Comparison of Zinc-Containing and Zinc-Free Hydraulic Packages Using Severe Laboratory Performance Tests

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Ever increasing demands on productivity, performance, worker's safety, as well as realization of total cost management lead to new and higher requirements placed on industrial lubricants. Higher machining speeds and new processes may cause much more thermal stress to the whole lubricating system. The paper will focus on comparison of traditional and modern hydraulic additive technology, considering highly refined base oils, compatibility of additive systems as well as widely used specification requirements.

Keywords: hydraulic fluid, zinc-free, zinc-containing, HLP, HF-0, phosphorus sulfide, raw materials, zinc dithiophosphates, filterability, hydrolytic stability

1. Introduction

The first hydraulic excavator was established by Demag in 1954 ("Demag B504"). The world's largest hydraulic excavator was introduced in 2008 by Terec ("O&K RH 400"). To get an idea about the difference in dimensions and performance of both, the relevant data are compared in Table 1.

These enormous differences result in strongly enhanced requirements for modern hydraulic fluids. The new strengthened requirements of DIN 51524 consider these requirements. Several tightened requirements were established¹⁾:

- The inclusion of the filtration tests according to EN ISO 13357
 - Dry filtration: F1: 80% min, F2: 60% min.
 - Wet filtration: F1: 70% min, F2: 50% min.
- Inclusion of a purity class according to ISO 4406
- Extension of the viscosity classes by ISO VG 15 and ISO VG 150
- Demulsification: 30 minutes max., respectively 60 minutes for ISO VG 68 and higher

All these properties are influenced by factors like raw material quality or process control. Figure 1 illustrates the various direct and indirect relationships that exist between these factors and the final product quality, in this case for a zinc-containing hydraulic fluid.

Table 1 Comparing the data of the first and the new largest hydraulic excavator

	Demag B504	O&K RH 400
Excavator dimensions [m] height / width / length	2.9 / 2.5 / 2.8	10.2 / 9.8 / 11
Motor	Deutz diesel 31 kW	Cummins diesel 3300 kW
Weight [tons]	11	980
Volume of bucket [m ³]	0.4	45
Volume of hydraulic fluid [liters]	< 1000	13000

Especially the filterability is very critical and depending on internal factors generated by the additive and external factors of the base oil²⁾:

- Internal factors:
 - Hydrolytic stability
 - Ion exchange processes
 - Structural changes caused by thermal, oxidative and mechanical stress
 - Interaction between single components

Figure 1 Schematic representation of the influence of the raw material quality on the hydraulic fluid

- External factors:
 - Purity of the base oil
 - Purity of the blend of base oil and additive
 - Purity of the hydraulic system (tubes, handling in the case of re-filling etc.)
 - Material compatibility with single hydraulic components
 - Intrusion of dirt particles (dust, sand, etc.)

2. Theoretical background

For ash-containing hydraulic packages, zinc dithiophosphates (ZnDTP's – typical with carbon chains of 3 - 8 carbon atoms) are still used as antiwear additives. The production route of ZnDTP's is a heterogeneous reaction between a fluid and a solid phase and basically consists of a two step chemical process³⁾, the alcoholysis of phosphorous decasulfide, P_4S_{10} (Figure 2, reaction I), and the subsequent neutralization of the generated dithiophosphoric acid

with zinc oxide (Figure 2, reaction II). Although, there are only a few supplier sources for P_4S_{10} worldwide, the quality may differ significantly as shown in Figure 2 on the right side. Technical samples of P_4S_{10} consist of about 48-52% P_4S_{10} and other phases which can be regarded as some kind of “defective” P_4S_{10} phases with missing sulfur atoms, namely P_4S_9 , P_4S_7 and phosphorus polysulfides (“PPS”), covering all species with a stoichiometry of $(PS_n)_x$. It is known that these kind of zero dimensional lattice point defects have a strong influence on the atomic diffusion and therefore on the reactivity of a solid⁴⁾. Already during the first reaction step, besides the main product, several by-products can be generated, depending on the P_4S_{10} quality and the process parameters. As a consequence, different P_4S_{10} qualities and process parameters eventually result in different qualities of the ZnDTP and therefore in different performances of the hydraulic fluid.

