

Memo: Evaluation of Contamination Level in Hydraulic Fluid (used) and Turbine oil (used) based on ISO class codes

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Background

Recently, one of the participants of the Hydraulic Fluid (used) iis15L07 proficiency test (PT) asked iis whether it is possible to evaluate the Contamination Level in Hydraulic Fluid (used) based on ISO class codes rather than based on counts per ml. This would make it easier to compare with other PTs, such as Turbine Oil (iis14L02) and it is more common to report the Contamination Level in ISO classes instead in particles per ml.

In proficiency tests of Turbine Oil iis13L10 (in 2013) and iis14L02 (in 2014) the Level of Contamination was indeed determined in ISO classes and method ISO 4406:1999 was used as reference method. Unfortunately, ISO 4406 does not mention a target reproducibility (R) value which could be used to calculate the z-(target) scores. In PT round iis14L02 it was concluded that using the actual counts (reported as particles/ml) instead of ISO classes would be more valid to run the statistical evaluation on the reported PT results (see page 9 of report iis14L02). The ISO classes are categorical data of which each increasing class code is twice the quantity range of particles compared to the previous code. This makes the ISO class a (kind of) logarithmic scale. It appeared that ASTM D7647:10 contains a reproducibility value for the counts per ml and therefore iis decided for the Determination of Level of Contamination Level to move from ISO classes to counts per ml in the next PTs.

Surprisingly, ASTM D7647 mentions also reproducibility values for the ISO classes. Therefore, iis decided to evaluate the last PTs again based on ISO classes.

Procedure

The proficiency test data of the Determination of Level of Contamination of the last PTs of Hydraulic Fluid (used) iis15L07 and Turbine Oil (used) iis15L03 were used to explore the PT results when the reported counts per ml of these PTs were converted to ISO classes. The reproducibility values of ASTM D7647 for the ISO classes were used to calculate the z-scores after the reported values of counts per ml were converted to ISO classes. The outcome of this conversion were compared to the corresponding PT evaluations.

Discussion

The conversion to ISO scale and the PT evaluation of both proficiency tests of Hydraulic Fluid (used) iis15L07 and Turbine Oil (used) iis15L03 are given in Tables 1 and 2 (z-scores only) and in Appendices 1 and 2 below (test results and z-scores). The PT results of both rounds are listed in Appendices 3 and 4. The z-scores of both statistical evaluations are compared in tables 1 and 2 below. To compare the effect of the conversion to ISO classes on the statistical evaluations the mean ISO class values are compared to the mean counts per ml converted to ISO classes, see Table 3.

lab	method	ps ≥ 4 μm		ps ≥ 6 μm		ps ≥ 14 μm	
		“ISO”	“counts”	“ISO”	“counts”	“ISO”	“counts”
		z-score	z-score	z-score	z-score	z-score	z-score
325	ISO4406	-1.54	-1.64	-4.82	-3.07	-1.81	-1.65
349	ISO4406	3.40	4.25	4.51	4.59	2.39	2.51
398	ISO4407	1.76	1.13	-0.16	-0.87	-1.81	-1.50
562	ISO4406	1.76	2.26	2.18	3.36	2.39	1.08
603	ISO4406	-1.54	---	-2.49	---	-1.81	---
862	ISO4406	0.11	-0.83	-0.16	-1.14	-1.81	-1.36
1146	ISO11500	1.76	0.72	2.18	1.83	3.79	3.84
1243	ISO4407	-3.18	-1.90	-2.49	-2.68	-1.81	-1.36
1417	ISO4406	-3.18	-1.93	-4.82	-2.99	-3.21	-1.89
1435	ISO4406	6.70	37.53	9.18	35.11	0.99	0.67
1571	ISO4406	1.76	1.47	2.18	2.28	0.99	0.78
1807	ISO4406	-1.54	-1.26	-0.16	-0.88	0.99	0.52
1920	ISO4406	-1.54	-1.10	-0.16	-1.12	-0.41	-1.24
1981	ISO4406	9.99	99.89	13.84	116.06	-0.41	-0.78
6002	ISO4406	0.11	-0.73	2.18	1.64	2.39	1.31
6016	ISO4407	0.11	-0.45	-0.16	-0.96	-0.41	-0.93
7011	ISO4406	1.76	---	2.18	---	-0.41	---

