis. The samples were put into three separate sample flasks for averaging of results. Incompleteness of discharge volume was evaluated through weighing of vessel 6 after completion of drain process indicated by dripping.

Viscous oil heating temperature was limited to 355 K in order to avoid loss of light ends.

In order to find out how hydrodynamic action affects fluid structure we employed micrographic imaging technology to have a closer look at oil structure in various operating conditions.

At the first stage of experimental research the lab testing was done to assess the hydrodynamic impact on rheological properties of viscous oils represented by Mangyshlak oil characterized by setting point of 300 K, paraffin content at 16%, water ratio 0,25% and salinity level at 321 mg/l.

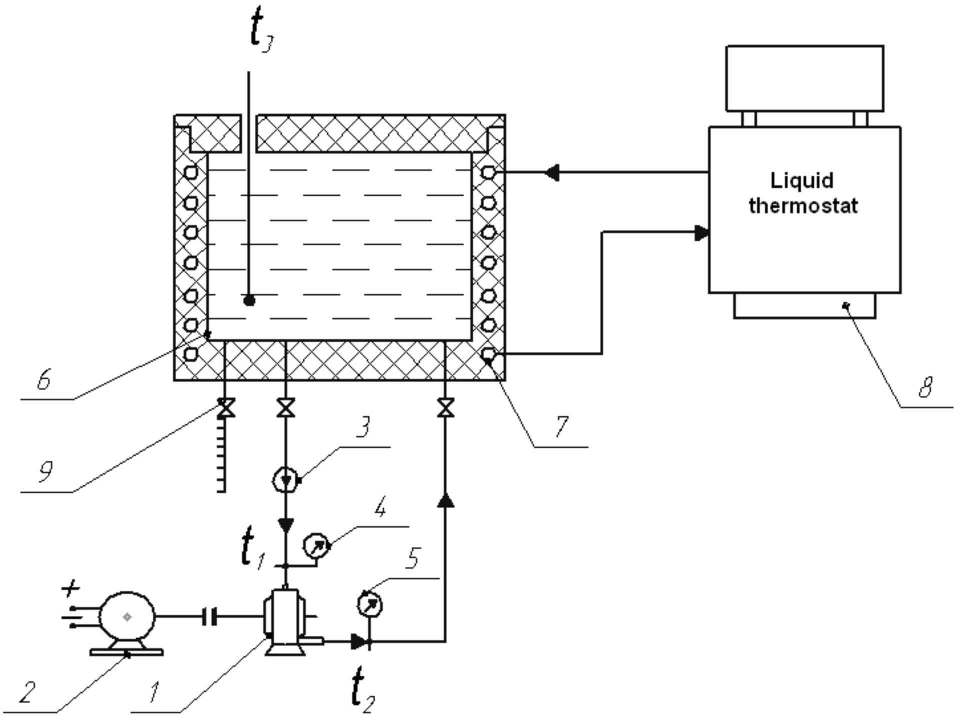

Fig. 3 Test unit layout drawing
Рис. 3. Схема экспериментальной установки

Research results

Table 1 presents some of the preliminary results and test data that give us a solid reason to believe, even at that early stage, that the hydrodynamic impact on viscous oils and oil products significantly affects their rheological properties such as viscosity, fluidness and thixotropic characteristics.

Thus, mechanical activation of oil allows us to reduce oil viscosity by almost three times and the pour point by 9 ^{0}C while increasing the time required for the thixotropic properties to recover by more than 10 times with the temperature level being in all cases equal.

Table 1

Experimental study results

Crude	Dynamic viscosity, μ N·c/m^2		Time of thixotropic recovery, h		Pour point, K	
	Before mechanical treatment	After treatment	Before mechanical treatment	After treatment	Before mechanical treatment	After treatment
Mangyshlak oil with pour point at 300K	2,2	0,72	16	165	313	304

Fig. 4 shows rate of temperature change of oil in vessel against time that indirectly describes the thermal capacity of dissipative heating. We can distinguish three segments of temperature curve. The first segment (a) is rather close to plateau in shape due to uneven penetration of heat into the fluid. The second segment (b) reflects uniform heating, whereas the third segment (c) shows that heat penetration into the fluid slows down because of heat dissipation into the ambient environment.