Although, the main function of the ZnDTP in hydraulic oils is providing wear protection via the formation of layers⁵⁾, the quality of the ZnDTP also has a strong influence on other key properties of the hydraulic fluid like sulfur content, phosphorus content, color, odor, hydrolytic stability, copper corrosion and filterability⁶⁾.

3. Experimental section

3.1. Filtration test according to ISO 13357⁷⁾

The test fluid is filtered under specified conditions through a membrane of 0.8 μm pore diameter, and the time for a nominated series of volume filtrations is recorded. Filterabilities are calculated from ratios of the filtration rate near the start of filtration to the filtration rate at specified higher filtered volumes. The result of the test is the average of three determined values. Ideally, the filtration rate should remain constant over time.

3.1.1. Definitions

- Filterability: Dimensionless number, expressed as a

Figure 2 Reaction scheme for the synthesis of ZnDTP

percentage, which is the relationship between two filtration rates.

- Stage I filterability: Ratio, expressed as a percentage, between 240 ml and the volume of oil actually filtered in the time that 240 ml would have theoretically taken, assuming no plugging of membrane.
- Stage II filterability: Ratio, expressed as a percentage, between the flow rate near the start of the filtration, and the flow rate between 200 mL and 300 mL of filtered volume.

3.1.2. Calculations

3.1.2.1. Stage I filterability

FI = $((V - 10) / 240) * 100$ with:

- V = volume at time T_V in ml,
- $T_V = 6 * (T_{50} - T_{10}) + T_{10}$ in seconds

3.1.2.2. Stage II filterability

FII = $2.5 * (T_{50} - T_{10}) / (T_{300} - T_{200})$

3.1.3. Principle

The test fluid is treated with water at an elevated temperature, filtered under specified conditions through a membrane of 0.8 μm mean pore diameter, and the time for a nominated series of volume filtrations is recorded. Filterabilities are calculated from ratios of the filtration rate near the start of filtration to the filtration rate at specified higher filtered volumes. The result of the test is the average of three determined values.

3.2. Hydrolytic stability test according to ASTM D 2619⁸⁾

75 g of the test fluid, 25 g of water and a preweighed bright copper test specimen are placed in a pressure-type beverage bottle. The bottle is closed tightly and rotated, end over end, in an oven at 93 °C for 48 hours. The layers (water / oil) are separated and insoluble components are weighted. Weight change of the copper strip is measured. Viscosity change and acid number change of the fluid and the acidity of the water layer are determined.

3.3. Thermal stability test according to CM P-70⁹⁾

Clean, polished, preweighed copper and steel rods are placed in a 250 ml beaker, which contains 200 ml of the oil sample. It is imperative that the rods are completely below the surface of the oil and in contact with each other. Samples are placed in an electric oven at 135 °C for 168 hours (depending on the standard, there are also other parameters possible). After cooling to room temperature, the following tests are carried out:

- Oil sample: Neutralization number, sludge
- Copper rod: Deposit, metal loss, visual rating
- Steel rod: Deposit, metal loss, visual rating

3.4. Additive packages tested

The additive packages discussed in section 3.1. are zinc-containing packages containing antiwear

components, phosphites, defoamer, antioxidants, demulsifier, dispersants and corrosion inhibitors. The only difference of the different packages is the quality of the phosphorous sulfide used for the production of the antiwear component. All other components remained constant.

The difference of the old and new packages discussed in section 3.3 is the quality of the phosphorous sulfide and the phosphite used for the additive package production.

3.5. Base oil used

For all tests, we used a mineral oil from Exxon Mobile with an ISO VG 46. The oil is a blend of Blend of core 150 and core 600 Exxon Mobil base oils. The physical and chemical data are stated in Table 2.