Table 1 Calculated target z-scores based on ISO class or counts/ml of PT iis15L07 of Hydraulic Fluid (used) of the determination of level of contamination on sample #15220, see also Appendix 3.
Bold: all z-scores <-2.80 or >2.80

Note: Labs 603 and 7011 reported their PT results in ISO classes; therefore their “counts” z-scores could not be calculated.

lab	method	ps ≥ 4 μm		ps ≥ 6 μm		ps ≥ 14 μm	
		“ISO”	“counts”	“ISO”	“counts”	“ISO”	“counts”
		z-score	z-score	z-score	z-score	z-score	z-score
178	ISO4406	0.86	0.12	-0.33	0.27	2.27	2.10
179	ISO4406	-4.08	-2.03	-2.67	-2.65	-0.53	-1.02
325	ISO4406	2.51	1.64	4.33	4.91	-0.53	-0.58
331	ISO4406	2.51	2.09	4.33	5.58	0.87	0.86
340	ISO4406	0.86	-0.09	-2.67	-2.05	-3.33	-1.77
349	ISO4406	0.86	1.35	2.00	4.02	3.67	5.50
360	ISO4406	-2.43	-1.72	-5.00	-2.67	-1.93	-1.56
398	ISO4406	0.86	0.71	-0.33	-1.30	-3.33	-1.66
432	ISO4406	2.51	1.94	2.00	2.33	2.27	4.35
541	ISO4406	0.86	-0.16	-2.67	-2.11	-1.93	-1.57
657	ISO4406	-5.73	-2.34	-7.33	-3.33	-3.33	-1.75
663	ISO4406	0.86	0.90	2.00	1.43	0.87	0.31
862	ISO4406	0.86	0.22	-2.67	-2.05	-3.33	-1.71
922	ISO4406	-0.78	-0.83	-0.33	-0.09	-1.93	-1.16
1023	ISO4406	0.86	0.76	2.00	0.39	-0.53	-0.96
1059	D7647	-5.73	-2.25	-5.00	-2.84	-0.53	-1.07
1146	ISO11500	-2.43	---	-0.33	---	-0.53	---
1417	ISO4406	0.86	1.18	-2.67	-1.82	-1.93	-1.22
1431	ISO4406	-2.43	-1.50	2.00	1.96	2.27	2.88
1599	ISO4406	2.51	2.26	9.00	41.51	6.47	41.76
1981	ISO4406	5.80	15.22	4.33	9.49	5.07	22.94

Table 2 Calculated target z-scores based on ISO class or counts/ml of PT iis15L03 of Turbine Oil (used) of the determination of level of contamination on sample #15056, see also Appendix 4.
Bold: all z-scores <-2.80 or >2.80

Note: Lab 1146 reported the PT results in ISO classes; therefore the “counts” z-scores could not be calculated.

Proficiency Tests	ps ≥ 4 μm		ps ≥ 6 μm		ps ≥ 14 μm	
	mean(n)	mean(n)	mean(n)	mean(n)	mean(n)	mean(n)
	“ISO” classes	“counts” converted to ISO class	“ISO” classes	“counts” converted to ISO class	“ISO” classes	“counts” converted to ISO class
iis15L07 Hydraulic Fluid (used)	15	15	13	14	10	11
iis15L03 Turbine Oil (used)	21	22	18	18	12	13

Table 3 Comparison of the calculated mean values over the ISO classes (converted from counts/ml) to the ISO class based on the calculated mean value over the reported counts/ml (PTs iis15L07 and iis15L03) of the determination of level of contamination.

