

## Research on mixing and testing VG 22 hydraulic oil for use in military technical vehicles

Ngo Quoc Khanh\*

Military Petroleum Technical Institute, Petroleum Department, Pho Yen, Me Linh, Hanoi, Vietnam.

\*Corresponding author: ngoquockhanh292@gmail.com

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### ABSTRACT

*The paper presents the results of research on the formulation and performance evaluation of VKX.AU hydraulic oil with a viscosity grade of VG 22, developed based on an improved formulation aimed at enhancing transmission efficiency and equipment reliability under specific military operating conditions. The product was blended from high-quality refined base oils combined with a specialized additive package, including a pour point depressant, antioxidant, anti-wear agent, and rust inhibitor, ensuring physicochemical stability and long-term durability. Test results show that the formulated VKX.AU hydraulic oil meets the quality standards equivalent to the imported product specified in TU 38.1011232–89, with several superior properties such as enhanced anti-wear, anti-rust, and demulsifying performance. In addition, the blended oil demonstrated good compatibility with sealing materials used in the hydraulic system of the 105 mm artillery.*

**Keywords:** Hydraulic system; Hydraulic oil; Base oil; Additive; Anti-wear; Pour point depressant.

### 1. INTRODUCTION

The hydraulic oil plays a key role in hydraulic transmission and control systems by performing important functions of power transmission, lubrication, sealing and cooling [1, 2]. Due to the diversity of system structures and operating conditions (temperature, pressure, etc.) [3, 6], hydraulic oil is classified according to many different criteria, and mostly by viscosity (ISO 3448) [8], by characteristics and purposes of use (ISO 6743/4) [9] or by technical performance (ISO 11158) [7]. Among them, the ISO VG 22 viscosity hydraulic oil has a wide range of applications, is mainly provided by international brands such as Shell (Tellus S2 V22), BP (Energol HLP 22), Mobil, Total, or Russian specialized hydraulic oil products used for military technical vehicles [4, 5]. These products are usually formulated from mineral or synthetic base oils, combined with additives to improve anti-wear, oxidation stability, defoaming and rust resistance. The current development trend of hydraulic oils focuses on improving energy efficiency, extending equipment lifespan, reducing friction and wear, while replacing mineral base oils with biodegradable biobased oils, optimizing environmentally friendly additives, and meeting stringent international technical standards [14-16].

Vietnam has mostly produced the hydraulic oil on a small scale with a few products that meet high standards, especially for low viscosity such as VG 22. Domestic research is currently in the early stages compared to countries with developed lubricant industries (USA, Germany, Japan, and Russia) [10-12]. Some research institutions, such as Hanoi University of Science and Technology, Ho Chi Minh City University of Technology, Vietnam Institute of Industrial Chemistry (VIIC) have implemented a number of projects of producing lubricants from group II/III base oils, but have not focused on VG 22 hydraulic oil yet. Companies such as PV Oil Lube, Vilube, Saigon Petro, Mipex Lubricants currently produce commonly HLP 32/46/68 products commonly, while VG 22 oil is mainly produced according to special orders or imported for repackaging. Testing of VG 22 lubricants faces major limitations due to the lack of comprehensive, in-depth assessments previously available, such as testing for oxidation stability according to

GOST 981, testing for wear properties according to ASTM D2882 (or GOST 9490) or compatibility with sealing materials in hydraulic systems [10, 11].

In that context, the research and development of domestic hydraulic oil with technical properties equivalent to or superior to imported products is extremely necessary. The objective is to produce VG 22 hydraulic oil that meets the Russian Federation's TU 38 1011232-89 Standard for AU hydraulic oil [13], which can operate stably in a wide temperature range, start at low temperature up to -30 °C, and withstand short-term high temperature up to 125 °C without causing quality deterioration or damage to equipment. At the same time, the product needs to be suitable for Vietnam's climate and specific military operating conditions, to ensure the efficiency in practical applications and industrial production, and enhance the localization capacity of supporting industrial products in the fields of mechanics, automation and manufacturing.

## 2. EXPERIMENT

### 2.1. Used raw materials and chemicals

The research used Korean Group II base oils such as N70, N150. The quality indicators of the base oils are presented in table 1.