Table 2 Chemical and physical data for the base oil used

Data	Unit	Value
Viscosity class	ISO VG	46
Viscosity Index	-	106
C (aromatic)	%	6.5
C (naphthenic)	%	32.6
C (paraffinic)	%	60.9
Sulphur	%	0.38

4. Results

4.1. Zinc-containing hydraulic HF-0 packages

In order to proof the influence of the raw material quality on the hydraulic fluid performance, two phosphorus decasulfide samples of different origin have been tested. Both samples were treated under absolutely identical conditions. Of course, every manufacturer has his own know how but a general description can be found in literature³⁾. First, the sulfide was reacted with an appropriate alcohol in order to obtain the dithiophosphoric acid (Figure 2, reaction I). In a second step, the dithiophosphoric acid was neutralized with zinc oxide to the zinc dithiophosphate (Figure 2, reaction II). In the next step, both ZnDTP's obtained via the synthesis were topped up with other additive components like defoamer, dispersant, demulsification agent, antioxidant, corrosion inhibitors and yellow metal deactivators in order to get a fully formulated hydraulic

Table 3 Chemical and physical data for two different sources of phosphorus decasulfides

	P ₄ S ₁₀ I	P ₄ S ₁₀ II
Melting point by DSC	280 °C	285 °C
Net Formula	P ₄ S _{10,10}	P ₄ S _{9,86}
Undesired PPS content	> 10%	< 10%

oil package.

The chemical and physical data of both sulfides are listed in Table 3. At first sight, the differences only seem to be minor. The sulfide P₄S₁₀ I has slightly higher sulfur content and a higher content of undesired PPS. Additionally, the melting point of P₄S₁₀ I is about 5 centigrade lower than for P₄S₁₀ II, indicating a higher amount of impurities.

In Table 4, the relevant test results with the fully formulated hydraulic oil containing the ZnDTP produced by using the different P₄S₁₀ types are compared. It is obvious, that the hydraulic oil based on P₄S₁₀ I does not fulfill all relevant requirements for HF-0. This is obviously due to the slightly higher content of sulfur (the sulphur content is approx. 1.72% higher in the phosphorus sulphide I, corresponding to approx. additional 20 ppm sulphur in the hydraulic fluid) and PPS that worsens the copper corrosion. The hydrolytic stability for P₄S₁₀ I based ZnDTP is also slightly worse than for the P₄S₁₀ II based ZnDTP but still meeting the requirement. Another critical test is the wet filtration,

Table 4 Relevant test results with the fully formulated hydraulic oil containing the ZnDTP produced by using the different P₄S₁₀ types are compared

	Hydraulic oil made with a ZnDTP based on		Requirements
	P ₄ S ₁₀ I	P ₄ S ₁₀ II	
	0.8 % additive package in mineral oil		
Filtration ISO 13357			
-1 wet	F1 = 64.6 F2 = block	F1 = 93.3 F2 = 88.7	F1 min. 70 F2 min. 50
-2 dry	F1 = 98.8 F2 = 96.6	F1 = 99.6 F2 = 98.2	F1 min. 80 F2 min. 60
Cu-Corrosion ASTM D130			
3 h [rate]	3b-4a	1a	Max. 2
24 h [rate]	3b-4a	1a	
RPVOT ASTM D2272 [min.]	152	147	Min. 120
Hydrol. Stab. ASTM D2619 TAN 48 h [mg KOH/g]	0.44	0.32	Max. 10
Cu Mass loss [mg/cm ²]	0.366	0.305	
Rating	Not suitable for HF-0	Suitable for HF-0	

because ZnDTP is sometimes suspected to worsen the wet filtration⁷⁾. The filtration of the Zn-containing package II in this example is still excellent, due to the high quality of the used ZnDTP. Despite the fact, that the hydrolytic stability is sufficient in ASTM D 2619, it is obviously not sufficient in the wet filtration. This is most probably due to the reaction of the zinc additive and water forming deposits and gels. The reaction product zinc hydroxide, Zn(OH)₂, can form very fine nanometer-sized precipitates, which are able to block the 800 nm filter pores of the filters used for the filtration according to ISO 13357¹⁾.