It appears that the evaluation in ISO scale is quite comparable to evaluation in counts per ml of the PT results. The same trends are visible. Both evaluations, ISO scale and counts per ml, show a calculated reproducibility about twice/three times the requirements of ASTM D7647 which indicates that this determination is very problematic.

A difference is observed in the outlier analysis of PT Turbine Oil iis15L03. The range in counts per ml is larger in Turbine Oil iis15L03 than in Hydraulic Fluid iis16L07. Each ISO class is twice in range in counts per ml as the previous class code. This means that the conversion is not a linear conversion and therefore higher counts per ml are converted to less extreme ISO classes than the original values are compared to the reported values of the group. This is also observed when the mean values are calculated over the ISO classes and compared to the mean counts/ml values converted to ISO classes (see Table 3); 4 of the 6 comparisons the ISO class based on counts/ml is 1 class higher. Of course this has implications on the calculations of the target z-scores.

Another difference between the evaluation in ISO classes and counts per ml is that lower counts per ml are more emphasized in the ISO class evaluation. These values are put in different ISO classes. In the counts per ml evaluation the higher counts will be more emphasized because these higher counts per ml values will presumably get the same ISO class and are therefore no longer different. The consequence in the evaluation in ISO classes is that lower counts received a z-score lower than -2.8. For example one of the labs got a z-score of -2.03 in counts per ml but -4.26 in ISO classes. The opposite is also observed that more extreme values of counts per ml received a z-score higher than 2.8 while the evaluation in ISO class the z-score is lower than 2.8. For example one of the labs got a z-score of 2.18 in ISO classes but 3.36 in counts per ml. This is especially observed at particle sizes $\geq 6 \mu\text{m}$ and $\geq 14 \mu\text{m}$.

Note: z-scores <-3 or >3 indicates an unsatisfactory performance compared to the average of the group and method target standard deviation.

Conclusion:

Although the ISO class is not a linear scale the PT performance of contamination level can be evaluated as such. It will give a better understanding of the determination and performance of the participants. The use of the ISO scale reduces the effect of extreme counts on the statistical evaluation whilst the lower count values are more emphasised.

Therefore in future proficiency tests of iis when the contamination level parameter is part of the round robin the counts per ml will still be asked to make it possible to evaluate the Level of Contamination both in counts per ml as well in ISO classes. It is good to be able to compare both evaluations because of the logarithmic character of the ISO scale and implications on outlier analysis and normality check of the distribution.

Nevertheless, it can be concluded that the evaluation of the Level of contamination in ISO classes may give insightful information about the performance of this determination. Especially, it will give a better balance between the lower counts and higher counts when the ISO classes are used.

Appendix 1: Hydraulic Fluid (used) iis15L07; Level of contamination on sample #15220, expressed in ISO classes.

lab	method	ISO class ps ≥ 4 µm	ISO 'z-score'	ISO class ps ≥ 6 µm	ISO 'z-score'	ISO class ps ≥ 14 µm	ISO 'z-score'
325	ISO4406	14	-1.54	11	-4.82	9	-1.81
349	ISO4406	17	3.40	15	4.51	12	2.39
398	ISO4407	16	1.76	13	-0.16	9	-1.81
562	ISO4406	16	1.76	14	2.18	12	2.39
603	ISO4406	14	-1.54	12	-2.49	9	-1.81
862	ISO4406	15	0.11	13	-0.16	9	-1.81
1146	ISO11500	16	1.76	14	2.18	13	3.79
1243	ISO4407	13	-3.18	12	-2.49	9	-1.81
1417	ISO4406	13	-3.18	11	-4.82	8	-3.21
1435	ISO4406	19 D(0.05)	6.70	17 D(0.05)	9.18	11	0.99
1571	ISO4406	16	1.76	14	2.18	11	0.99
1807	ISO4406	14	-1.54	13	-0.16	11	0.99
1920	ISO4406	14	-1.54	13	-0.16	10	-0.41
1981	ISO4406	21 D(0.05)	9.99	19 D(0.05)	13.84	10	-0.41
6002	ISO4406	15	0.11	14	2.18	12	2.39
6016	ISO4407	15	0.11	13	-0.16	10	-0.41
7011	ISO4406	16	1.76	14	2.18	10	-0.41
n		15		15		17	
outliers		2		2		0	
mean (n)		14.933		13.067		10.294	
st.dev (n)		1.2228		1.1629		1.4038	
R(calc.)		3.424		3.256		3.931	
R(D7647:10 – ISO class)		1.700		1.200		2.000	

