SP Energy Networks

Unusual High Acidity in Distribution Transformers - Results Analysis

27th November 2024

Background

An Early Degradation Phenomenon Identified through Transformer Oil Database Analysis

S.J. Tee, Q. Liu, Z.D. Wang
School of Electrical and Electronic Engineering
The University of Manchester
Manchester, M13 9PL, UK

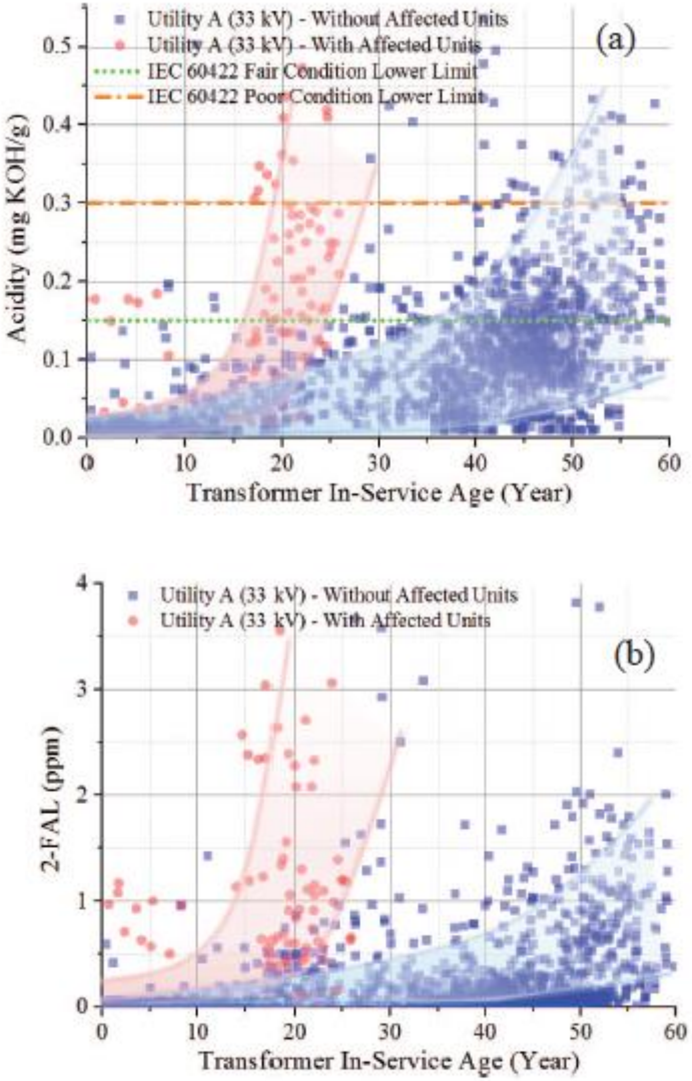
G. Wilson, P. Jarman, R. Hooton
The National Grid Company
Warwick, CV34 6DA, UK

D. Walker
Scottish Power
Blantyre, G72 0HT, UK

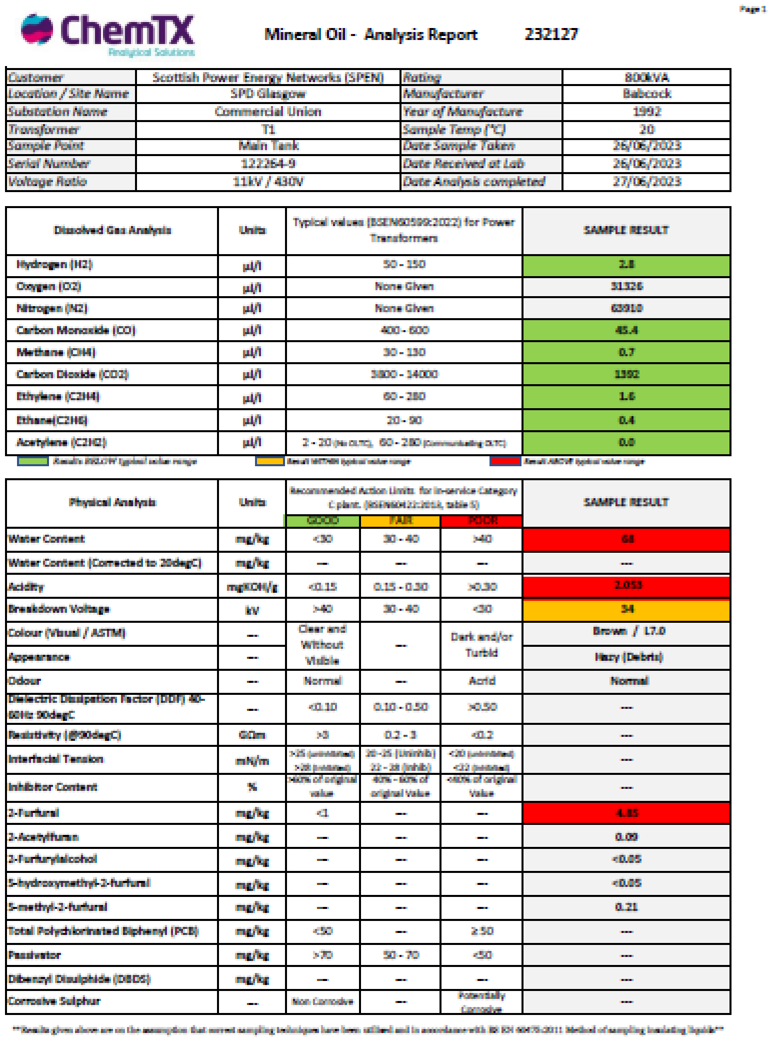
and P. Dyer
UK Power Networks
Crawley, RH10 9FL, UK

ABSTRACT

1 INTRODUCTION



Commercial Union – 200 SVS



Page 1

ChemTX
Analytical Solutions

Mineral Oil - Analysis Report 232127

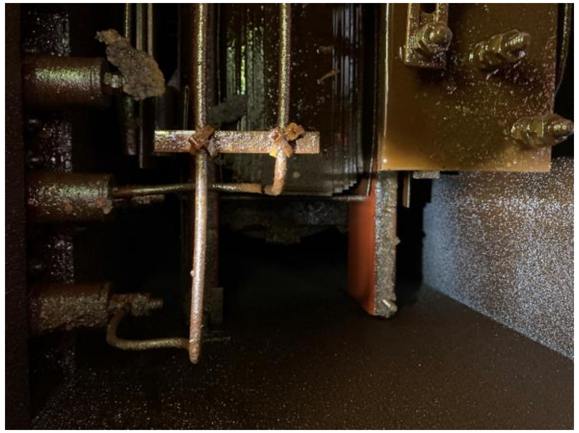
Customer	Scottish Power Energy Networks (SPEN)	*Rating*	800kVA
Location / Site Name	SPD Glasgow	*Manufacturer*	Babcock
Substation Name	Commercial Union	*Year of Manufacture*	1992
Transformer	T1	*Sample Temp (°C)*	20
Sample Point	Main Tank	*Date Sample Taken*	26/06/2023
Serial Number	122264-9	*Date Received at Lab*	26/06/2023
Voltage Ratio	11kV / 430V	*Date Analysis completed*	27/06/2023

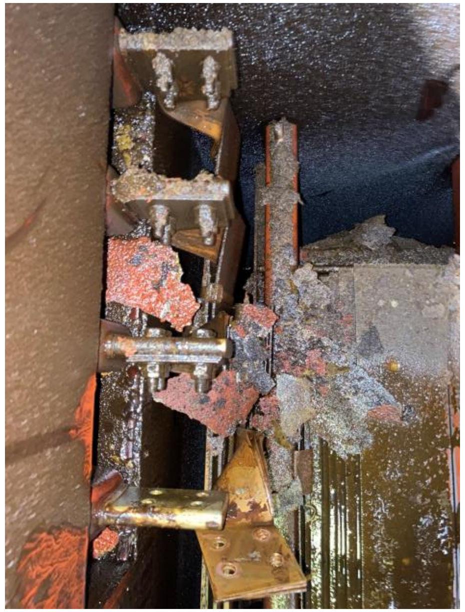
Dissolved Gas Analysis	Units	Typical values (BSEN60599:2022) for Power Transformers	SAMPLE RESULT
Hydrogen (H2)	µl/l	50 - 150	2.8
Oxygen (O2)	µl/l	None Given	31326
Nitrogen (N2)	µl/l	None Given	63910
Carbon Monoxide (CO)	µl/l	400 - 600	45.4
Methane (CH4)	µl/l	30 - 130	0.7
Carbon Dioxide (CO2)	µl/l	3800 - 14000	1392
Ethylene (C2H4)	µl/l	60 - 280	1.6
Ethane(C2H6)	µl/l	20 - 90	0.4
Acetylene (C2H2)	µl/l	2 - 20 (No OLTC), 60 - 280 (Communicating OLTC)	0.0