*Table 1. Quality indicators of N70, N150 base oils.*

No.	Analytical indicators	Analytical methodologies	N70 base oil	N150 base oil
1	Kinematic viscosity at 40 °C, cSt	GOST 33-2016	14.29	30.58
2	Viscosity index	GOST 25371-2018	94	113
3	Acid number, mg KOH/g	GOST 5985-2022	NA	NA
4	Ash content, %wt	GOST 1461-2023	0	0
5	Metal corrosion testing	GOST 2917-76	Conformed	Conformed
6	Water-soluble acid and alkali content	GOST 6307-75	NA	NA
7	Mechanical impurities content, %wt	GOST 6370-2018	NA	NA
8	Water content, %wt	GOST 2477-2014	NA	NA
9	ASTM colour	ASTM D 1500-24	L 0.5	L 0.5
10	Open cup flash point, °C	GOST 4333-2021	194	208
11	Pour point, °C	GOST 20287-91	- 42	- 30
12	Density at 20 °C, kg/m <sup>3</sup>	GOST 3900-22	844.9	848.6

**Additives:** Additives used for research on mixing and testing include Ionol oxidation inhibitor (Oxiris - Spain); Lubrizol 5800 anti-wear and rust inhibitor (USA) and TF 248 pour point depressant. These additives are widely used in the market as low-toxicity, environmentally friendly, with the ability to increase thermal and oxidation resistance to extend oil life and optimize energy efficiency and protect equipment in harsh conditions.

Others not listed in the paper are chemicals of analytical purity. The products have full certificates of origin (CO) and certificates of quality (CQ) from the manufacturers.

### 2.2. Tools and equipment

Laboratory preparation equipment includes an analytical balance with accuracy up to 0.0001 g; measuring cylinders with capacities of 50 mL, 100 mL; heat-resistant cups of 250 mL, 500 mL; stirrers with speeds from 20 to 500 rpm; an electric stove and thermometer to control temperature.

The pilot-scale mixing equipment was designed and manufactured by the Military Petroleum Technical Institute (MPTI)/Petroleum Department. It is made of 304 stainless steel with a 0.75 kW gear motor, a stirring blade with a speed of up to 200 rpm and a thermometer with a thermocouple sensor head. It is equipped with a bottom and wall heater.

### 2.3. Research methodologies

Physico-chemical analytical methodologies are used to ensure that VKX.AU oil meets the Russian Federation’s TU 38 1011232-89 Standard for AU hydraulic oil. Eleven physico-chemical analytical methodologies and six function tests have conducted to assess the quality of raw materials and products. These methodologies are in accordance with current standards, and ensure accuracy, objectiveness and scientific analysis results. The tests have been carried out at the Petroleum Chemistry Laboratory (VILAS 001) of the Military Petroleum Technical Institute / Petroleum Department/General Department of Logistics and Technology.

Some indicators determined by the GOST Framework cannot be tested in Vietnam (due to a lack of equipment), so equivalent ASTM standards are applied instead within the scope of the research. Specifically, GOST 19199 (Testing rust resistance on steel plates) is replaced with ASTM D665; GOST 12068 (Determination of demulsibility) is replaced with ASTM D1401; and GOST 20284 (Determination of oil colour) is replaced with ASTM D1500. ASTM D 892 standard is applied to test foaming properties.

## 3. RESULTS AND DISCUSSION

### 3.1. Mixing formula

#### Base oil selection:

The base oils for hydraulic oils require appropriate viscosity for operating temperatures, high viscosity index for viscosity stability, lubricity, anti-wear, anti-oxidation, anti-foam and anti-emulsification properties, high flash point, low pour point, and compatibility with system sealing materials. Additionally, base oils may be mineral, synthetic, or natural depending on the applications to meet environmental requirements such as biodegradability.

Korean Group II base oils are produced by modern technology by being treated with not only solvents but also hydro, so they have good demulsibility, high flash point, low TAN and no metal corrosion. Therefore, Korean Group II base oils N70 and N150 are selected oil as raw materials for producing VKX.AU hydraulic oil. From the analysis of the quality indicators of Group II base oils (in table 1), the products have been calculated and blended specifically in the laboratory. To have the mixture of base oils with suitable kinematic viscosity at 40 °C within the required level of 16 ÷ 22 cSt, the mixing ratio between base oils is N70/N150 = 35/65 (%wt). The quality indicators of the mixture of base oils (N70/N150) are presented in table 2.

