Study on the formulation of transmission lubricating oil for military motor vehicles

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ABSTRACT

This paper presents the formulation and performance evaluation of a compounded transmission oil for military motor vehicles as a replacement for imported TAP-15V oil. The developed oil, formulated from selected base oils and a multifunctional additive package, satisfied all requirements of GOST 23652, with a kinematic viscosity of 14,58 mm²/s at 100 °C, a pour point of -26 °C, and a flash point of 234 °C. Four-ball tests showed improved tribological performance compared with TAP-15V oil, achieving a wear index of 720 N and a weld load of 5508 N. The results demonstrate that the formulated oil is suitable for practical application as an alternative to imported TAP-15V oil.

Keywords: Transmission oil; Base oil; Additive; Extreme pressure (EP) additive; Pour point depressant.

1. INTRODUCTION

Transmission oil is a specialized lubricant used in mechanical transmission systems to ensure stable and reliable power transmission while reducing friction and wear. In addition to lubrication, it also contributes to heat dissipation, oxidation and corrosion protection, and prolonged equipment service life. These oils are widely used in automotive and industrial gear systems as well as in military vehicles operating under severe conditions such as high loads, shock loading, and wide temperature variations [1, 15].

Among military transmission lubricants, TAP-15V oil of the Russian Federation has been extensively used in armored vehicles and military transport vehicles due to its high stability and load-carrying capability [15, 16]. Operational practice has shown that TAP-15V performs effectively under heavy-duty and shock-loading conditions. The oil is also equivalent to SAE 90 viscosity grade according to SAE J306C, facilitating maintenance and logistics support [7].

Conventional transmission oils are commonly formulated from mineral base oils combined with additive systems containing extreme-pressure (EP), anti-wear, antioxidant, corrosion inhibitor, and pour point depressant additives. Traditional sulfur-phosphorus EP additives and ZnDDP anti-wear additives provide effective tribofilm formation under boundary lubrication conditions but may exhibit limitations related to corrosive wear and thermal degradation [2-4].

In recent years, transmission lubricant technology has developed toward multifunctional additive systems capable of simultaneously improving anti-wear properties, oxidation resistance, thermal stability, and friction reduction. Current research trends focus on environmentally friendly ashless additives, boron-containing compounds, ionic liquids, and optimized sulfur-phosphorus chemistries. In addition, nanomaterials such as MoS2, graphene, h-BN, TiO2, and CuO have attracted considerable attention due to their ability to reduce friction and wear through protective tribofilm formation and surface-mending mechanisms [5, 6, 8]. Nevertheless, maintaining nanoparticle dispersion stability and compatibility with conventional additives remains a major challenge. Modern studies increasingly focus on tribofilm chemistry, mechanochemical reactions, and interactions between additives and metallic surfaces using advanced analytical techniques such as SEM, EDS, and XPS [12-14].

In Vietnam, research on transmission oils remains limited, with most studies focusing on imported product evaluation or commercial lubricant formulation. Studies concerning TAP-15V-equivalent oils according to GOST 23652, particularly regarding additive synergism and tribological performance, have not been widely reported. Therefore, this study aims to formulate and evaluate a domestically produced transmission oil intended to replace imported TAP-15V oil based on suitable base oils and additive systems in accordance [15]. The scientific novelty of the work lies in optimizing additive interactions to enhance load-carrying capacity and anti-wear performance while maintaining suitable physicochemical and low-temperature properties for military operating conditions.

2. EXPERIMENT

2.1. Used raw materials and chemicals

The base oils used in this study were Group II base oils, namely N600 and BS150 from South Korea. The quality characteristics of these base oils are presented in Table 1.