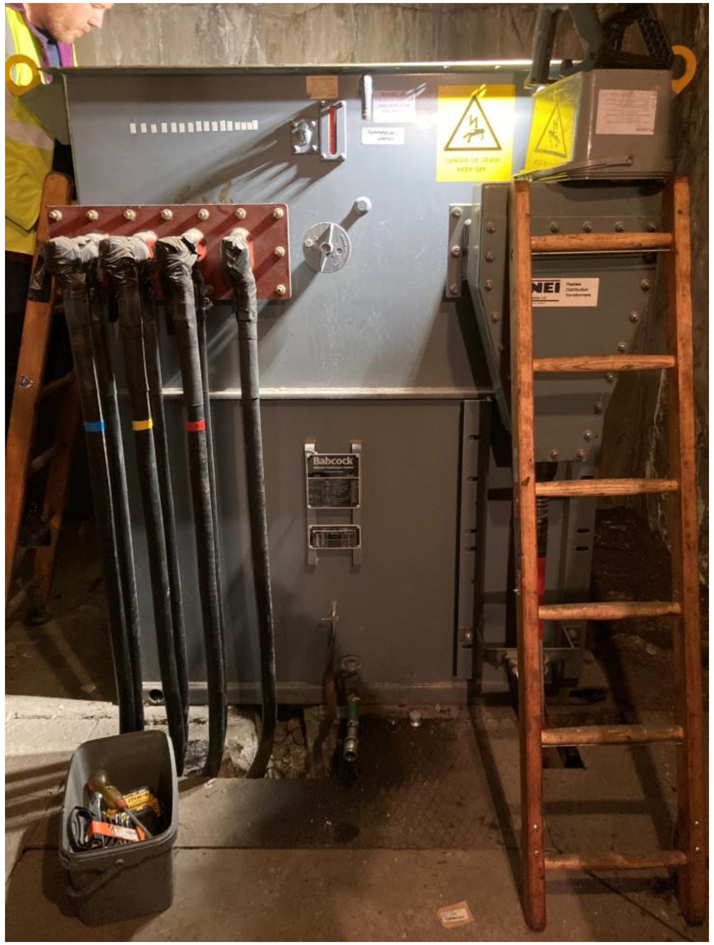
🟩 Results BELOW typical value range 🟨 Result WITHIN typical value range 🟥 Result ABOVE typical value range

Physical Analysis	Units	Recommended Action Limits for In-service Category C plant. (BSEN60422:2013, table 5)			SAMPLE RESULT
		GOOD	FAIR	POOR	
Water Content	mg/kg	<30	30 - 40	>40	68
Water Content (Corrected to 20degC)	mg/kg	---	---	---	---
Acidity	mgKOH/g	<0.15	0.15 - 0.30	>0.30	2.053
Breakdown Voltage	kV	>40	30 - 40	<30	34
Colour (Visual / ASTM)	---	Clear and Without Visible	---	Dark and/or Turbid	Brown / L7.0
Appearance	---				Hazy (Debris)
Odour	---	Normal	---	Acrid	Normal
Dielectric Dissipation Factor (DDF) 40-60Hz 90degC	---	<0.10	0.10 - 0.50	>0.50	---
Resistivity (@90degC)	GΩm	>3	0.2 - 3	<0.2	---
Interfacial Tension	mN/m	>25 (uninhibited) >28 (inhibited)	20 - 25 (Uninhib) 22 - 28 (Inhib)	<20 (uninhibited) <22 (inhibited)	---
Inhibitor Content	%	>60% of original value	40% - 60% of original Value	<40% of original Value	---
2-Furfural	mg/kg	<1	---	---	4.85
2-Acetylfuran	mg/kg	---	---	---	0.09
2-Furfurylalcohol	mg/kg	---	---	---	<0.05
5-hydroxymethyl-2-furfural	mg/kg	---	---	---	<0.05
5-methyl-2-furfural	mg/kg	---	---	---	0.21
Total Polychlorinated Biphenyl (PCB)	mg/kg	<50	---	≥ 50	---
Passivator	mg/kg	>70	50 - 70	<50	---
Dibenzyl Disulphide (DBDS)	mg/kg	---	---	---	---
Corrosive Sulphur	---	Non Corrosive	---	Potentially Corrosive	---

Results given above are on the assumption that correct sampling techniques have been utilised and in accordance with BS EN 60475:2011 Method of sampling insulating liquids







Investigation

- Following the investigation of the Commercial Union Tx, the Oil Dashboard was analysed to spot any trends with similar units.

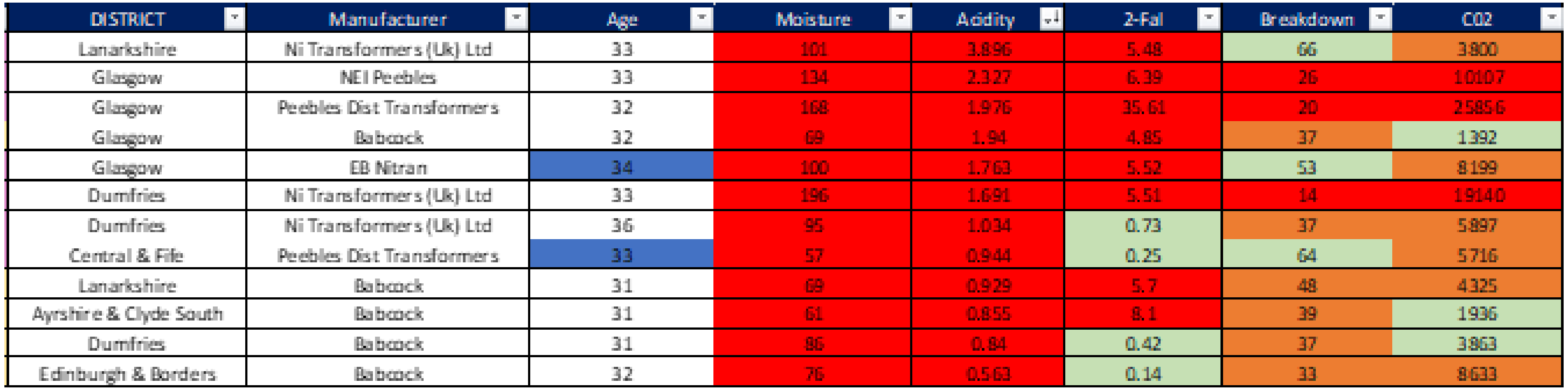
- Our original theory of oil contamination initially led us to transformers manufactured roughly 30+ years ago. Correlations were found between high acidity and 2-fal with units from Babcock, NEI Peebles and NI Transformers. With the vast majority falling between at 1988-1996.

- The re-sampling and analysis of oil dashboard revealed that many of these units are suffering from very poor oil results, and in many cases breaching the 0.5 limit for acidity. This can be seen in two trends -

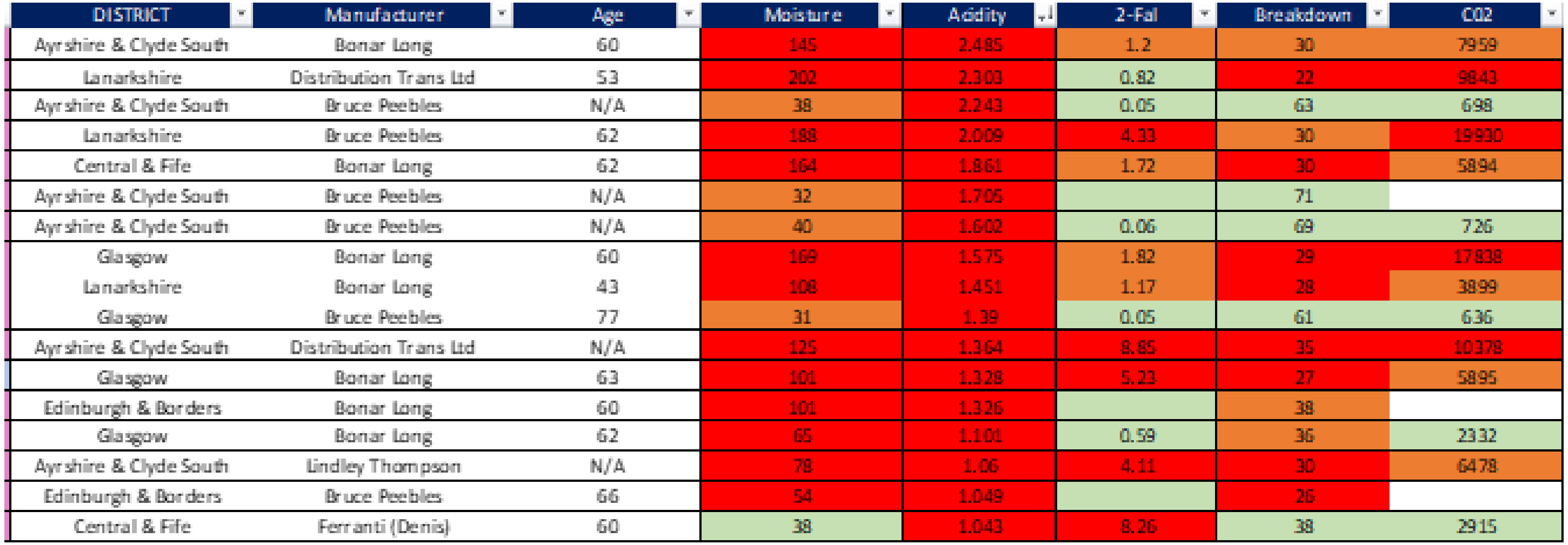
- 30 year old units (Radiator Issue) Total Volume – 1806 Units (359 Babcock, 1447 NEI/Peebles/NI).