D(0.05)=straggler in Dixon's outlier test and were not used in the statistical evaluations

Appendix 2: Turbine Oil (used) iis15L03; Level of contamination on sample #15056, expressed in ISO classes.

lab	method	ISO class ps ≥ 4 µm	ISO 'z-score'	ISO class ps ≥ 6 µm	ISO 'z-score'	ISO class ps ≥ 14 µm	ISO 'z-score'
178	ISO4406	22	0.86	18	-0.33	14	2.27
179	ISO4406	19	-4.08	17	-2.67	12	-0.53
325	ISO4406	23	2.51	20	4.33	12	-0.53
331	ISO4406	23	2.51	20	4.33	13	0.87
340	ISO4406	22	0.86	17	-2.67	10	-3.33
349	ISO4406	22	0.86	19	2.00	15	3.67
360	ISO4406	20	-2.43	16	-5.00	11	-1.93
398	ISO4406	22	0.86	18	-0.33	10	-3.33
432	ISO4406	23	2.51	19	2.00	14	2.27
541	ISO4406	22	0.86	17	-2.67	11	-1.93
657	ISO4406	18	-5.73	15	-7.33	10	-3.33
663	ISO4406	22	0.86	19	2.00	13	0.87
862	ISO4406	22	0.86	17	-2.67	10	-3.33
922	ISO4406	21	-0.78	18	-0.33	11	-1.93
1023	ISO4406	22	0.86	19	2.00	12	-0.53
1059	D7647	18	-5.73	16	-5.00	12	-0.53
1146	ISO11500	20	-2.43	18	-0.33	12	-0.53
1417	ISO4406	22	0.86	17	-2.67	11	-1.93
1431	ISO4406	20	-2.43	19	2.00	14	2.27
1599	ISO4406	23	2.51	22	9.00	17	6.47
1981	ISO4406	25	5.80	20	4.33	16	5.07
n		21		21		21	
outliers		0		0		0	
mean (n)		21.476		18.143		12.381	
st.dev (n)		1.7498		1.6518		2.0119	
R(calc.)		4.900		4.625		5.633	
R(D7647:10 – ISO class)		1.700		1.200		2.000	

Appendix 3: Determination of Level of contamination on sample #15220; results in counts per ml from PT iis15L07 Hydraulic Fluid (used).

lab	method	≥ 4 μm	mark	z(targ)	≥ 6 μm	mark	z(targ)	≥ 14 μm	mark	z(targ)
325	ISO4406	91.67		-1.64	13.53		-3.07	2.93		-1.65
349	ISO4406	739		4.25	182		4.59	32		2.51
398	ISO4407	397		1.13	62		-0.87	4		-1.50
562	ISO4406	521		2.26	155		3.36	22		1.08
603	ISO4406	14	ex	-2.35	12	ex	-3.14	9	ex	-0.78
862	ISO4406	181		-0.83	56		-1.14	5		-1.36
1146	ISO11500	351.67		0.72	121.27		1.83	41.27		3.84
1243	ISO4407	64		-1.90	22		-2.68	5		-1.36
1417	ISO4406	60.33		-1.93	15.23		-2.99	1.30		-1.89
1435	ISO4406	4397.40	G(0.01)	37.53	853.43	G(0.01)	35.11	19.13		0.67
1571	ISO4406	433.92		1.47	131.29		2.28	19.89		0.78
1807	ISO4406	134.33		-1.26	61.60		-0.88	18.13		0.52
1920	ISO4406	151.1		-1.10	56.5		-1.12	5.8		-1.24
1981	ISO4406	11252	C,G(0.01)	99.89	2634	C,G(0.01)	116.06	9		-0.78
6002	ISO4406	192.6		-0.73	117.1		1.64	23.6	C	1.31
6016	ISO4407	223		-0.45	60.0		-0.96	8		-0.93
7011	ISO4406	16	ex	-2.33	14	ex	-3.05	10	ex	-0.64
	normality	suspect			OK			OK		
	n	13			13			15		
	outliers	2 (+ 2excl)			2 (+2 excl)			0 (+2 excl)		
	mean (n)	272.36			81.04			14.47		
	st.dev. (n)	204.006			54.691			11.870		
	R(calc.)	571.22			153.14			33.24		
	R(D7647:10)	307.76			61.59			19.53		