4.2. Dependence on treat rate

As the wet filtration is a crucial test, the influence of treat rate on the filtration was regarded in order to find out the maximum treat rate that could be used to fulfill the filtration requirements according to ISO 13357. The wet filtration was compared for the ZnDTP technology based on P₄S₁₀ I and on P₄S₁₀ II. In a further experiment, a HF-0 additive package of the next generation containing these both ZnDTP samples with a standard treat rate of 0.6% was tested. The ZnDTP concentration was varied from 0.1% up to 1.5%. The tests were run with ZnDTP in mineral oil alone and with the ZnDTP in an additive package using equivalent ZnDTP concentrations.

In Figure 3, the wet filtration results are shown. The ZnDTP produced with P₄S₁₀ I shows a pass over the whole concentration range, but is borderline pass at lower concentrations. Additionally, the filtration factors are heavily fluctuating over the whole concentration regime. The result for the ZnDTP produced with P₄S₁₀ II shows a much more stable behavior and shows a clear pass over the whole concentration regime. These results clearly indicate again that the filterability of a hydraulic fluid is influenced by the quality of the ZnDTP used over a broad concentration regime.

In order to check influence of the package technology on this effect, wet filtration test was carried out with an

Figure 3 Wet filtration results for ZnDTP's in a mineral oil ISO VG 46 produced by using P₄S₁₀ I and P₄S₁₀ II. Minimum requirements for both factors are indicated

Figure 4 Wet filtration results for ZnDTP produced by using P_4S_{10} II and the package that contains this ZnDTP in a mineral oil ISO VG 46 and P_4S_{10} II. Minimum requirements for both factors are indicated

HF-0 additive package of the new generation based on the ZnDTP synthesized with P_4S_{10} II, the better one of both raw materials used. The additive package treat rate was adjusted in such a way in order to have equivalent ZnDTP concentrations as for the pure ZnDTP (see Figure 4).

As the filtration factor F1 and the filtration factor F2 are better for the package formulation than for the pure ZnDTP sample, it has to be concluded, that a tailor-made package formulation can even improve the filterability properties. The new generation of packages contains several components that stabilize the ZnDTP and therefore prevent a hydrolysis and a subsequent blocking of the filter pores. These examples illustrate that a proper selection of the raw material and the balancing of all components in a hydraulic additive package are the key factors in formulating a modern hydraulic package.

In order to proof, that the filterability is somehow linked to the hydrolytic stability, the hydrolytic stabilities

Figure 5 Comparison of hydrolytic stability and filterability for the HF-0 hydraulic package in mineral oil

for three different concentrations of the additive package were measured and compared with the filterability. The trend can be seen from Figure 5. With higher concentrations, important parameters like TAN and copper loss significantly increases and the filtration factors F1 and F2 simultaneously decrease, indicating a worsening of the filterability. Of course, one has to consider, that the hydrolytic stability and filterability measured also may be affected by other components used in the additive package and not only by the ZnDTP. But there are strong indications, that the ZnDTP has a major influence on these properties. This can be confirmed by the fact that zinc-free hydraulic packages do not show a decrease in the hydrolytic stability to that extend⁽¹⁾. As shown in Table 5, the hydrolytic stability is much better for zinc-free packages when using the same treat rates.

4.3. Comparing zinc-containing and zinc-free packages

At first, the major differences between zinc-containing and zinc-free packages should be discussed briefly: Zinc-free hydraulic oils have an excellent thermal and hydrolytic stability and therefore an expected longer lifetime and less maintenance than zinc-containing hydraulic oils. Another important advantage of zinc-free hydraulic oils is their ability to operate in fine clearance spool valves where cleanliness is critical. Hydrolytic stability is a problem faced by all systems made from metal as they will suffer corrosion if exposed to water, even if this water exists as only droplets within oil. Whilst all hydraulic oils may suffer water ingress through contact with wet air, coolant ingress or process water contamination, conventional zinc-containing oils do tend to suffer more. This is a