Table 1. *Quality specifications of N600 and BS150 base oils.*

No.	Analytical indicators	Analytical methodologies	N600	BS150
1	Kinematic viscosity, mm^2/s (cSt): - at 40 °C - at 100 °C,	GOST 33/ASTM D 445	108,2 12,13	447,6 33,68
2	Viscosity index	GOST 25371/ASTM D2270	102	111
3	Pour point, °C	GOST 20287/ASTM D97	-16	- 10
4	Mechanical impurities content, %wt	GOST 6370	NA	NA
5	Water content, %wt	GOST 2477/ASTM D95	NA	NA
6	Density at 15 °C, g/cm^3	GOST 3900/ASTM D1298	0,8704	0,8777
7	Open cup flash point, °C	GOST 4333/ASTM D92	268	262
8	ASTM colour	ASTM D1500	L0,5	0,5
9	Metal corrosion testing	GOST 2917/ASTM D130	Conformed	Conformed

Additives: The additives used for formulation and evaluation in this study include the pour point depressant Lubrizol 6662 (USA); the antioxidant and anti-wear additive ZnDDP (Zinc Dialkyl Dithiophosphate); and the extreme-pressure additive EP VICH 3839 (Afton, USA). These additives are widely used in the market, are of relatively low toxicity, and are environmentally friendly. 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.

The transmission oil samples were prepared by blending the selected base oils at 60 - 70 °C under continuous mechanical stirring at 500 - 700 rpm until a homogeneous mixture was obtained. The additive package, including extreme-pressure, anti-wear, antioxidant, corrosion inhibitor, and pour point depressant additives, was then added sequentially under controlled stirring conditions. The blending process was maintained at 70 - 80 °C for approximately 1 - 2 h to ensure complete dissolution and uniform dispersion of all additives in the base oil matrix. After blending, the formulated oils were cooled to room temperature and stored in sealed containers prior to physicochemical and tribological evaluation.

2.3. Research methodologies

The physico-chemical analytical methodologies are used to ensure that VKX.TAP-15V oil meets the Russian Federation's GOST 23652 Standard. To carry out the study, the research team employed analytical methods in accordance with GOST standards or their equivalent ASTM D methods to evaluate the quality of both raw materials and finished products. These methods comply with current standards and ensure accurate, objective, and scientifically reliable results. The tests were conducted at the Petroleum Testing Laboratory (VILAS 001) under the Military Institute of Petroleum Technology, Department of Petroleum, General Department of Logistics and Technical Services.

3. RESULTS AND DISCUSSION

3.1. Mixing formula

Base oil selection: The base oil used for formulating transmission oil must provide a viscosity appropriate to the SAE grade and possess a high viscosity index to maintain a stable lubricating film over a wide operating temperature range. Group II base oils from Korea are produced using advanced technology; in addition to solvent refining, they undergo hydro-processing, which provides good demulsibility, high flash point, and low total acid number (TAN), thereby minimizing the risk of metal corrosion. Accordingly, the research team selected Korean Group II base oils N600 and BS150 as the raw materials for formulating VKX.TAP-15V transmission oil. Based on the analysis results of the quality parameters of the Group II base oils (Table 1), the research team performed calculations and conducted laboratory-scale blending. To obtain a base oil mixture with a kinematic viscosity at 100 °C within the required range of 14 - 16 mm²/s (cSt), the blending ratio was determined as N600/BS150 = 4/1 (%wt). The quality characteristics of the base oil mixture (N600/BS150) are presented in Table 2.

Table 2. *Quality indicators of the mixture of base oils N600/BS150.*

No.	Analytical indicators	Analytical methodologies	Mixture of base oils (N600/BS150 = 4/1)
1	Kinematic viscosity, mm^2/s (cSt): - at 40 ^oC - at 100 ^oC,	GOST 33/ASTM D 445	140,1 14,41
2	Viscosity index	GOST 25371/ASTM D2270	101
3	Pour point, ^oC	GOST 20287/ASTM D97	**-12**
4	Mechanical impurities content, %wt	GOST 6370	0
5	Water content, %wt	GOST 2477/ASTM D95	0
6	Density at 15 ^oC, g/cm^3	GOST 3900/ASTM D1298	0,8704
7	Open cup flash point, ^oC	GOST 4333/ASTM D92	268
8	ASTM colour	ASTM D1500	L0,5
9	Metal corrosion testing	GOST 2917/ASTM D130	Conformed
10	Wear characteristics on the four-ball tester: - Wear index I_z, N (kgf); - Weld load P_s, N (kgf).	GOST 9490/ASTM D4172	**165 (16.8)** **1303 (133)**

Based on the evaluation results presented in Table 2, the base oil blend is of high quality and can be used as a raw material for the production of VKX.TAP-15V transmission oil. However, it is necessary to investigate and select suitable additive types and appropriate blending ratios for this base oil in order to enhance its anti-wear and extreme-pressure performance, as well as to ensure that the final product achieves a low pour point.