- Circa 60 year old units

Transformers Oil Test Results

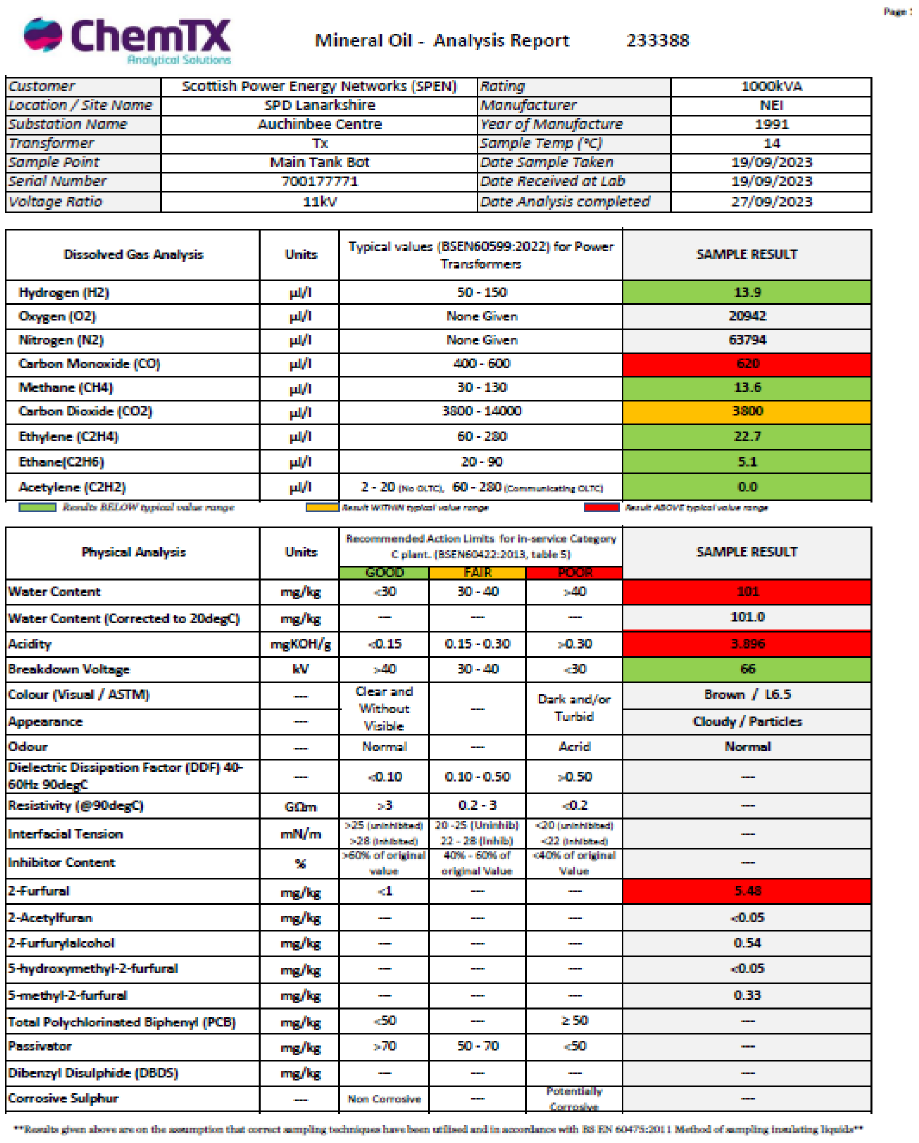


DISTRICT	Manufacturer	Age	Moisture	Acidity	2-Fal	Breakdown	C02
Lanarkshire	Ni Transformers (Uk) Ltd	33	101	3.896	5.48	66	3800
Glasgow	NEI Peebles	33	134	2.327	6.39	26	10107
Glasgow	Peebles Dist Transformers	32	168	1.976	35.61	20	25856
Glasgow	Babcock	32	69	1.94	4.85	37	1392
Glasgow	EB Nitran	34	100	1.763	5.52	53	8199
Dumfries	Ni Transformers (Uk) Ltd	33	196	1.691	5.51	14	19140
Dumfries	Ni Transformers (Uk) Ltd	36	95	1.034	0.73	37	5897
Central & Fife	Peebles Dist Transformers	33	57	0.944	0.25	64	5716
Lanarkshire	Babcock	31	69	0.929	5.7	48	4325
Ayrshire & Clyde South	Babcock	31	61	0.855	8.1	39	1936
Dumfries	Babcock	31	86	0.84	0.42	37	3863
Edinburgh & Borders	Babcock	32	76	0.563	0.14	33	8633



DISTRICT	Manufacturer	Age	Moisture	Acidity	2-Fal	Breakdown	C02
Ayrshire & Clyde South	Bonar Long	60	145	2.485	1.2	30	7959
Lanarkshire	Distribution Trans Ltd	53	202	2.303	0.82	22	9843
Ayrshire & Clyde South	Bruce Peebles	N/A	38	2.243	0.05	63	698
Lanarkshire	Bruce Peebles	62	188	2.009	4.33	30	19930
Central & Fife	Bonar Long	62	164	1.861	1.72	30	5894
Ayrshire & Clyde South	Bruce Peebles	N/A	32	1.705		71	
Ayrshire & Clyde South	Bruce Peebles	N/A	40	1.602	0.06	69	726
Glasgow	Bonar Long	60	169	1.575	1.82	29	17838
Lanarkshire	Bonar Long	43	108	1.451	1.17	28	3899
Glasgow	Bruce Peebles	77	31	1.39	0.05	61	636
Ayrshire & Clyde South	Distribution Trans Ltd	N/A	125	1.364	8.85	35	10378
Glasgow	Bonar Long	63	101	1.328	5.23	27	5895
Edinburgh & Borders	Bonar Long	60	101	1.326		38	
Glasgow	Bonar Long	62	65	1.101	0.59	36	2332
Ayrshire & Clyde South	Lindley Thompson	N/A	78	1.06	4.11	30	6478
Edinburgh & Borders	Bruce Peebles	66	54	1.049		26	
Central & Fife	Ferranti (Denis)	60	38	1.043	8.26	38	2915

Case Studies - Auchinbee Centre



Page :

ChemTX Analytical Solutions

Mineral Oil - Analysis Report 233388

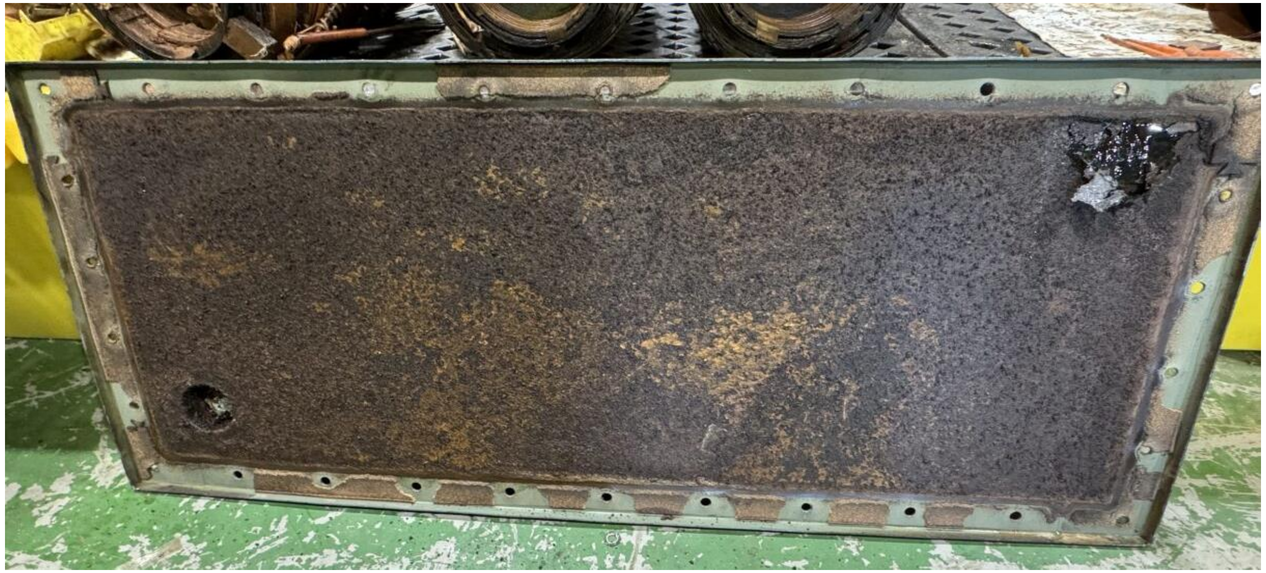
Customer	Scottish Power Energy Networks (SPEN)	*Rating*	1000kVA
Location / Site Name	SPD Lanarkshire	*Manufacturer*	NEI
Substation Name	Auchinbee Centre	*Year of Manufacture*	1991
Transformer	Tx	*Sample Temp (°C)*	14
Sample Point	Main Tank Bot	*Date Sample Taken*	19/09/2023
Serial Number	700177771	*Date Received at Lab*	19/09/2023
Voltage Ratio	11kV	*Date Analysis completed*	27/09/2023

