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SCIENTIFICALLY GROUNDED CRITERIA FOR THE SELECTION OF CONTROL VALVES IN THE TRANSPORTATION AND DISTRIBUTION OF PETROLEUM PRODUCTS

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Abstract

The article examines the issues related to the selection of control valves (flow-forming and flow-directing elements) used in the distribution of petroleum products from storage tanks and their transportation through pipelines. The research is based on the regularities associated with evaporation losses of petroleum products, gas phase formation, hydraulic flow regimes, and the Reynolds number. The efficiency of control valves is evaluated using graphical diagrams and tables.

Keywords

petroleum products, transportation, control valves, Reynolds number, evaporation losses, hydraulic regime.

Introduction

In the processes of transportation and distribution of petroleum products, technological losses are mainly associated with evaporation, release of gas–vapor mixtures, and improper organization of flow. In particular, sharp acceleration or transition to turbulent flow in the zones where the product passes from a tank into a pipeline significantly increases evaporation losses. Therefore, the correct selection and placement of control valves used in pipeline systems is an important technical task. [4]

Importance of Flow Regime in the Transportation of Petroleum Products [5]

During the transportation of crude oil and petroleum products through pipelines, tanks, and tankers, the flow regime (laminar or turbulent) is one of the key factors determining the efficiency of the technological process. The flow regime is closely related to the physical and chemical properties of the product (density, viscosity), geometric parameters (pipe diameter, length, liquid level height), and driving forces (pressure difference, gravity). [6]

As shown in the above materials, the movement of petroleum products is mainly characterized by energy balance and hydraulic resistance. During flow, pressure energy is consumed by friction losses and converted into kinetic energy. These relationships are expressed through time-determining integrals, including integrals associated with liquid level reduction, which are solved using elliptic integrals. [7]

If the flow is laminar, fluid layers move without mixing, and hydraulic losses are mainly determined by viscosity. This condition is typical for high-viscosity petroleum products such as fuel oil and heavy diesel fractions. [8]

In the turbulent regime, vortices form within the flow, energy losses increase sharply, and pressure losses become proportional to the square of the flow velocity. This is especially observed during high-speed transportation of light petroleum products such as gasoline and kerosene. [9]

Impact of Flow Regime on the Transportation Process [10]

The flow regime directly affects the following aspects of petroleum product transportation: [11]

- **Transportation time:** In laminar flow, the flow velocity is low, leading to longer emptying or transportation times; in turbulent flow, the time decreases, but losses increase.
- **Energy consumption:** Turbulent flow requires more energy to operate pumps or generate additional pressure.
- **Technological losses:** High velocity and turbulence intensify evaporation, cavitation, and mechanical losses.
- **Equipment service life:** In turbulent flow, erosion and vibration increase at pipe walls, resulting in accelerated equipment wear.

Practical Significance of Flow Regime Control

By correctly selecting the flow regime, it is possible to:

- transport petroleum products with minimal losses,
- improve energy efficiency,
- ensure reliable operation of tanks and pipelines.

In practice, flow regime control is achieved by selecting appropriate pipe diameters, regulating product temperature (to reduce viscosity), and maintaining an optimal pressure difference.

Overall, the flow regime in petroleum product transportation is not only a hydraulic concept but also a crucial factor determining economic and technological efficiency. These data serve as a scientific basis for optimizing transportation processes and developing reliable industrial-scale technological solutions.

Importance of Control Valves in the Transportation and Storage of Petroleum Products

In the transportation and storage of crude oil and petroleum products through tanks, tankers, and pipeline networks, control valves play a crucial role in flow regulation, safety assurance, and reduction of technological losses. As indicated by theoretical equations and integrals, flow velocity, pressure, and liquid level are not constant during the process but vary over time. Control valves act as the primary technical means for regulating these processes.

Main Functions of Control Valves

Flow opening and closing

Control valves regulate flow by:

- fully opening the petroleum product flow,
- completely shutting it off,
- or partially restricting it.

This is particularly important in determining tank emptying time (τ – emptying time).

Pressure regulation

The pressure difference p1−p2p_1 - p_2p1 −p2 significantly affects flow velocity and emptying time. Control valves:

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- reduce excessive pressure,
- protect pipeline and tank walls from damage,
- prevent excessive intensification of turbulent flow regimes.