*Table 2. Quality indicators of the mixture of base oils N70/N150.*

No.	Analytical indicators	Analytical methodologies	Russian AU oil	Mixture of base oils (N70/N150)	Specification
1	Kinematic viscosity at 40 °C, cSt	GOST 33-2016	19.41	18.61	16 ÷ 22
2	Acid number, mg KOH/g	GOST 5985-2022	0.01	NA	≤ 0.05
3	Viscosity index	GOST 25371-2018	138	182	-
4	Ash content, %wt	GOST 1461-2023	0.001	0	≤ 0.005
5	Metal corrosion testing	GOST 2917-76	Conformed	Conformed	Conformed
6	Water-soluble acid and alkali content	GOST 6307-75	NA	NA	NA
7	Mechanical impurities content, %wt	GOST 6370-2018	NA	NA	NA

No.	Analytical indicators	Analytical methodologies	Russian AU oil	Mixture of base oils (N70/N150)	Specification
8	Water content, %wt	GOST 2477-2014	NA	NA	NA
9	ASTM colour	ASTM D 1500-24	L 0.5	L 0.5	≤ 2.5
10	Open cup flash point, °C	GOST 4333-2021	214	204	≥ 165
11	Pour point, °C	GOST 20287-91	<- 45	- 38	≤ - 45
12	Density at 20°C, kg/m <sup>3</sup>	GOST 3900-22	866.4	846.6	≤ 890
13	Thermal oxidation stability: - Oxidation residue content - Oxidation acid acid	GOST 981-75	0	0	-
14	Four-ball wear at 196N load for 1 hour: - Wear diameter D <sub>i</sub>	GOST 9490-75	0.92	0.83	-
15	Foaming properties, mL/mL: - Cycle I (at 24 °C) - Cycle II (at 94 °C) - Cycle III (at 24 °C after 94 °C)	ASTM D 892-23	30/0 10/0 30/0	10/0 5/0 10/0	-
16	Rust	ASTM D 665-19	Severe rust (> 5%)	Severe rust (> 5%)	-
17	Demulsibility	ASTM D 1401-21	40-39-1 (20)	40-40-0 (5)	-

Table 2 shows that the mixture of base oils is of high quality and can be used as a raw material for producing VKX.AU hydraulic oil. However, additives and mixing ratios should be selected and assessed to improve its anti-oxidation, anti-wear and rust resistance and ensure that the product has a low pour point.

#### **Selection of additive ratio:**

*Antioxidant additive IONOL* (2,6-di-tert-butyl-4-methylphenol) is selected due to its effective prevention from the oxidation of base oils by capturing and eliminating free radicals formed during the working process of the oil. IONOL may limit the formation of peroxides, organic acids and dirt, maintain the colour stability, viscosity and lubrication properties of the oil for a long time. In addition, it is well-soluble in mineral oil, compatible with other additives and brings high economic efficiency when used at low concentrations.

The tests conducted to check the antioxidant capacity of AU hydraulic oil (Russian Federation); N70/N150 mixture of base oils; VG22M PV hydraulic oil (PVoil) and AWS 22 (BP) Castrol oil have resulted that the mixture of base oils created oxidation residue (0.012 % wt) and very high acid number (TAN = 14.33 mgKOH/g) compared with equivalent commercial lubricants. The experimental mixing ratios were 0.2 % wt; 0.4 % wt; 0.6 % and 0.8 % wt of IONOL additive in the mixtures of base oils, respectively. The test results are shown in table 3.

It can be seen from table 3 that the increase in antioxidant additive content shall improve the antioxidant stability. Specifically, when the antioxidant additive at a ratio of 0.4% wt is added to

**Research**

N70/N150 mixture of base oils, the TAN and residue content of the oil meet the requirements of AU oil. The oil's oxidation color (at figure 1) proves the good antioxidant capacity of the IONOL additive. When the additive content is increased by more than 0.4% wt, the stability increases insignificantly. As a result, the IONOL additive at a ratio of 0.4% wt is selected to be mixed into the N70/N150 base oil mixture.