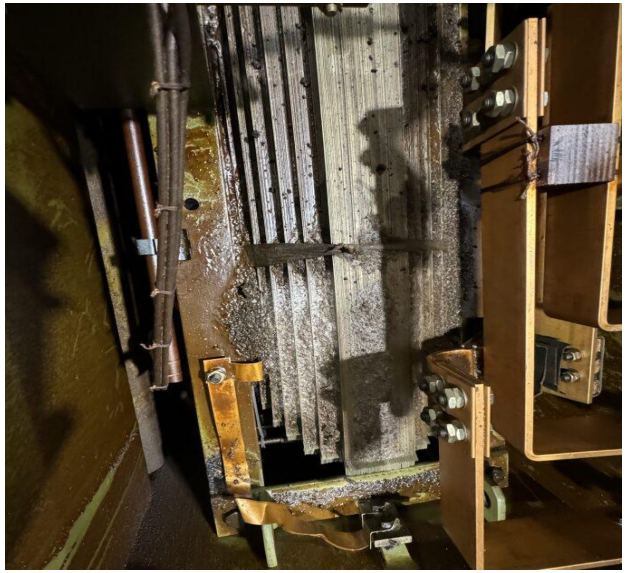
Dissolved Gas Analysis	Units	Typical values (BSEN60599:2022) for Power Transformers	SAMPLE RESULT
Hydrogen (H_2)	µl/l	50 - 150	13.9
Oxygen (O_2)	µl/l	None Given	20942
Nitrogen (N_2)	µl/l	None Given	63794
Carbon Monoxide (CO)	µl/l	400 - 600	620
Methane (CH_4)	µl/l	30 - 130	13.6
Carbon Dioxide (CO_2)	µl/l	3800 - 14000	3800
Ethylene (C_2H_4)	µl/l	60 - 280	22.7
Ethane(C_2H_6)	µl/l	20 - 90	5.1
Acetylene (C_2H_2)	µl/l	2 - 20 (No OLTC), 60 - 280 (Communicating OLTC)	0.0

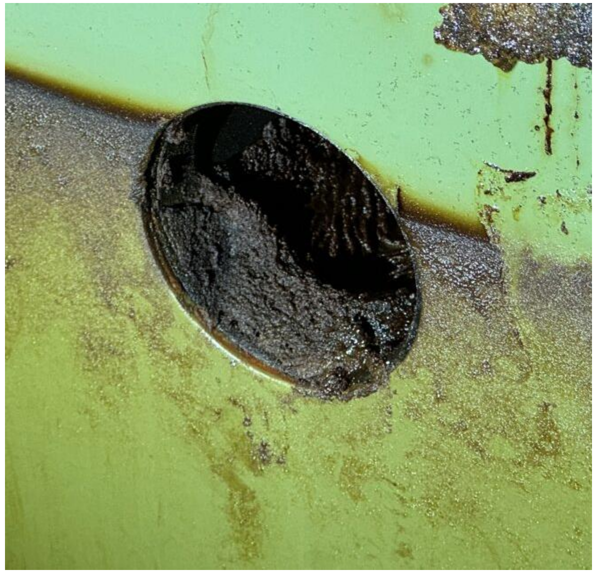
🟩 Results BELOW typical value range 🟨 Result WITHIN typical value range 🟥 Result ABOVE typical value range

Physical Analysis	Units	Recommended Action Limits for in-service Category C plant. (BSEN60422:2013, table 5)			SAMPLE RESULT
		GOOD	FAIR	POOR	
Water Content	mg/kg	<30	30 - 40	>40	101
Water Content (Corrected to 20degC)	mg/kg	---	---	---	101.0
Acidity	mgKOH/g	<0.15	0.15 - 0.30	>0.30	3.896
Breakdown Voltage	kV	>40	30 - 40	<30	66
Colour (Visual / ASTM)	---	Clear and Without Visible	---	Dark and/or Turbid	Brown / L6.5
Appearance	---				Cloudy / Particles
Odour	---	Normal	---	Acrid	Normal
Dielectric Dissipation Factor (DDF) 40-60Hz 90degC	---	<0.10	0.10 - 0.50	>0.50	---
Resistivity (@90degC)	GΩm	>3	0.2 - 3	<0.2	---
Interfacial Tension	mN/m	>25 (uninhibited) >28 (inhibited)	20 -25 (Uninhib) 22 - 28 (Inhib)	<20 (uninhibited) <22 (inhibited)	---
Inhibitor Content	%	>60% of original value	40% - 60% of original Value	<40% of original Value	---
2-Furfural	mg/kg	<1	---	---	5.48
2-Acetylfuran	mg/kg	---	---	---	<0.05
2-Furfurylalcohol	mg/kg	---	---	---	0.54
5-hydroxymethyl-2-furfural	mg/kg	---	---	---	<0.05
5-methyl-2-furfural	mg/kg	---	---	---	0.33
Total Polychlorinated Biphenyl (PCB)	mg/kg	<50	---	≥ 50	---
Passivator	mg/kg	>70	50 - 70	<50	---
Dibenzyl Disulphide (DBDS)	mg/kg	---	---	---	---
Corrosive Sulphur	---	Non Corrosive	---	Potentially Corrosive	---

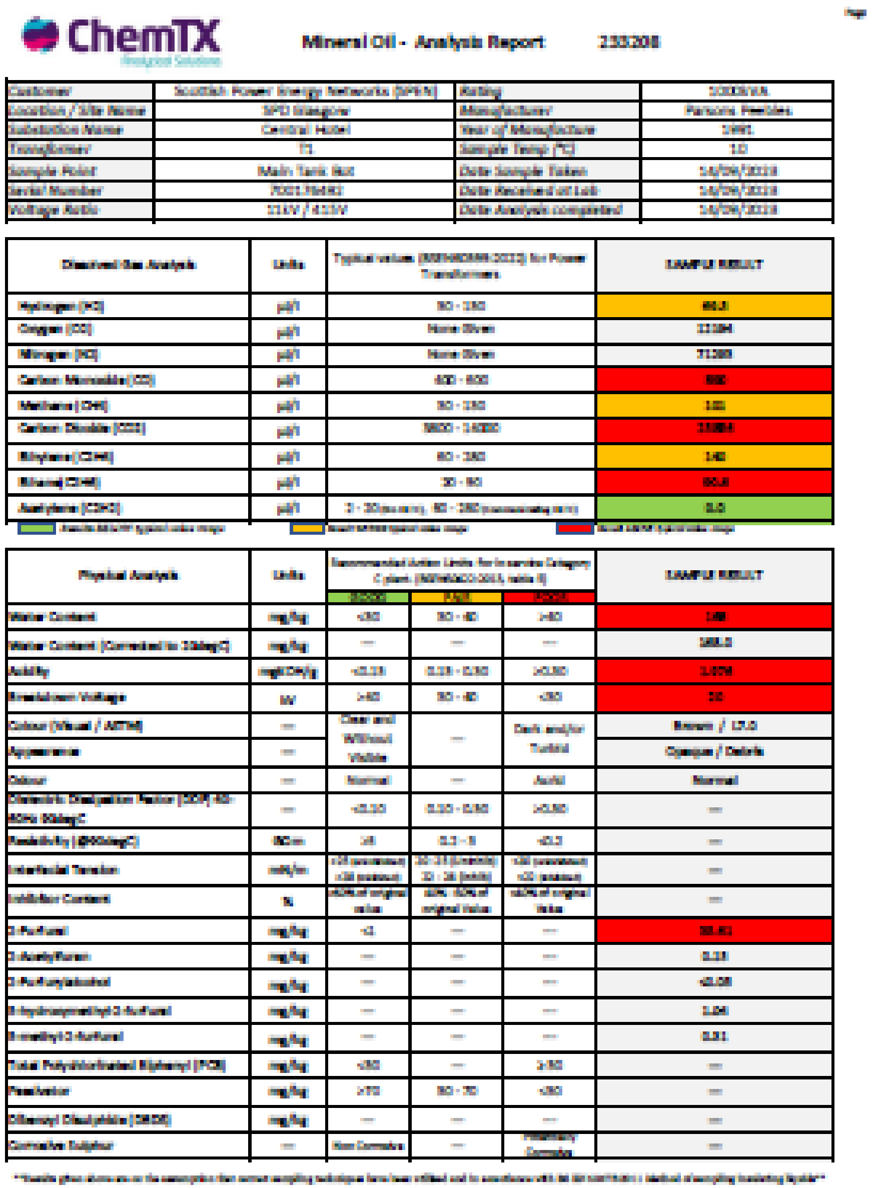
Results given above are on the assumption that correct sampling techniques have been utilised and in accordance with BS EN 60475:2011 Method of sampling insulating liquids