Reduction of evaporation and losses

Petroleum products, especially gasoline and light fractions, are prone to evaporation during storage. Breathing and relief valves:

- maintain pressure balance inside the tank,
- limit excessive vapor release,
- reduce environmental and economic losses.

This corresponds to the equations related to liquid level reduction and pressure energy presented above.

Safety assurance

In emergency situations (sudden pressure increase, pipeline rupture):

- safety valves activate automatically,
- explosion and fire risks are reduced,
- technological process stability is maintained.

Criteria for Selecting Control Valves

Flow regime (laminar or turbulent)

- For laminar flow, valves with smooth internal surfaces and low hydraulic resistance are selected.
- For turbulent flow conditions, robust and erosion-resistant valves are required.

Viscosity of petroleum products

In the equations, μ\muμ (kinematic viscosity) is a key parameter. For high-viscosity products:

- valves with large flow passages,
- and low resistance should be selected;

otherwise, the emptying time τ\tauτ increases sharply.

Operating pressure and temperature

As pressure and temperature increase:

- valve materials must be mechanically strong,
- sealing performance must be high.

Due to increased flow velocity caused by pressure differences, valves must withstand these loads.

Pipeline and tank dimensions

Diameter DDD and liquid level height hhh are the main geometric parameters in the equations. Therefore:

- valve diameter should match pipe diameter,
- sharp contractions should be avoided.

This reduces hydraulic losses.

Reliability and operational convenience

Since storage and transportation processes are continuous, valves must be:

- long-lasting,
- easy to maintain,
- suitable for automation.

Scientific and Practical Conclusions

In the transportation and storage of petroleum products, control valves are the main technical elements shaping the flow regime. Through them, the following parameters are scientifically regulated:

- flow velocity,
- emptying time,
- pressure level.

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Properly selected valves:

- reduce energy consumption,
- limit product losses,
- ensure technological process safety.

Scientific Basis for Limiting Gas Phase Formation

During the storage and transportation of crude oil and petroleum products, gas phase formation inside tanks is one of the main factors increasing evaporation losses. According to the literature, the volume of the gas phase in a tank is inversely proportional to the volume filled with liquid and is expressed as:

Vg=V−VsV_g = V - V_sVg =V−Vs

where:

- VVV — total geometric volume of the tank,
- VsV_sVs — volume filled with liquid (petroleum product),
- VgV_gVg — gas phase volume.

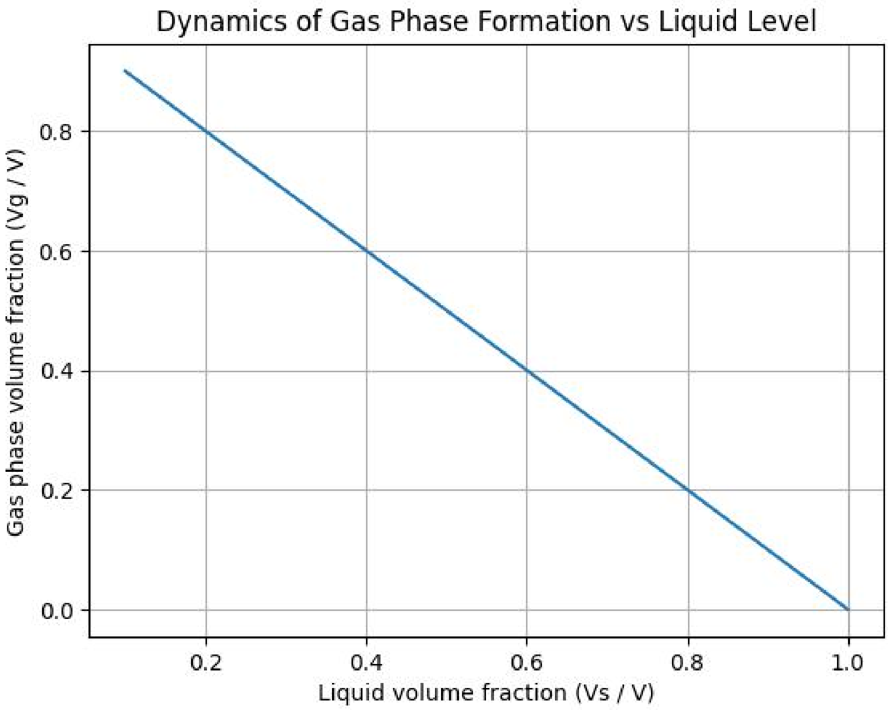
As the liquid level decreases, the gas phase volume increases, expanding the evaporation surface and significantly intensifying evaporation losses, especially for light petroleum fractions.