Table 5 Hydrolytic stability of a zinc-containing and a zinc-free package compared

Package Conc. [Mass%]		Zn-cont.	Zn-free
0.175	Cu loss [mg]	0.1069	0.1145
	TAN 0 h [mg KOH/g]	0.24	< 0.1
	TAN 48 h [mg KOH/g]	0.07	< 0.1
0.88	Cu loss [mg]	0.2901	0.0534
	TAN 0 h [mg KOH/g]	0.58	0.22
	TAN 48 h [mg KOH/g]	0.53	0.16
2.6	Cu loss [mg]	0.6641	0.0534
	TAN 0 h [mg KOH/g]	1.07	0.74
	TAN 48 h [mg KOH/g]	1.37	0.51

major concern for filtration, because filter blockages can lead to a failure of the system or, if oil vents through a relief valve, can deliver unfiltered oil containing contaminants to critical areas.

Because of the reduced heavy metal contamination zinc-free oils are environmentally friendly and cause lower disposal and effluent treat costs. When water is polluted with zinc, one of the consequences is that rivers are depositing zinc-polluted sludge on their banks and zinc may also increase the acidity of waters. Some fish can accumulate zinc in their bodies, when they live in zinc-contaminated waterways. When zinc enters the bodies of these fish it is able to bio magnify up the food chain¹²⁾. Toxic effects on the fish body also are possible¹³⁾. Finally, zinc can interrupt the activity in soils, as it negatively influences the activity of microorganisms¹⁴⁾. Zinc-free hydraulic oils do not show these effects.

The contributory antiwear effect of the ZnDTP can be achieved by use of other phosphorous containing compounds like phosphates, ash less dithiophosphates, e.g., or a combination of those. But the contributory oxidation and corrosion inhibition effects have to be achieved by more phenolic or aminic antioxidants and corrosion inhibitors, respectively.

Despite these numerous advantages, zinc-free packages are currently more expensive; so industry still widely uses the conventional mineral based products - acceptance levels are still low. Besides this, the zinc-free alternatives for ZnDTP, as for example (Other additives used in zinc-free fluids are usually tricresyl phosphates

(TCPs) or other sulfur phosphorus and/or amine combinations¹⁵⁾) ashless dithiophosphates, are no multifunctional additives like ZnDTP. Although they have good antiwear and EP properties, their anticorrosion properties are poor¹⁶⁾. Additionally, zinc-free packages may cause problems when replacing the fluid in a running system due to a possible incompatibility of the zinc-free and zinc-containing technology and vice versa.

In this section, the differences of performance between zinc-free and zinc-containing HLP and HF-0 hydraulic packages as well as compatibility aspects between both types will be discussed.

Different HLP packages are compared to a HF-0 package in terms of oxidation stability, hydrolytic stability and filterability. The new packages have been developed as a reply to the tightened requirements of the Denison HF-0 and DIN 51524 standards by using a balanced selection of appropriate new raw materials and establishing an adjusted production process.

In Table 6, the results for zinc-containing packages are shown. The new HF-0-package easily passes the tightened requirements concerning thermal oxidative and hydrolytic stability and filterability, the HLP packages do not. Despite that fact, the new HLP-packages show a significant better performance than the old packages. As during the wet filtration, the filter pores are blocked by using the old packages, the filterability with the new packages is pretty good and even fulfills the Denison HF-0 requirements. Also the results for the oxidation stability and the hydrolytic stability are much better for

Table 6 Performance data for different zinc-containing (ZC) packages for HF-0 (package ZC00) and HLP (the rest) hydraulic fluids. Old and new technologies are shown