Case Studies – Central Hotel

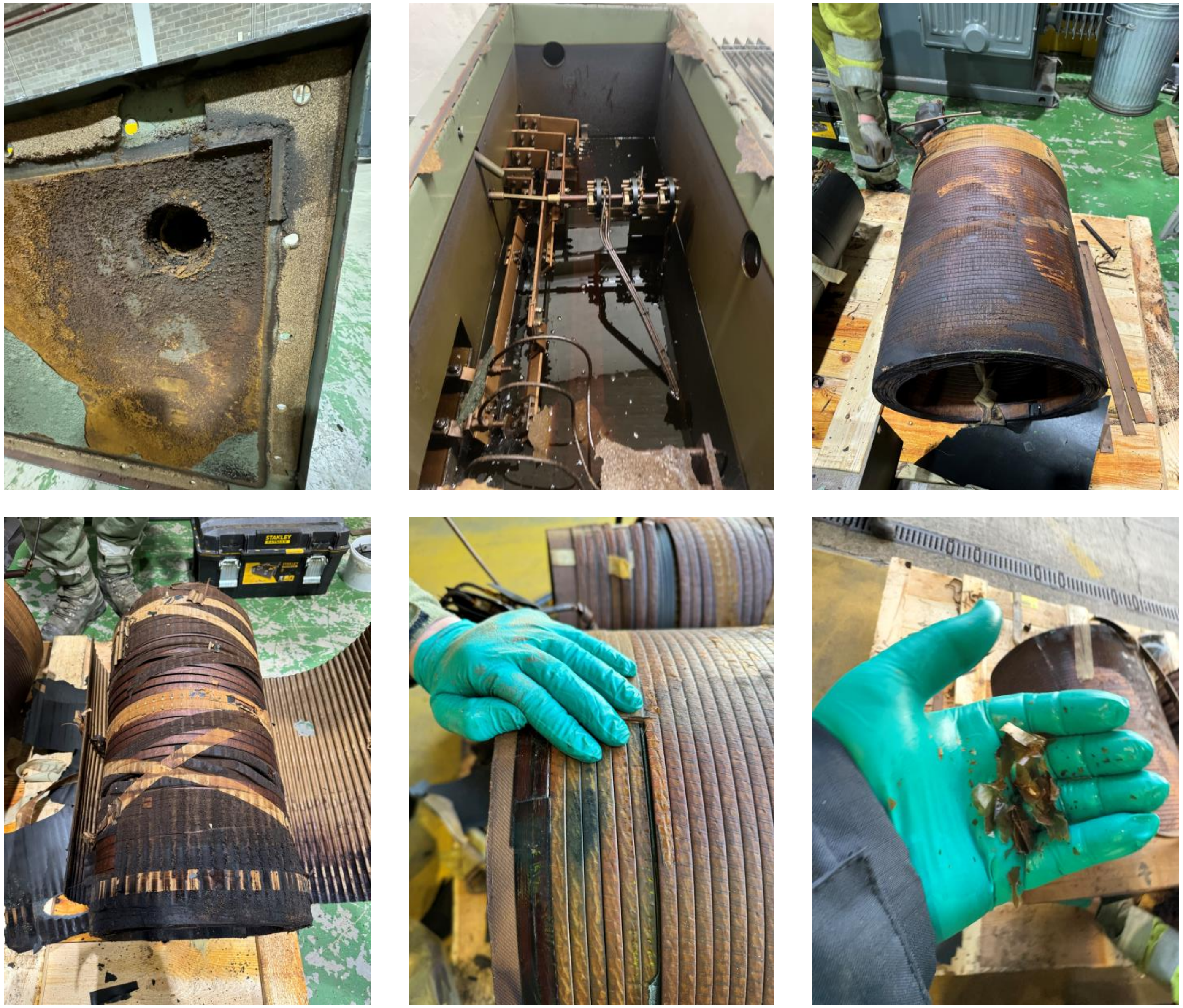


ChemTX Mineral Oil - Analysis Report 233208

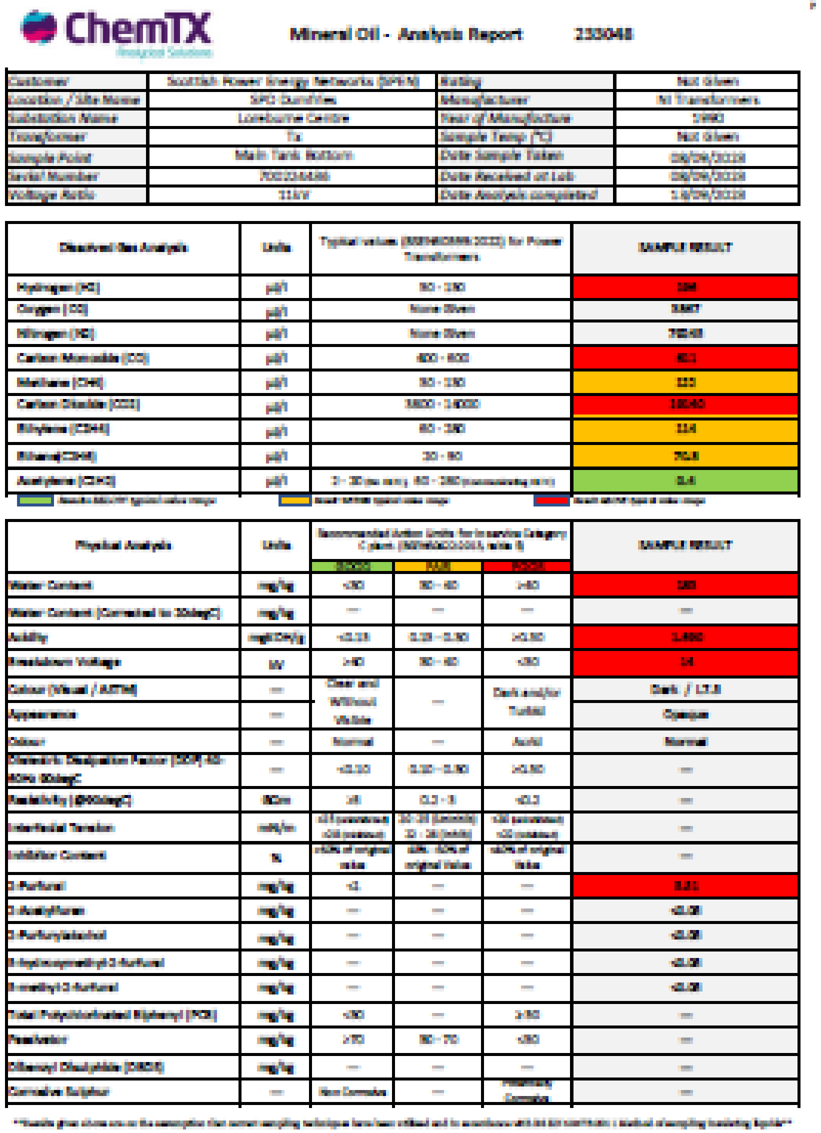
Customer	Scottish Power Energy Networks (SPEN)	Rating	1000kVA
Location / Site Name	SPD Glasgow	Manufacturer	Parsons Peebles
Substation Name	Central Hotel	Year of Manufacture	[illegible]
Transformer	T1	Sample Temp (°C)	10
Sample Point	Main Tank Bot	Date Sample Taken	[illegible]
Serial Number	[illegible]	Date Received at Lab	[illegible]
Voltage Ratio	11kV / 433V	Date Analysis completed	[illegible]

Dissolved Gas Analysis	Units	Typical values (BSEN60599:2022) for Power Transformers	SAMPLE RESULT
Hydrogen (H2)	µl/l	50 - 150	[illegible]
Oxygen (O2)	µl/l	None Given	[illegible]
Nitrogen (N2)	µl/l	None Given	[illegible]
Carbon Monoxide (CO)	µl/l	400 - 600	[illegible]
Methane (CH4)	µl/l	30 - 130	[illegible]
Carbon Dioxide (CO2)	µl/l	3800 - 14000	[illegible]
Ethylene (C2H4)	µl/l	60 - 280	[illegible]
Ethane (C2H6)	µl/l	20 - 90	[illegible]
Acetylene (C2H2)	µl/l	3 - 50 [illegible], 80 - 270 [illegible]	0.0