Selection of additive ratio: Lubrizol 6662 pour point depressant is a styrene–ester polymer-based additive specifically designed to improve the low-temperature flow properties of lubricants. The product is optimized for API Group I, II, and III base oils, enabling lubricants to meet stringent low-temperature performance requirements.

Table 3. *Effect of Lubrizol 6662 pour point depressant on the base oil.*

No.	Components	**Pour point, ºC (GOST 20287/ASTM D97)** Specification: < -20 ºC	**Kinematic viscosity at 100 ºC, mm^2/s (GOST 33/ASTM D445)** Specification: 14 ÷ 16 mm^2/s
I	**Type of oils**		
1	Russian TAP-15V Oil	- 28	14,01
2	Mixture of base oils N600/BS150	- 12	14,41
3	PV transmission oil 90 EP GL-4	-12	16,38
4	Shell Spirax S2 A 80W-90	- 27	14,70
5	Total Transmission TM multigrade	-36	15,25
II	**Lubrizol 6662 depressant is added**		
1	0,1 %wt	-14	14,45
2	0,3 %wt	-18	14,56
3	0,5 %wt	-22	14,63
4	**0,7 %wt**	**-26**	**14,75**
5	0,9 %wt	-28	15,11

The test results presented in Table 3 indicate that the multigrade transmission oils from Shell and Total exhibit low pour points, demonstrating good fluidity at low temperatures. This characteristic makes them suitable for operation in temperate climates or environments with significant temperature fluctuations. However, a notable drawback of these products is their relatively high cost compared with transmission oils imported from the Russian Federation and domestically produced products, which may affect economic feasibility for large-scale application.

For the domestic lubricant produced by PV Oil, the test results show a higher pour point and a kinematic viscosity outside the specified limits for TAP-15V transmission oil according to GOST 23652. To overcome the limitation related to pour point, the research team incorporated Lubrizol 6662 pour point depressant into the formulation. The results indicate that increasing the additive concentration significantly reduces the pour point; however, the viscosity tends to increase, which may adversely affect starting and operation at low temperatures. Therefore, it is necessary to determine an optimal treat rate to balance low-temperature fluidity and viscosity stability. Based on the evaluation of physicochemical properties, a concentration of 0,7 wt.% was selected, enabling the pour point to be reduced to below -26 °C while maintaining viscosity within the standard limits, thereby meeting operational requirements under low-temperature conditions.

Extreme-pressure and anti-wear additives:

The elemental analysis of TAP-15V transmission oil imported from the Russian Federation was conducted at the Chemicals and Materials Testing Laboratory – VILAS 067. The results obtained according to ASTM D5185 (Inductively Coupled Plasma–Atomic Emission Spectrometry, ICP-AES) indicate that the zinc (Zn) content is 0,167 wt.% and the phosphorus (P) content is 0,145 wt.%. The total sulfur content, determined in accordance with ASTM D4294 (Energy Dispersive X-ray Fluorescence Spectrometry, EDXRF), is 1,94 wt.%.

The above results indicate that, in addition to the sulfur–phosphorus (S–P) extreme-pressure additive system, which forms protective sulfide/phosphide films on metal surfaces to enhance load-carrying capacity and prevent scuffing or seizure, TAP-15V transmission oil also contains a zinc-based additive, typically ZnDDP. This additive performs the following functions: (i) enhancing anti-wear performance under moderate load and boundary lubrication conditions, thereby complementing the EP S–P system at elevated loads and temperatures; (ii) improving the oxidative stability of the oil, particularly in sulfur-rich environments that tend to promote oxidation at high temperatures; and (iii) contributing to a balanced performance between load-carrying capacity and wear protection, thus enhancing the overall stability and effectiveness of the additive system.

The research team evaluated four oil samples, including: M_1 – imported TAP-15V transmission oil; M_2 – a base oil blend of N600/BS150 at a mass ratio of 4/1; M_3 – the N600/BS150 (4/1) base oil blend containing 2 wt.% extreme-pressure additive EP (VICH 3839, Afton, USA); and M_4 – the N600/BS150 (4/1) base oil blend formulated with 2 wt.% VICH 3839 and 0,5 wt.% ZnDDP anti-wear additive.