Package in paraffin. Mineral oil (ISO VG 46)	CM-Heat-Meth. A	Beverage Bottle (ASTM D2619)	ISO Filtration 13357-1/-2	
	Spec. HF-0 (TP-02100): Sludge: max. 100 mg/100 ml Fe- and Cu-appearance: rep.	Specifications: Acidity: max. 4 mg KOH/g Cu-loss: max. 0.2 mg/cm ²	-2 / Dry F1: min 80 F2: min. 60	-1 / Wet F1: min 70 F2: min. 50
ZC00 - new 0.8 Mass%	Sludge: 0 mg/100 ml Cu-appearance: 1 Fe-appearance: 1	Acidity : 0 mg KOH/g Cu-loss: 0.1 mg/cm ²	F1: 90.4 F2: 84.7	F1: 91.7 F2: 75.6
ZC02 - old 0.8 Mass%	Sludge: > 100 mg/100 ml Cu-appearance: 10 Fe-appearance: 4	Acidity: 2.73 mg KOH/g Cu-loss: 0.31 mg/cm ²	F1: 84.2 F2: 27.4	Blocking
ZC04 - old 0.8 Mass%	Sludge: > 100 mg/100 ml Cu-appearance: 10 Fe-appearance: 3	Acidity: 2.54 mg KOH/g Cu-loss: 0.48 mg/cm ²	F1: 41.7 F2: 9.8	Blocking
ZC05 - new 0.8 Mass%	Sludge: 48.3 mg/100 ml Cu-appearance: 7 Fe-appearance: 1	Acidity: 0.24 mg KOH/g Cu-loss: 0.44 mg/cm ²	F1: 98.8 F2: 98.3	F1: 88.3 F2: 74.2
ZC07 - new 0.45 Mass%	Sludge: 28.5 mg/100 ml Cu-appearance: 6 Fe-appearance: 1	Acidity: 1.72 mg KOH/g Cu-loss: 0.4 mg/cm ²	F1: 95.8 F2: 92.3	F1: 90.8 F2: 81.8

Table 7 Performance data for different zinc-free (ZF) packages for HF-0 (package ZF00) and HLP (the rest) hydraulic fluids. Old and new technology is shown

Package in paraffin. Mineral oil (ISO VG 46)	CM-Heat-Meth. A	Beverage Bottle-Test (ASTM D 2619)	ISO Filtration 13357-1/-2	
	Spec. HF-0 (TP-02100): Sludge: max. 100 mg/100 ml Fe- and Cu-appearance: rep.	Specifications: Acidity: max. 4 mg KOH/g Cu-loss: max. 0.2 mg/cm ²	-2 / Dry F1: min 80 F2: min. 60	-1 / Wet F1: min 70 F2: min. 50
ZF00 - new 0.6 Mass%	Sludge: 10.1 mg/100 ml Cu-appearance: 2 Fe-appearance: 1	Acidity: 2.16 mg KOH/g Cu-loss: 0 mg/cm ²	F1: 97.9 F2: 95.7	F1: 87.9 F2: 74.8
ZF03 - old 0.8 Mass%	Sludge: 13.3 mg/100 ml Cu-appearance: 5 Fe-appearance: 3	Acidity: 4.9 mg KOH/g Cu-loss: 0 mg/cm ²	F1: 90.0 F2: 80.3	F1: 83.3 F2: 70.7
ZF05 - new 0.5 Mass%	Sludge: 19.6 mg/100 ml Cu-appearance: 4 Fe-appearance: 1	Acidity: 5.6 mg KOH/g Cu-loss: 0 mg/cm ²	F1: 95.5 F2: 89.4	F1: 86.7 F2: 80.0

the new packages. These results indicate again the importance of choosing the right raw material for the ZnDTP-production - when done for the new packages, the filtration tests can be passed.

Different results are obtained for zinc-free additive packages as shown in Table 7. As expected, the HF-0 package is by far the best. For the HLP-packages, the results for the new technology and the old technology are similar, but both HLP show a performance much closer to the HF-0 technology than for the zinc-containing packages.