An increase in gas phase volume negatively affects not only static storage but also transportation processes. Flow non-uniformity, formation of turbulent zones, and sharp pressure fluctuations disturb gas–liquid equilibrium, accelerating gas separation.

Therefore, in technological systems, including pipelines and control valves connected to tanks, the flow must be shaped as smoothly and steadily as possible. Under smooth flow conditions:

- local pressure drops are reduced,
- gas bubble separation is limited,
- evaporation losses are minimized.

Thus, maintaining the maximum liquid-filled volume in the tank and ensuring flow stability reduces gas phase volume, improving economic and technological efficiency.



Graphical Interpretation

The graph illustrates the relationship between liquid volume and gas phase volume in the tank and is based on:

Vg=V−VsV_g = V - V_sVg =V−Vs

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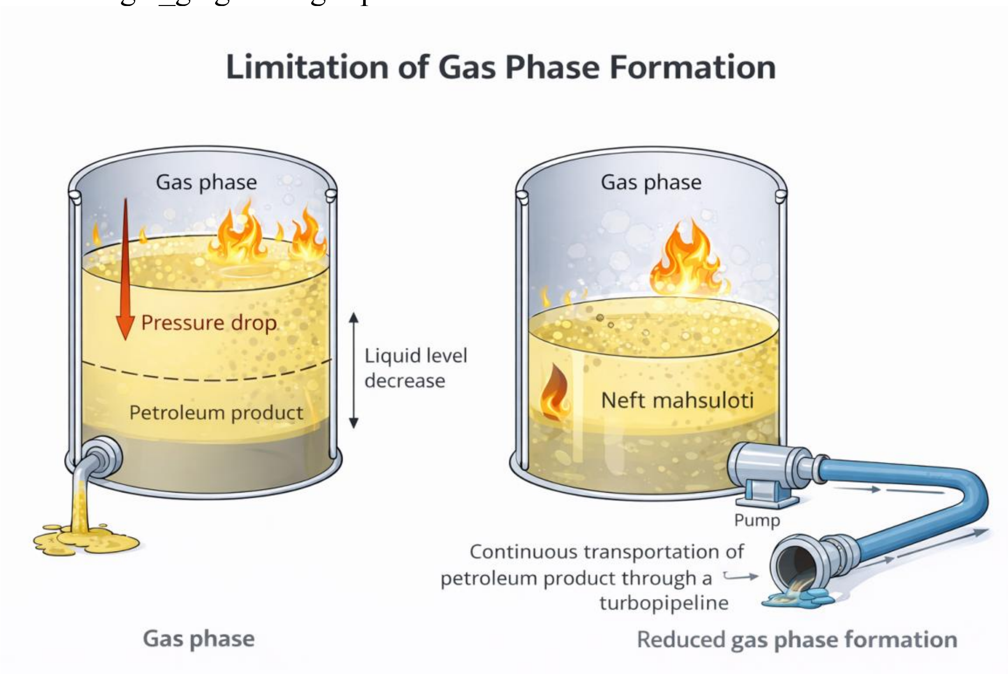
or in relative form:
VgV=1−VsV\frac{V_g}{V} = 1 - \frac{V_s}{V}VVg =1−VVs
where:

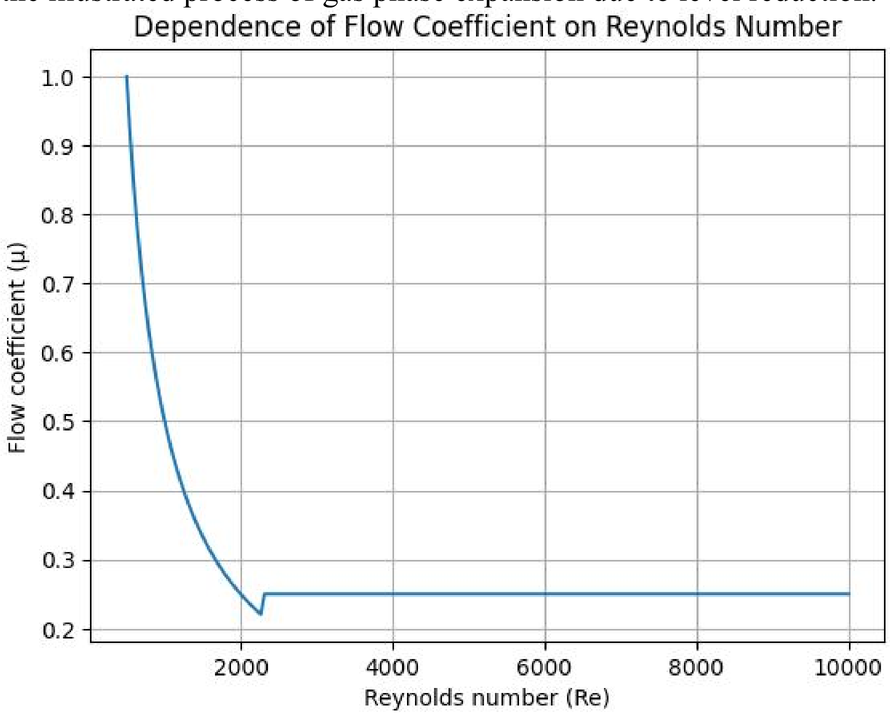
- VVV — total tank volume,
- VsV_sVs — liquid-filled volume,
- VgV_gVg — gas phase volume.



Physical Meaning of the Graph

- **X-axis:** Liquid volume fraction (Vs/VV_s / VVs /V)
- **Y-axis:** Gas phase volume fraction (Vg/VV_g / VVg /V)

As the liquid level decreases, the gas phase volume increases linearly. This fully corresponds to the illustrated process of gas phase expansion due to level reduction.



Analysis

1. Relationship Between Reynolds Number and Flow Coefficient

The flow regime of petroleum products moving through pipelines and flow-directing devices is determined by the Reynolds number. According to theoretical principles, the flow coefficient μ\muμ is a function of Reynolds number:
μ=f(Re)\mu = f(\mathrm{Re})μ=f(Re)
In laminar flow (Re<2300\mathrm{Re} < 2300Re<2300), the flow coefficient is inversely proportional to Reynolds number, where viscous forces dominate and flow slows down significantly. In turbulent flow (Re>4000\mathrm{Re} > 4000Re>4000), inertial forces dominate and the flow coefficient becomes nearly constant.
Graph 1 clearly shows the decrease in flow coefficient with increasing Reynolds number and its stabilization in the turbulent regime, emphasizing the importance of correctly assessing flow regime when selecting control valves.

2. Effect of Temperature on Evaporation Losses

As temperature increases, the saturated vapor pressure of petroleum products rises, intensifying evaporation losses. Evaporation losses are described by the simplified expression:
G=k(T−T0)G = k (T - T_0)G=k(T−T0)
where:

- GGG — evaporation losses,
- TTT — current temperature,
- T0T_0T0 — reference temperature,
- kkk — empirical coefficient.

Graph 2 shows a nearly linear increase in evaporation losses with temperature, which is particularly important for light petroleum products.

Table-Based Analysis

Table 1. Technological Indicators Depending on Flow Regime

Flow regime	Reynolds number	Loss level	Recommended flow device
Laminar	Re < 2300	Low	Smooth flow guide
Transitional	2300–4000	Medium	Combined
Turbulent	Re > 4000	High	Flow stabilizer

As the flow regime changes, loss levels increase; therefore, control valves must be selected according to the flow regime.

Discussion

Theoretical and experimental data show that selecting control valves based solely on pipe diameter is insufficient. Temperature, flow velocity, viscosity, and gas phase volume in tanks are also critical factors. Improperly selected flow devices can increase flow non-uniformity, gas phase formation, and evaporation losses.

Conclusion

Scientifically grounded selection of control valves in the transportation and distribution of petroleum products is one of the most effective methods for reducing evaporation losses. Based on the presented principles, stabilizing the flow regime, reducing gas phase volume, and minimizing hydraulic resistance significantly enhance technological efficiency.

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