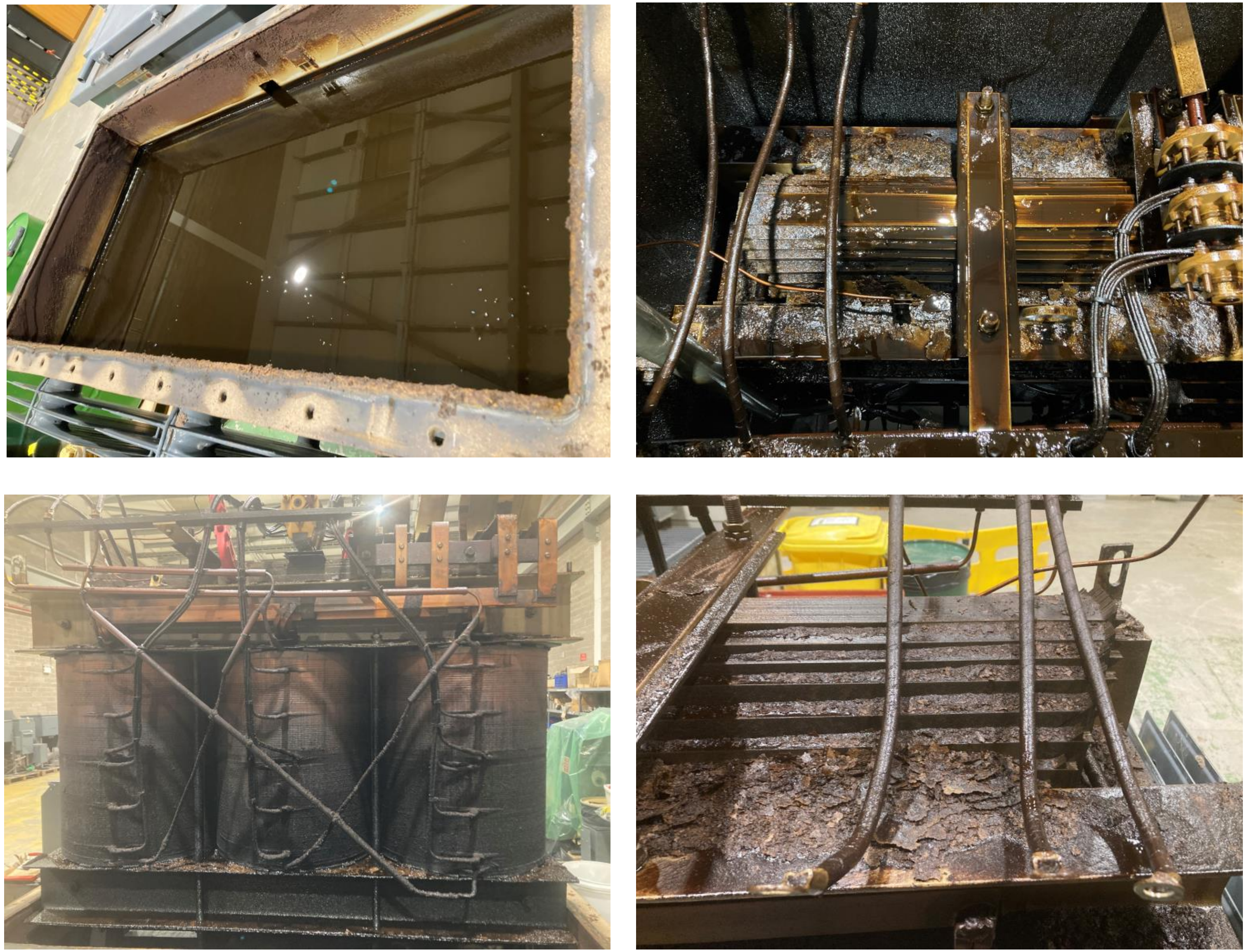
Physical Analysis	Units	Recommended Action Limits for in-service Category C plant. (BSEN60422:2013, table 5)			SAMPLE RESULT
		GOOD	FAIR	POOR	
Water Content	mg/kg	<20	20 - 40	>40	[illegible]
Water Content (Corrected to 20degC)	mg/kg	—	—	—	[illegible]
Acidity	mgKOH/g	<0.15	0.15 - 0.30	>0.30	[illegible]
Breakdown Voltage	kV	>60	50 - 60	<50	[illegible]
Colour (Visual / ASTM)	—	Clear and Without Visible	—	Dark and/or Turbid	Brown / [illegible]
Appearance	—				Opaque / Debris
Odour	—	Normal	—	Acrid	Normal
Dielectric Dissipation Factor (DDF) 40-60Hz 90degC	—	<0.10	0.10 - 0.50	>0.50	—
Resistivity (@90degC)	GΩm	[illegible]	[illegible]	[illegible]	—
Interfacial Tension	mN/m	[illegible]	[illegible]	[illegible]	—
Inhibitor Content	%	[illegible] of original value	[illegible] of original Value	[illegible] of original Value	—
2-Furfural	mg/kg	[illegible]	—	—	[illegible]
2-Acetylfuran	mg/kg	—	—	—	[illegible]
2-Furfurylalcohol	mg/kg	—	—	—	[illegible]
5-hydroxymethyl-2-furfural	mg/kg	—	—	—	[illegible]
5-methyl-2-furfural	mg/kg	—	—	—	[illegible]
Total Polychlorinated Biphenyl (PCB)	mg/kg	<50	—	>50	—
Passivator	mg/kg	>70	50 - 70	<50	—
Dibenzyl Disulphide (DBDS)	mg/kg	—	—	—	—
Corrosive Sulphur	—	Non Corrosive	—	Potentially Corrosive	—