The lubricating performance of the samples was evaluated using the four-ball test in accordance with GOST 9490, based on the following characteristic parameters: Weld load (P_s); Wear index (I_z) and Wear scar diameter (D_i). The test results are presented in Figure 1 and Table 4.

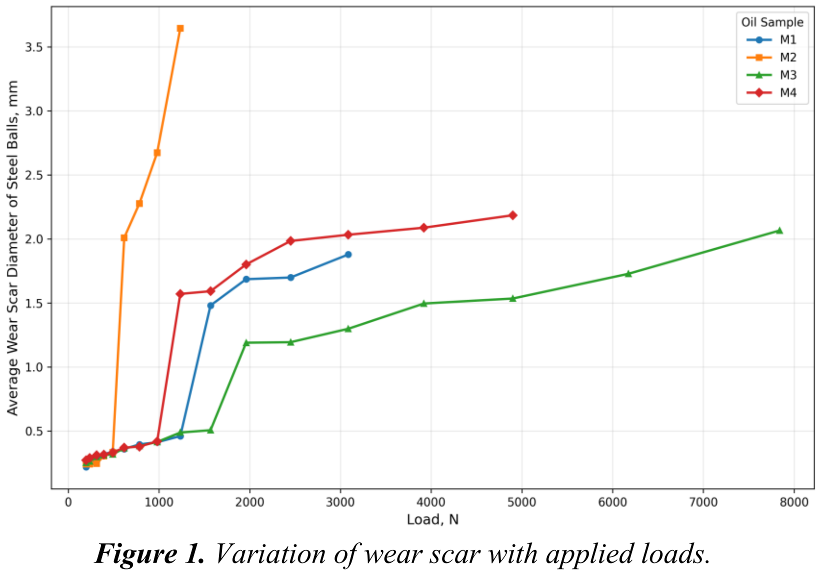

Figure 1. *Variation of wear scar with applied loads.*

The four-ball test results in accordance with GOST 9490 (Table 4 and Figure 1) reveal significant differences in lubricating performance among the oil samples. The N600/BS150 base oil blend (M_2) exhibited very limited load-carrying capacity. At a load of 617 N, the wear scar diameter increased sharply to over 2,0 mm and continued to rise rapidly with increasing load. The test could not be continued at higher load levels due to seizure of the steel balls at 1303 N. These results indicate that the base oil without extreme-pressure (EP) additives is incapable of forming a protective film under boundary lubrication and high-load conditions, leading to metal-to-metal contact and severe adhesive wear. The imported TAP-15V transmission oil (M_1) maintained a relatively stable wear scar diameter up to approximately 1235 N, after which it increased rapidly at higher load levels. The weld load reached 3685 N, indicating that the commercial additive system provides moderate-to-high load-carrying capacity, suitable for the typical operating conditions of mechanical transmission assemblies.

Table 4. *Four-ball test results for wear index.*

Load, N	Average wear scar diameter of the steel balls, mm			
	M$_1$	**M$_2$**	**M$_3$**	**M$_4$**
196	0,22	0,241	0,254	0,272
235	0,264	0,243	0,264	0,291
314	0,266	0,246	0,299	0,312
392	0,319	0,306	0,312	0,317
490	0,34	0,334	0,319	0,333
617	0,361	2,01	0,367	0,371
784	0,396	2,277	0,384	0,379
980	0,413	2,673	0,415	0,42
1235	0,461	3,644	0,489	1,571
1568	1,481	-	0,507	1,592
1960	1,686	-	1,19	1,801
2450	1,699	-	1,194	1,984
3087	1,879	-	1,299	2,033
3920	-	-	1,496	2,088
4900	-	-	1,535	2,185
6174	-	-	1,728	-
7840	-	-	2,066	-

The sample M_3 (base oil + 2 wt.% EP additive VICH 3839) exhibited superior load-carrying capacity. The wear scar diameter increased gradually with load and remained stable even in the high-load region; the weld load exceeded 9232 N (Table 5). These results clearly demonstrate the effectiveness of the S–P type EP additive. Under high load and temperature at the contact interface, the additive decomposes to form metal sulfide/phosphide compounds on the steel surface, generating a durable tribochemical reaction film that reduces micro-welding and significantly enhances extreme-pressure performance.