Results for lab 603 and 7011 were excluded; the reported results are ISO classes instead of counts per ml

G(0.01)=outlier in Grubbs' outlier test

C=final test result after checking of first reported suspect result

Lab 1981: first reported resp. 1742, 351

Lab 6002: first reported 53.6

Appendix 4: Determination of Level of contamination on sample #15056; results in counts per ml from PT iis15L03 Turbine Oil (used).

lab	method	≥ 4 μm	mark	z(targ)	≥ 6 μm	mark	z(targ)	≥ 14 μm	mark	z(targ)
178	ISO4406	26405		0.12	2489		0.27	91		2.10
179	ISO4406	4602		-2.03	652		-2.65	23		-1.02
325	ISO4406	41807.80		1.64	5411.93		4.91	32.60		-0.58
331	ISO4406	46442		2.09	5830		5.58	64		0.86
340	ISO4406	24305.9		-0.09	1026.8		-2.05	6.6		-1.77
349	ISO4406	38924		1.35	4849		4.02	165		5.50
360	ISO4406	7673.1		-1.72	639.4		-2.67	11.3		-1.56
398	ISO4406	32380		0.71	1503		-1.30	9		-1.66
432	ISO4406	44901		1.94	3785		2.33	140		4.35
541	ISO4406	23550		-0.16	993		-2.11	11.0		-1.57
657	ISO4406	1430		-2.34	223		-3.33	7		-1.75
663	ISO4406	34368		0.90	3220		1.43	52		0.31
862	ISO4406	27446		0.22	1026		-2.05	8		-1.71
922	ISO4406	16699		-0.83	2265		-0.09	20		-1.16
1023	ISO4406	32873.43	C	0.76	2565.37	C	0.39	24.27	C	-0.96
1059	D7647	2300.2		-2.25	534.4		-2.84	21.9		-1.07
1146	ISO11500	---		---	---		---	---		---
1417	ISO4406	37184.90		1.18	1174.47		-1.82	18.70		-1.22
1431	ISO4406	9987.0		-1.50	3552.0		1.96	108.0		2.88
1599	ISO4406	48110	ex	2.26	28446	R(0.01)	41.51	955	R(0.01)	41.76
1981	ISO4406	179906	R(0.01)	15.22	8295	R(0.05)	9.49	545	R(0.01)	22.94
	normality	OK			OK			not OK		
	n	18			18			18		
	outliers	1 (+1 excl)			2			2		
	mean (n)	25182.2			2318.9			45.19		
	st.dev. (n)	14904.09			1767.71			48.937		
	R(calc.)	41731.4			4949.6			137.02		
	R(D7647:10)	28455.9			1762.3			61.00		

Result for lab 1599 was excluded; because the other two results are outliers and response parameters are related

R(0.01)=outlier in Rosner's outlier test

R(0.05)=straggler in Rosner's outlier test

C=final test result after checking of first reported suspect result

Lab 1023: first reported resp. 3287343, 256537, 2427