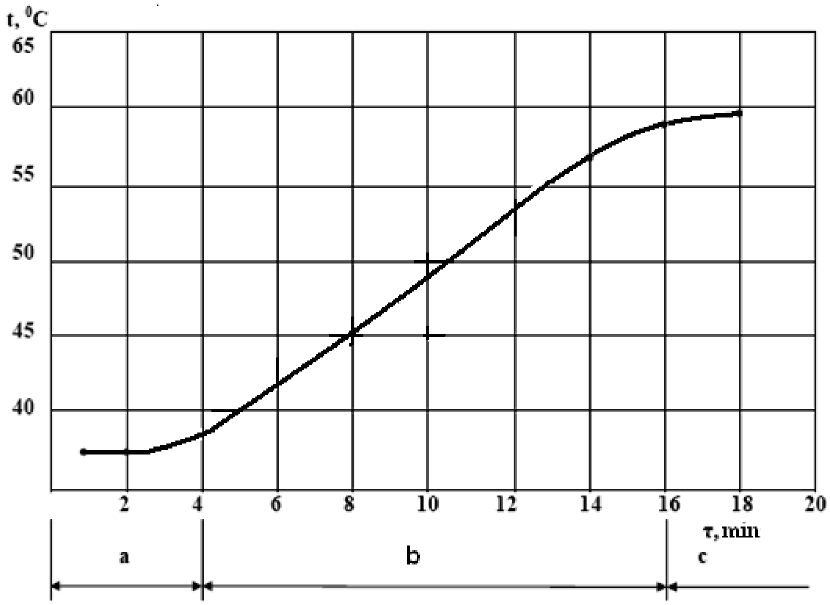

Fig. 4. Dependence of temperature change of oil in vessel on time

Рис. 4. Скорость изменения температуры вязкой нефти в емкости от времени

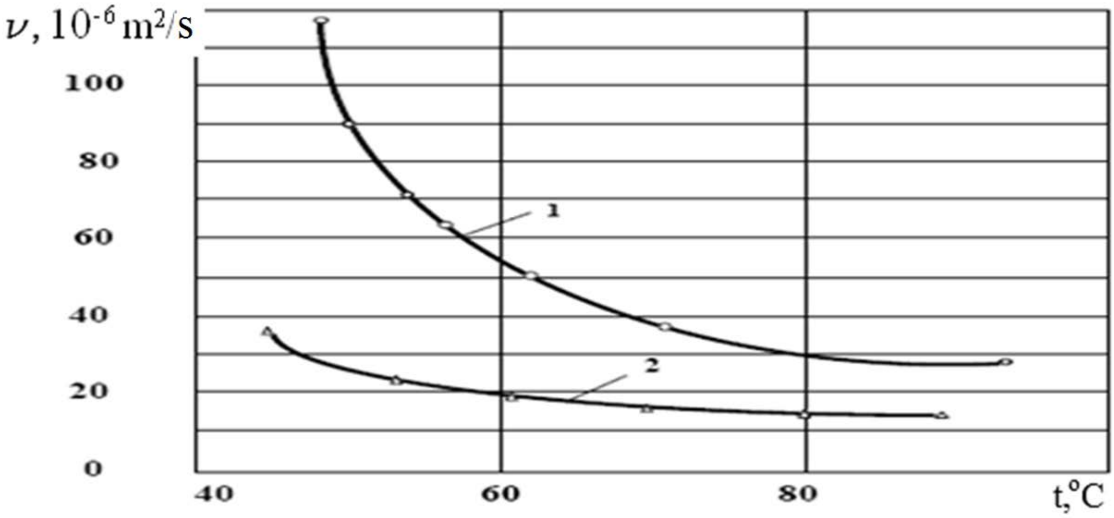

Fig. 5. Viscosity-temperature characteristics of oil: Before mechanical treatment; 2- After mechanical activation by hydrodynamic brake system

Рис. 5. Вязкостно-температурные характеристики нефти: 1 - необработанной нефти; 2 - после механоактивации гидротормозным устройством

Viscosity-temperature (kinematic viscosity ν vs. temperature) characteristics of viscous oil before and after mechanical activation in disk impeller are shown on fig. 5, whence it follows that exposure of viscous oil to intensive hydro-mechanical action in isothermal conditions will cause oil viscosity to decrease substantially at the same time increasing its fluidity.

The analysis of microfilm images of oil structure revealed that wax crystals in samples of oil that has not been put through mechanical activation process develop forms and group in clusters (druses) up to 0,22 mm in size, this correlates well with data in [9]. The observations confirmed that even one application of mechanical activation (single pass through mechanical activation system) was enough to turn wax crystals formations into highly dispersed structure (less than 0,0012 mm in size).

Therefore the preliminary results of experimental research are acceptable to confirm that combined effect of hydrodynamic impact and conversion of cavitations into heat will not only substantially reduce the viscosity of oil and increase its fluidity, but will also increase the time of recovery of thixotropic properties as compared to oil behavior in natural cooling after application of heat.

Practical implementation of the aforementioned engineering concept can be accomplished at the carriage repair plant or rail car production facilities. Actual operational application of this technology may require employment of detailed charts or schedules specifying the usage modes for various routes and profiles of railroad line sections that will help the locomotive crew to operate this technology in appropriate manner.

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