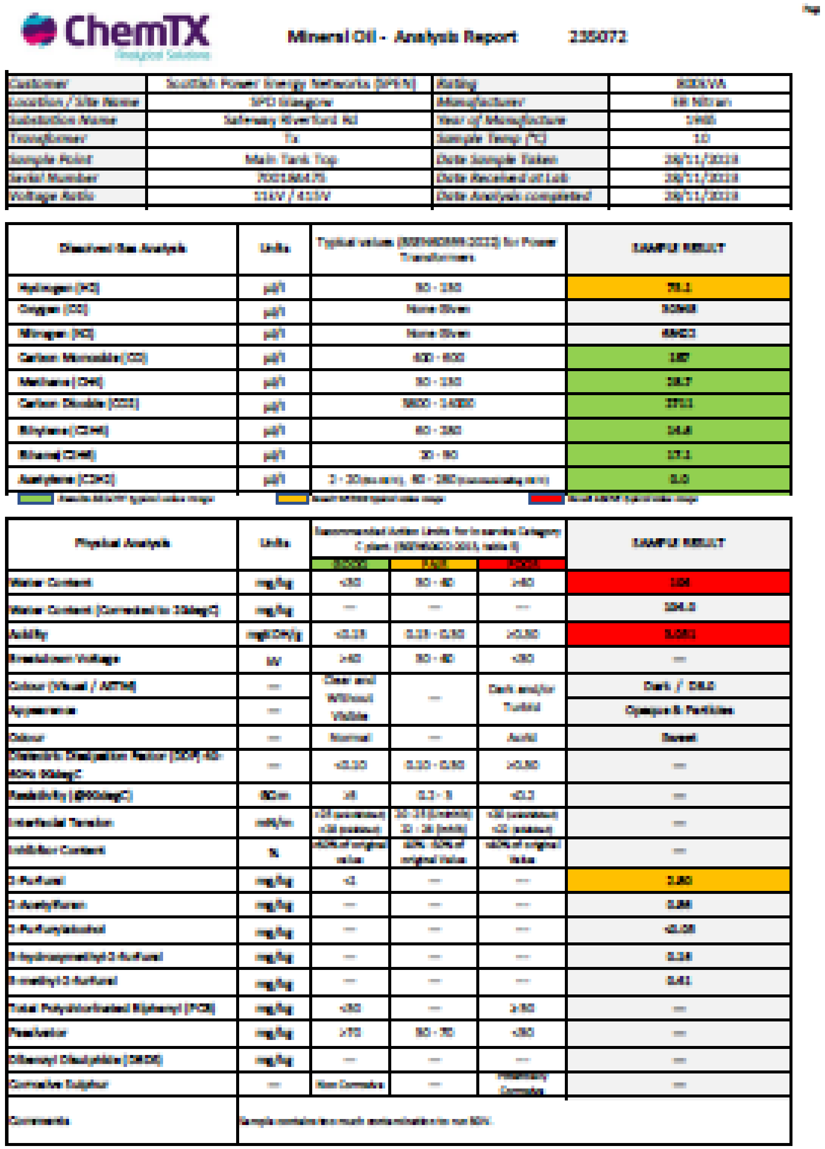
Case Studies – Loreburn



Mineral Oil - Analysis Report 233048

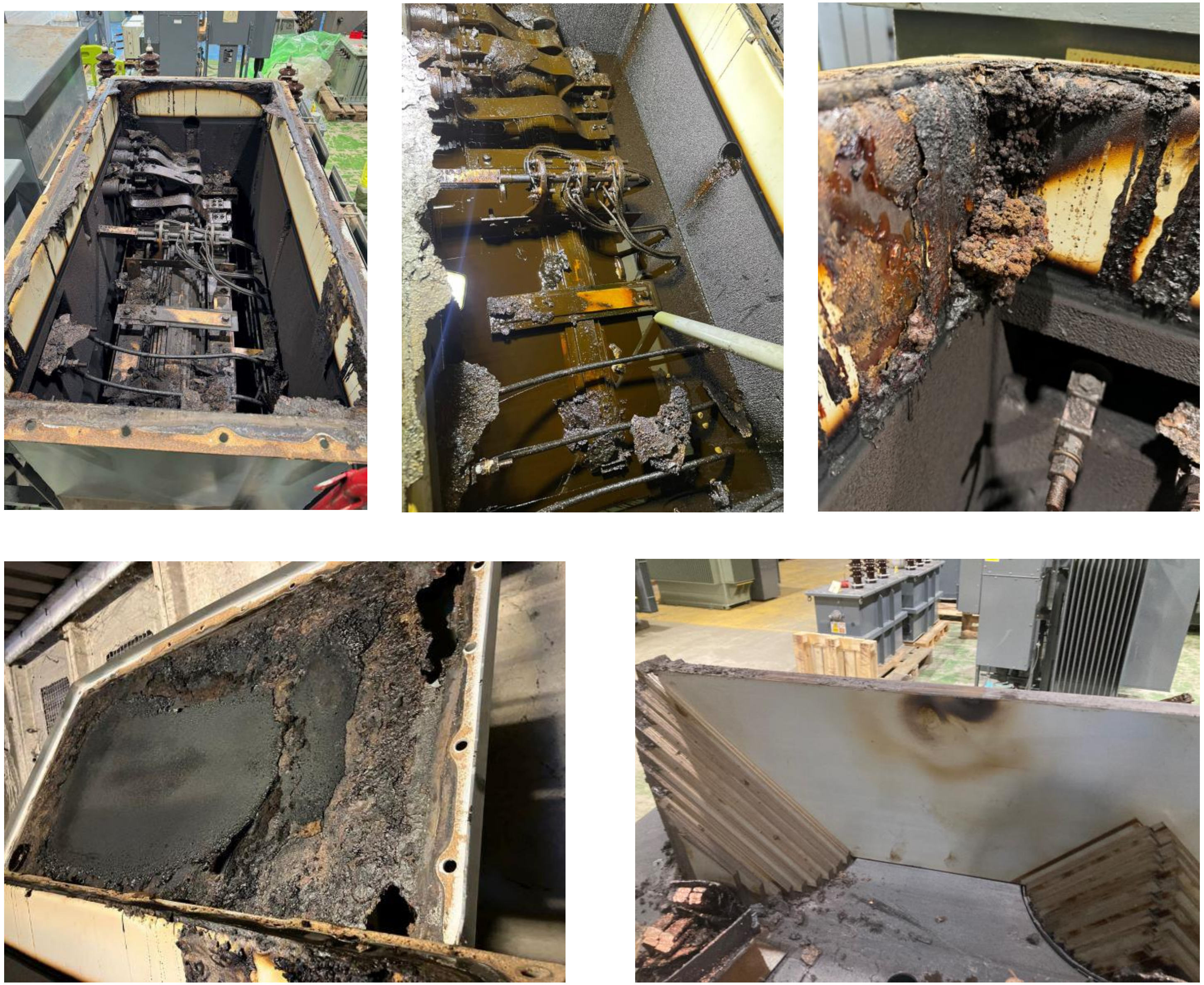


Case Studies – Riverford Road



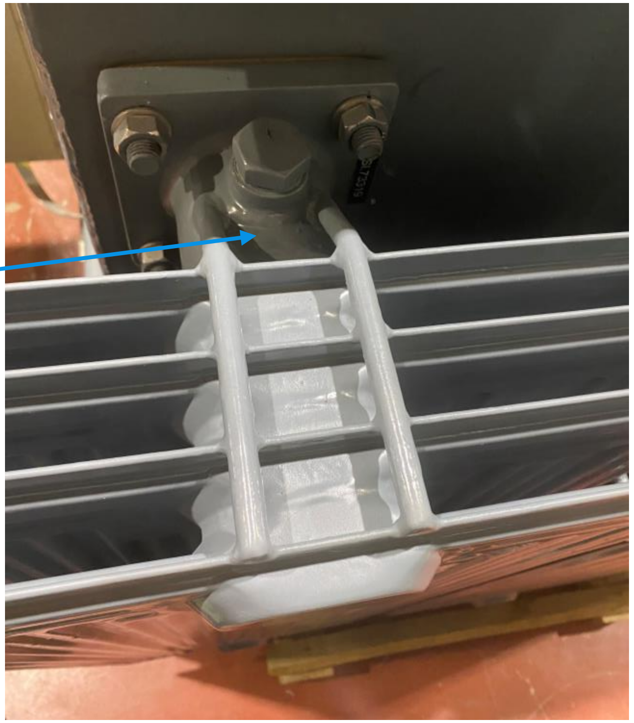
ChemTX

Mineral Oil - Analysis Report 235072



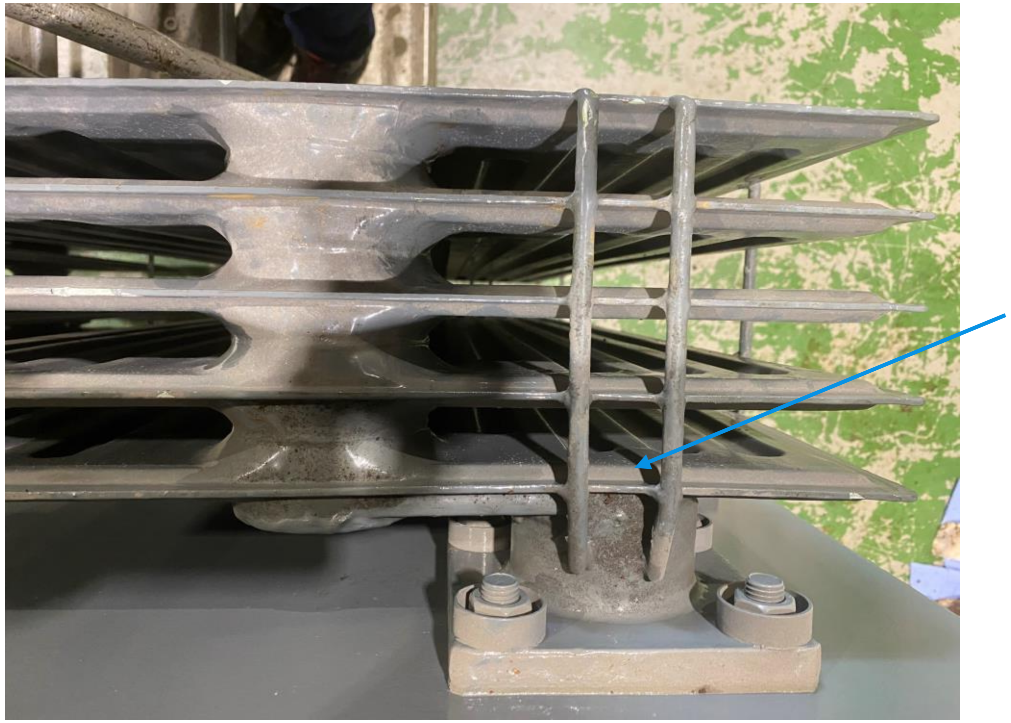
Radiator Header Design

Site visits with thermal cameras, and the post-mortem of the Commercial Union unit revealed the presence of a off-centre radiator header design. This design is prone to blockage in the presence of sludge leading to inadequate cooling and oil flow through the radiators. In turn the high acidity created is causing corrosion of internal lid, and high temperatures in the windings, reducing the mechanical strength of the paper. The worst affected units appear to be situated embedded in basements or in enclosures with poor ventilation and high humidity.