This is due to the fact that zinc-free hydraulics in general have a better thermal and hydrolytic stability and a better filterability. These enhanced properties are related to the non-ionic character of ashless DTP components used for these packages. In Figure 6, the basic chemical structures of ashless DTP and ZnDTP's are compared:

As seen from Table 6 and Table 7, the influence of the

Figure 6 Comparing the chemical structure of ZnDTP and ashless DTP compounds

phosphorus raw materials for zinc-free packages is not as high as for zinc-containing packages. The performance data for the different packages do not differ to a high extend due to the reduced sensibility against fluctuation of raw material quality.

An important learning from these data is that at least for HF-0 packages, the performance of zinc-containing packages is excellent and can even be as good as or slightly better than for zinc-containing packages only by optimizing the formulation by using the right raw materials and adjusting the process parameters.

Normally, one should never mix zinc-free hydraulic fluids with those containing zinc-based additives because a chemical reaction may occur and result in blocking of the filter, generation of sludge, foam and cause sticking. Hydraulic pump manufacturer normally refuses accountability for this case. Anyway, the compatibility between different zinc-containing and zinc-free packages was tested by using the filterability; combinations of old and new technologies also have been tested. At least two combinations show an excellent compatibility: the combination of the zinc-free and zinc-containing HF-0 packages and the new zinc-containing HLP package with the zinc-free HF-0 package. They can be mixed up to 50%. This is a great advantage when a hydraulic system operator wants to change the technology from a zinc-containing HF-0 to a zinc-free. He has not to expect any technical difficulties, when the change of the hydraulic fluids is done without a daintily cleaning after draining the old hydraulic fluid. The same is valid for the change from HLP to a HF-0 technology. But it also has to be mentioned, that a combination of an old and new technology is not possible at all. In any case, at least the wet filtration is worse, due to a chemical reaction between the zinc-containing and zinc-free packages (see Table 8).

Table 8 Compatibility for different zinc-free (ZF) and zinc-containing packages old and new technology is shown (“+”: pass, “-”: fail)

Hydraulic additive package in paraffin. Mineral oil ISO VG 46		Compatibility in a 50:50 blend	
Zinc-containing	Zinc-free	ISO 13357-2 “dry”	ISO 13357-1 “wet”
New technology ZC00 0.8 Mass%	Old technology ZF03 0.8 Mass %	-	-
Old technology ZC05 0.8 Mass%	Old technology ZF03 0.8 Mass %	+	-
Old technology ZC04 0.8 Mass%	New technology ZF00 0.8 Mass %	-	-
New technology ZC00 0.8 Mass%	New technology ZF00 0.6 Mass %	+	+
New technology ZC05 0.8 Mass%	New technology ZF00 0.6 Mass %	+	+

5. Summary and conclusions

Increasing demands on productivity, performance, worker's safety, as well as realization of total cost management lead to new and higher requirements placed on industrial lubricants. Higher machining speeds and new processes may cause much more thermal stress to the whole lubricating system.

Between the introduction of the first hydraulic excavator which was established by Demag in 1954 and the world's largest hydraulic excavator introduced in 2008 by Terex, the dimensions of the equipment and the requirements for the performance of modern hydraulic fluids have changed dramatically. The new strengthened requirements of DIN 51524 do consider this. Several tightened requirements were established like the inclusion of the filtration tests according to EN ISO 13357, of a purity class according to ISO 4406 and the extension of the viscosity classes by ISO VG 15 and ISO VG 150. The demulsification was specified to 30 minutes max., respectively 60 minutes for ISO VG 68 and higher.

Only small differences in the quality of the chemical raw materials used for the production of hydraulic fluids decide whether the fluid passes the new tightened

requirements in terms of hydrolytic and oxidation stability and filterability or not. Zinc-containing hydraulic packages are still widely used, what is due to the lower price. Zinc-free packages have some technical and ecological advantages compared to zinc-containing packages but are still more expensive.

By choosing the right raw material quality and adjusting the production process, the technical performance of zinc-containing hydraulic oils can be as good as for zinc-free packages concerning critical properties like hydrolytic stability, oxidation stability and filterability. Together with the still lower price of the zinc-containing packages, from these results it has to be concluded, that zinc-containing hydraulic oils will be in use at least for the near future.

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