**Table 3.** Testing the antioxidant capacity of the oils according to GOST 981.

No.	Components	Oxidation according to GOST 981	
		TAN, mgKOH/g according to GOST 5985	Residue content, %wt
<b>I</b>	<b>Type of oils</b>		
1	Russian AU Oil	0.2	0
2	N70/N150 mixture of base oils	<b>14.33</b>	<b>0.012</b>
3	VG22M PV hydraulic oil	0.12	0
4	AWS 22 Castrol oil	0.65	0
<b>II</b>	<b>IONOL Additive is added into the N70/N150 mixture of base oils</b>		
1	0.2 %wt	0.3	0.002
2	<b>0.4 %wt</b>	<b>NA</b>	<b>0</b>
3	0.6 %wt	NA	0
4	0.8 %wt	NA	0



**Figure 1.** Samples of Oil's oxidation color according to GOST 981.

a) Sample with Ionol additive 0.4 %wt (left); b) Sample without additive (right).

TF-248 pour point depressant, referring to copolymers of alkyl methacrylate (C<sub>12</sub>–C<sub>18</sub>) or alkyl acrylate, is selected to improve the fluidity and rheological stability of oils at low temperature. It works by inhibiting the crystallization and growth of paraffin in the base oil to significantly reduce the pour point, ensuring that the oil still flows and lubricates effectively in cold conditions. The use of TF-248 is especially necessary for low viscosity hydraulic oils operating in cold climates or in environments with large temperature ranges, which contributes to maintaining the stability and reliability of the hydraulic system.

It is resulted from table 4 that hydraulic oils with VG 22 viscosity currently available on the market, have fulfilled good anti-oxidation and anti-wear properties, but often have a significantly higher pour point than required in the Russian Federation's Lubricant Standards (TU 38 1011232-89), which affects the work stability of the oil in cold climates or in areas with large temperature ranges.

To overcome this drawback, the TF-248 pour point depressant is supplemented to the formulation. When the depressant is increased, the pour point is decreased significantly, but the viscosity of the oil tends to increase, which affects the ability to start and drive at low temperatures. Therefore, it is necessary to determine the optimal mixing ratio to balance the ability to dilute and viscosity stability. Through experiments to determine physical and chemical properties, the appropriate TF-248 additive ratio was selected as 0.5 %wt to allow for lowering the oil's pour point below - 47 °C while maintaining the viscosity within the standard limit of VG 22. This result

demonstrates the effectiveness of the additive in adjusting the low temperature properties, while ensuring the operating requirements of hydraulic oil in harsh conditions.

**Table 4.** Effect of TF 248 pour point depressant on base oils.

No.	Components	Pour point, °C (GOST 20287-91) Specification: < - 45 °C	Kinematic viscosity at 40 °C, cSt (GOST 33-2016) Specification: 16 ÷ 22 cSt
<b>I</b>	<b>Type of oils</b>		
1	Russian AU Oil	- 48	19.41
2	Mixture of base oils N70/N150	<b>- 38</b>	18.61
3	VG22M PV hydraulic oil	-10	19.31
4	AWS 22 Castrol oil	-15	18.92
<b>II</b>	<b>TF 248 depressant is added</b>		
1	0.1 %wt	- 40	-
2	0.2 %wt	- 42	18.81
3	0.3 %wt	- 44	19.01
4	0.4 %wt	- 45	19.23
<b>5</b>	<b>0.5 %wt</b>	<b>- 47</b>	<b>19.42</b>
6	0.6 %wt	- 48	19.60

Lubrizol 5800 anti-wear and rust resistance additive provides outstanding performance in foam control, anti-wear, hydrolytic stability, oxidation stability, rust resistance and thermal stability, contributing to improve the performance of lubricating oil. In addition, LZ 5800 also protects well against non-ferrous metals and strong water separation ability to maintain the stability and durability of the lubrication system under severe operating conditions.

**Table 5.** Tests for anti-wear and rust resistance.

No.	Components	Four-ball wear according to GOST 9490: - Wear diameter (D <sub>w</sub> ) under load of 196 N, mm	Rust resistance according to ASTM D665	TAN, mgKOH/g according to GOST 5985 Specification of AU oil ≤ 0.05
<b>I</b>	<b>Type of oils</b>			
1	Russian AU Oil	0.92	Severe rust (>5%)	0.01
2	N70/N150 mixture of base oils	0.83	Severe rust (>5%)	NA
3	VG22M PV hydraulic oil	0.31	Stainless	<b>0.59</b>
4	AWS 22 Castrol oil	0.68	Stainless	<b>0.08</b>
<b>II</b>	<b>Lubrizol 5800 Additive is added</b>			
1	0.1 %wt	0.82	Stainless	0.02
2	0.2 %wt	0.75	Stainless	0.025
3	0.3 %wt	0.68	Stainless	0.03
4	<b>0.4 %wt</b>	<b>0.45</b>	<b>Stainless</b>	<b>0.04</b>
5	0.5 %wt	0.42	Stainless	0.07
6	0.6 %wt	0.35	Stainless	0.08