Table 5. *Test results for weld load and anti-wear performance.*

No.	**Components**	**Wear index (I_z), N (kgf)**	**Weld load (P_s), N (kgf)**	**Wear scar diameter (D_i), mm**
1	Russian oil TAP-15V (M_1)	600 (61,3)	3685 (376)	0,334
2	Mixture of base oils N600/BS150 (M_2)	165 (16,8)	1303 (133)	0,925
3	Mixture of base oils + 2 %wt EP additive VICH 3839 (M_3)	> 1476 (150,6)	> 9232 (942)	0,611
4	Mixture of base oils + 2 %wt EP additive + 0,5 %wt ZnDDP (M_4)	720 (73,4)	5508 (562)	0,306

The sample M_4 (2 wt.% EP + 0.5 wt.% ZnDDP) showed the smallest wear scar diameter at low load (196 N), and its 1-hour wear value was lower than those of M_1 and M_3, confirming improved anti-wear performance due to ZnDDP (Table 5). This additive forms a protective phosphate film under mild-to-moderate boundary lubrication conditions, thereby reducing wear during prolonged operation. However, the weld load of M4 (5508 N) was significantly lower than that of M_3, indicating that the combination of EP additive and ZnDDP may result in competitive adsorption on the metal surface, reducing extreme-pressure effectiveness under very high loads.

The different effects of ZnDDP on wear resistance and weld load can be explained by the distinct lubrication mechanisms governing anti-wear (AW) and extreme-pressure (EP) performance. ZnDDP is primarily an anti-wear additive. Under moderate load and temperature conditions, ZnDDP decomposes to form a protective phosphate/sulfide tribofilm on the metal surface, which effectively reduces direct metal-to-metal contact and decreases wear scar diameter. Therefore, the addition of ZnDDP in sample M4 improved the anti-wear performance observed in the four-ball wear test [9-11].

However, the weld load test is conducted under much more severe contact pressures and temperatures, where EP additives play the dominant role. In this regime, sulfur-containing EP additives are more effective because they rapidly form sacrificial reaction films with lower shear strength, preventing seizure and welding of the contact surfaces. The presence of ZnDDP may partially compete with or inhibit the surface reactions of EP additives, leading to the formation of a tribofilm that is beneficial for mild wear protection but less effective under extreme-pressure conditions [12, 13]. As a result, the weld load of sample M4 decreased despite the improvement in wear resistance.

Overall, the results indicate that the EP additive plays a decisive role in weld load capacity, while ZnDDP enhances anti-wear performance under low-to-moderate loads. Optimization of the EP/ZnDDP ratio is therefore essential to achieve a balance between extreme-pressure load-carrying capacity and long-term wear durability of the transmission oil.

Based on the above findings, the final formulation was established as presented in Table 6.

Table 6. *Formulation of VKX.TAP-15V transmission oil.*

No.	Components	% wt
1	**Base oil:** - N600 - BS150	96,80 77,44 19,36
2	**Pour point depressant:** - Lubrizol 6662	0,7
3	**Extreme-pressure additive:** - VICH 3839	2
4	**Anti-wear and antioxidant additive:** - ZnDDP	0,5

3.2. Evaluation of the formulated oil quality

The anti-wear performance of the oil sample was evaluated using a four-ball tester in accordance with two standard methods: GOST 9490 (with load applied by a calibrated weight system) and ASTM D4172 (with load applied pneumatically). The results obtained from the two methods demonstrated strong agreement and high consistency. As appropriate equipment for direct measurement of dynamic viscosity at -15 °C is not available in Vietnam, this parameter was determined indirectly by calculation based on the measured kinematic viscosity and density values. The quality evaluation in accordance with GOST 23652 is presented in Table 7.

The test results demonstrate that the formulated product fully complies with the specifications for TAP-15V transmission oil imported from the Russian Federation.