Traditional headers allow for connection to all radiator fins

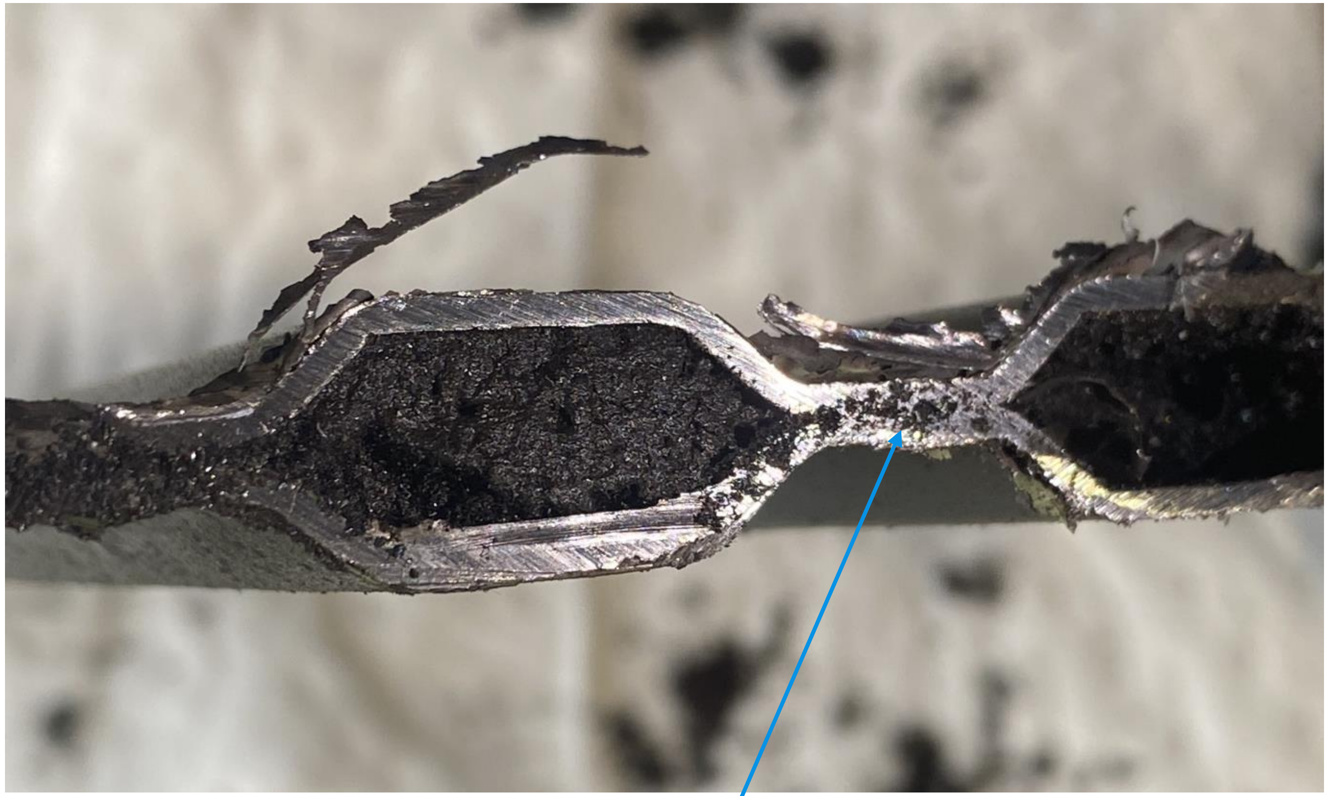
Typical Header Design

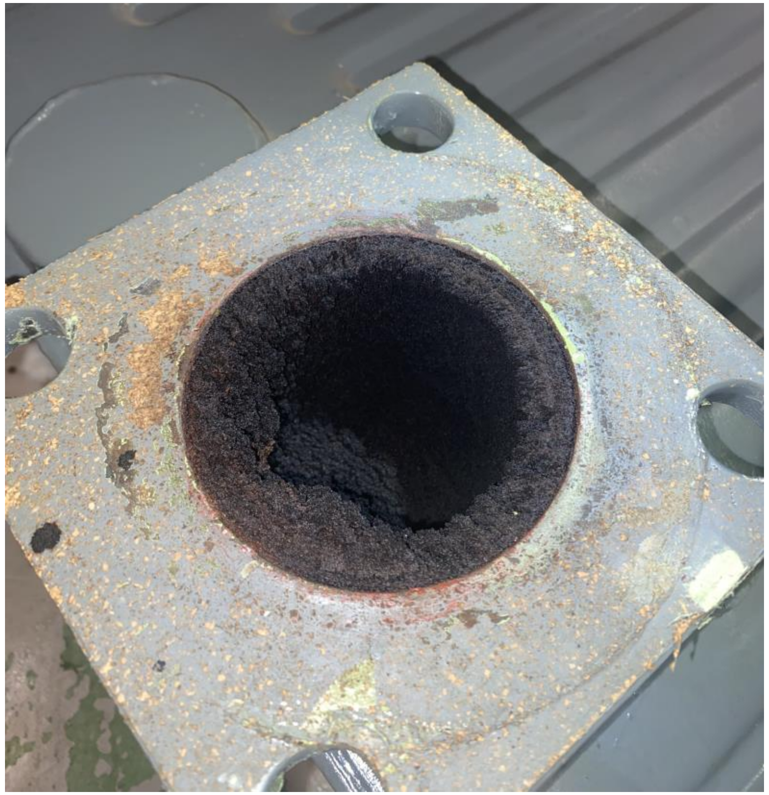


This design only connects one fin to the header inlet from the main tank, rather than all 5 restricting oil flow and causing sludge to form

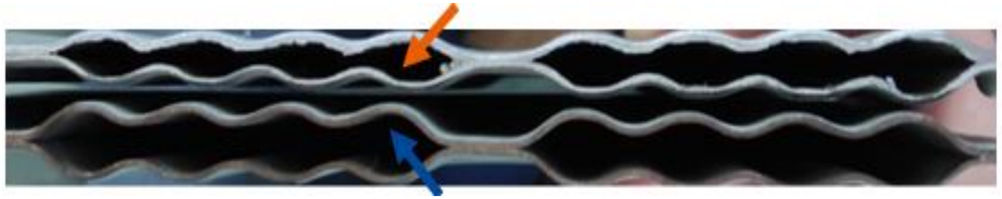
Header Design Under Investigation

Unusual Tank Attached Radiator Header Design - Effects

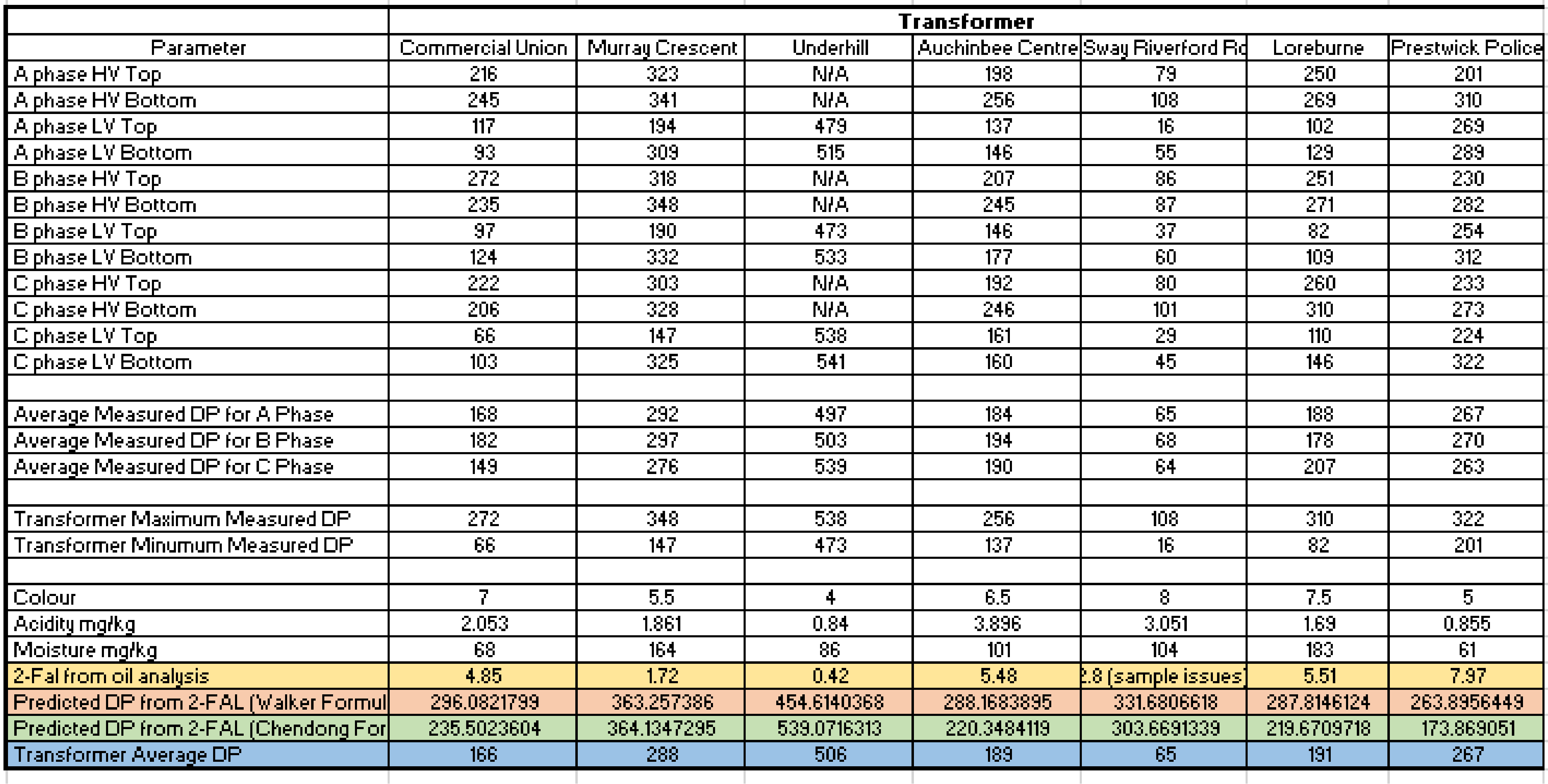




Due to radiator punching, there is significantly less space within radiator fins to allow oil to circulate properly when compared to other radiator designs



Sampling – Colour and Smell



	Transformer						
Parameter	Commercial Union	Murray Crescent	Underhill	Auchinbee Centre	Sway Riverford Rd	Loreburne	Prestwick Police
A phase HV Top	216	323	N/A	198	79	250	201
A phase HV Bottom	245	341	N/A	256	108	269	310
A phase LV Top	117	194	479	137	16	102	269
A phase LV Bottom	93	309	515	146	55	129	289
B phase HV Top	272	318	N/A	207	86	251	230
B phase HV Bottom	235	348	N/A	245	87	271	282
B phase LV Top	97	190	473	146	37	82	254
B phase LV Bottom	124	332	533	177	60	109	312
C phase HV Top	222	303	N/A	192	80	260	233
C phase HV Bottom	206	328	N/A	246	101	310	273
C phase LV Top	66	147	538	161	29	110	224
C phase LV Bottom	103	325	541	160	45	146	322
Average Measured DP for A Phase	168	292	497	184	65	188	267
Average Measured DP for B Phase	182	297	503	194	68	178	270
Average Measured DP for C Phase	149	276	539	190	64	207	263
Transformer Maximum Measured DP	272	348	538	256	108	310	322
Transformer Minumum Measured DP	66	147	473	137	16	82	201
Colour	7	5.5	4	6.5	8	7.5	5
Acidity mg/kg	2.053	1.861	0.84	3.896	3.051	1.69	0.855
Moisture mg/kg	68	164	86	101	104	183	61
2-Fal from oil analysis	4.85	1.72	0.42	5.48	2.8 (sample issues)	5.51	7.97
Predicted DP from 2-FAL (Walker Formul	296.0821799	363.257386	454.6140368	288.1683895	331.6806618	287.8146124	263.8956449
Predicted DP from 2-FAL (Chendong For	235.5023604	364.1347295	539.0716313	220.3484119	303.6691339	219.6709718	173.869051
Transformer Average DP	166	288	506	189	65	191	267
]

Investigation

- Investigations are still ongoing, but it is thought that oil supplied in the period late 1980's to the mid 1990's is at risk of significant degradation within its normal expected lifetime.

- It has also been proven in switchgear (OR49) that where ***clean*** (unused or recycled) oil is used to replace severely degraded oil in units affected by oil sludging, the ***clean*** oil may also suffer from an increased rate of degradation after a relatively short service life. In extreme cases the clean oil may also suffer from the effects of sludging. This is due to the catalytic effects of the oxidation products that may remain in the tank.

- An indicator of potentially affected oil is high levels of Furfural (extraction solvent) which is believed to have been from the refining process.

- SPEN are still investigation the problem, but at this moment we know that a significant number of 11kV distribution transformers and several 33kV primary transformers are affected.

Thank You

Internal Use