Table 5 shows that the Castrol AWS 22 hydraulic oil sample has very good anti-wear ability to highly protect friction surfaces. However, the acid number of the product according to GOST 5985 exceeds the allowable limit, which can easily lead to the formation of metal-corrosive compounds, swelling of rubber materials and deterioration of the lubricant’s properties. The investigation into the effect of the content of LZ 5800 anti-wear and anti-rust additive on the properties of the base oils results in the optimal ratio between the additive and base oils is at 0.4%wt to enhance anti-wear ability while maintaining the acid number within the standard limit and ensuring the chemical stability of the product.

Figure 2 demonstrates that the oil sample has a significant improvement in rust resistance after LZ 5800 additive is added; namely, the metal surface after testing with distilled water for 4 hours shows almost no corrosion. This confirms the effectiveness of LZ 5800 in forming a polar protective film on the metal surface, preventing the effects of moisture and oxygen, thereby improving the protection and service life of the hydraulic system.



**Figure 2.** Rust resistance test according to ASTM D665.

- a) Test steel plate before adding LZ 5800 rust resistance additive (left);
- b) Steel plate after adding LZ 5800 additive (right).

From the above research results, a synthetic formulation was created as shown in Table 6.

**Table 6.** Formulation of VKX.AU hydraulic oil.

No.	Components	%wt
1	<b>Base oils:</b>	98.70
	- N70	34.55
	- N150	64.15
2	<b>Antioxidant additives:</b>	
	- Ionol	0.4
3	<b>Pour point depressant:</b>	
	- TF 248	0.5
4	<b>Antiwear and rust resistance additives:</b>	
	- Lubrizol 5800	0.4

### 3.2. Assessment of the quality of mixed oil

The quality of mixed oil is assessed according to TU 38 1011232-89 Standard and presented in table 7.

**Table 7.** Quality indicators of VKX.AU hydraulic oil.

No.	Analytical indicators	Analytical methodologies	VKX.AU oil	Specification
1	Kinematic viscosity at 40°C, cSt	GOST 33-2016	19.42	16 ÷ 22
2	Viscosity index	GOST 25371-2018	170	-
3	Acid number, mg KOH/g	GOST 5985-2022	0.04	≤ 0.05

No.	Analytical indicators	Analytical methodologies	VKX.AU oil	Specification
4	Ash content, %wt	GOST 1461-2023	0	≤ 0.005
5	Metal corrosion testing	GOST 2917-76	Conformed	Conformed
6	Water-soluble acid and alkali content	GOST 6307-75	NA	NA
7	Mechanical impurities content, %wt	GOST 6370-2018	NA	NA
8	Water content, %wt	GOST 2477-2014	NA	NA
9	ASTM colour	ASTM D 1500-24	L 0.5	≤ 2.5
10	Open cup flash point, °C	GOST 4333-2021	206	≥ 165
11	Pour point, °C	GOST 20287-91	- 47	≤ - 45
12	Density at 20°C, kg/m <sup>3</sup>	GOST 3900-22	853.1	≤ 890
13	Thermal oxidation stability - Oxidation residue content - Oxidation acid acid	GOST 981-75	0 0.02	-
14	Four-ball wear properties at 196N load for 1 hour: - Wear diameter D <sub>i</sub>	GOST 9490-75	0.45	-
15	Foaming properties, mL/mL: - Cycle I (at 24 °C) - Cycle II (at 94 °C) - Cycle III (at 24 °C after 94 °C)	ASTM D 892-23	10/0 5/0 10/0	-
16	Rust	ASTM D 665-19	Stainless	-
17	Demulsibility	ASTM D 1401-21	40-40-0 (5)	-

The tests results that the product fully meets the standards for AU hydraulic oil imported from the Russian Federation.