Table 7. *Quality characteristics of VKX.TAP-15V transmission oil.*

No.	Analytical indicators	Specification	Analytical methodologies	VKX.TAP-15V	TAP-15V
1	Kinematic viscosity at 100 °C, mm^2/s (cSt)	14 ÷ 16	GOST 33/ASTM D445	14.58	14.01
2	Autoignition temperature, °C	≥ 165	GOST 12.1.044	246	252
3	Pour point, °C	≤ - 20	GOST 20287/ASTM D97	- 26	- 28
4	Mechanical impurities content, % wt	≤ 0.03	GOST 6370	NA	NA
5	Water content, % wt	Spot	GOST 2477/ASTM D95	NA	NA
6	Metal corrosion testing at 100 °C for 3 hours: - Steel strip; - Copper strip.	Conformed	GOST 2917/ASTM D130	Conformed	Conformed
7	Wear characteristics on the four-ball tester: - Wear index I_z, N (kgf); - Weld load P_s, N (kgf);	≥ 490 (50) ≥ 3283 (335)	GOST 9490/ASTM D4172	720 (73.4) 5508 (562)	600 (61.3) 3685 (376)
8	Compatibility with rubber, % Vol.	4 ÷ 10	GOST 9.030	5.26	5.4
9	Density at 20 °C, g/cm^3	≤ 0.930	GOST 3900/ASTM D1298	0.8735	0.8974
10	Water-soluble acid and alkali content, % wt	NA	GOST 6307	NA	NA
11	Open cup flash point, °C	≥ 185	GOST 4333/ASTM D92	234	240
12	Thermal oxidation stability at 155 °C for 50 hours: - Kinematic viscosity at 100 °C after oxidation, mm^2/s - Oxidation residue content, %wt	-	GOST 11063	15,72 0,18	15,61 0,2

4. CONCLUSIONS

The research results demonstrate that the formulated VKX.TAP-15V transmission oil fully complies with the technical requirements specified in GOST 23652 for transmission oils of Russia. Optimization of the extreme-pressure (EP) additive and ZnDDP anti-wear additive concentrations enabled the product to achieve an appropriate balance between high load-carrying capacity under severe operating conditions and long-term wear resistance during service. In addition, the results of copper strip corrosion and elastomer swelling tests indicate good compatibility with metallic and elastomeric materials used in transmission systems. This confirms the chemical stability and material safety of the formulated product. The obtained results validate the appropriateness of the selected base oils and additive system, while confirming the capability to fully replace equivalent imported products. The study contributes to mastering domestic transmission oil production technology, thereby establishing a foundation for supply autonomy and meeting the technical–tactical requirements of modern military equipment.

In the next phase, the study will be further refined through testing on a dedicated test rig simulating the operation of transmission systems using TAP-15V transmission oil, in order to more comprehensively evaluate performance characteristics under actual load and temperature conditions. Based on the results obtained, the product will be trialed on selected equipment, followed by pilot-scale production (zero series) and expanded field testing on military technical vehicles.

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TÓM TẮT

Nghiên cứu xây dựng công thức dầu truyền động cho các phương tiện cơ giới quân sự

Bài báo trình bày kết quả nghiên cứu xây dựng công thức và đánh giá tính năng dầu truyền động pha chế sử dụng cho phương tiện cơ giới quân sự, định hướng thay thế dầu TAP-15V nhập khẩu từ Liên bang Nga. Trên cơ sở lựa chọn dầu gốc có độ nhớt thích hợp và độ ổn định nhiệt – oxy hóa cao, nhóm nghiên cứu đã phối hợp hệ phụ gia cực áp, chống mài mòn cùng các thành phần chống oxy hóa, ức chế ăn mòn và hạ điểm đông đặc nhằm bảo đảm khả năng chịu tải lớn và làm việc tin cậy trong điều kiện tải trọng va đập và biến thiên nhiệt độ rộng. Các mẫu dầu được đánh giá theo các chỉ tiêu lý – hóa và tính năng theo GOST 23652-2023. Kết quả cho thấy sản phẩm đáp ứng đầy đủ yêu cầu kỹ thuật, có tính năng tương đương TAP-15V và phù hợp với điều kiện khai thác thực tế.

Từ khoá: Dầu truyền động; Dầu gốc; Phụ gia; Phụ gia cực áp (EP); Phụ gia hạ điểm đông.