*Table 8. Tests on 105 mm artillery elements.*

No.	Components	Rubber swelling, %wt at 80°C in 168 hours (TCVN 2752-2008)	Mechanical impurity content, %wt (GOST 6370-2018)
1	Russian Federation's AU oil	0.05	NA
2	VKX.AU oil	0.01	NA

The compatibility between the mixed hydraulic oil and the 105 mm artillery hydraulic system's materials, such as rubber, gaskets, pads and seals, was assessed by two tests. 1) Standard rubber samples provided by Factory Z133 (General Department of Logistics and Technology) were immersed in test oil at 80 °C for 168 hours; the swelling was determined by measuring the difference in weight of the samples before and after the test. 2) Actual parts (gaskets, pads, seals, etc.) of the 105 mm artillery hydraulic system were immersed in the mixed oil for 3 months, then the mechanical impurity content in the oil was tested according to GOST 6370-2018 Standard. The tests have demonstrated that the mass change of the rubber samples after 168 hours at 80 °C was within the allowable limit, and the mechanical impurity content in the oil after 3 months still meets the technical requirements. The results have shown that the mixed oil has good compatibility with rubber and sealing parts of the equipment, i.e., the oil does not cause excessive swelling, dissolve to deteriorate the rubber structure and generate mechanical impurities exceeding the allowable threshold under test conditions.

#### 4. CONCLUSIONS

It is concluded that the VKX.AU hydraulic oil product not only fully meets the technical requirements of the AU hydraulic oil standards imported from the Russian Federation, but also demonstrates some superior features compared to the comparator products. Specifically, the assessment on the four-ball device demonstrates that the mixed oil has high anti-wear to significantly reduce damage to the friction surface during operation. The oil also has fast demulsibility, good foam stability and outstanding rust resistance to maintain stable working performance of the hydraulic system in wet conditions or temperature changes. In addition, it can be seen that the tested oil has high compatibility with rubber materials, gaskets, seals and sealing parts commonly used in military equipment, without causing swelling or material destruction. The results confirm the effectiveness of the mixing formula, the reasonable selection of the additives, and the ability to completely replace imported products.

In the next phase, the research team plans to expand and refine the study on VKX.AU hydraulic oil in two main directions. First, investigating the replacement of mineral base oil with biodegradable base oil to develop an environmentally friendly version of VKX.AU. This biobased hydraulic fluid is expected to exhibit high biodegradability while maintaining key technical properties such as lubricity, oxidation stability, and anti-wear performance. This approach aligns with the global trend toward sustainable development and emission reduction in the lubricant industry. Second, conducting practical testing on a simulated recoil–run-out system of the 105 mm gun, in order to comprehensively evaluate the operational characteristics of VKX.AU under realistic conditions of load, pressure, and temperature typical for military equipment. These experiments will provide deeper insights into volumetric stability, film elasticity, anti-foaming behavior, and material compatibility, thereby establishing a scientific basis for the broader application of VKX.AU in both military and industrial hydraulic systems.

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### TÓM TẮT

#### **Nghiên cứu pha chế, thử nghiệm dầu thủy lực VG 22 sử dụng cho các phương tiện kỹ thuật quân sự**

*Bài báo trình bày kết quả nghiên cứu pha chế và đánh giá tính năng của dầu thủy lực VKX.AU có cấp độ nhớt VG 22, được phát triển theo công thức cải tiến nhằm nâng cao hiệu suất truyền động và độ tin cậy của thiết bị trong điều kiện làm việc đặc thù quân sự. Sản phẩm được pha chế từ dầu gốc tinh luyện chất lượng cao, kết hợp với hệ phụ gia chuyên dụng bao gồm chất hạ điểm đông, phụ gia chống oxy hóa, phụ gia chống mài mòn và chất ức chế gỉ, bảo đảm tính ổn định lý – hóa và độ bền sử dụng lâu dài. Kết quả thử nghiệm cho thấy dầu thủy lực VKX.AU đạt chất lượng tương đương sản phẩm nhập khẩu theo tiêu chuẩn TU 38.1011232–89, trong đó một số chỉ tiêu như khả năng chống mài mòn, chống gỉ và khử nhũ thể hiện ưu điểm vượt trội. Ngoài ra, dầu pha chế còn chứng minh được khả năng tương thích tốt với vật liệu làm kín trong hệ thống thủy lực của pháo 105 mm.*

**Từ khóa:** Hệ thống thủy lực; Dầu thủy lực; Dầu gốc; Phụ gia; Chống mài mòn; Chất hạ điểm đông.