Evaluation of Transformer Solid Insulation

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Direct Evaluation

The mechanical properties of insulating paper can be established by direct measurement of its tensile strength or degree of polymerization (DP). These properties are used to evaluate the end of reliable life of paper insulation. It is generally suggested that DP values of 150-250 represent the lower limits for end-of-life criteria for paper insulation; for values below 150, the paper is without mechanical strength. Direct measurement of these properties is not practical for in-service transformers

Analysis of paper insulation for its DP value requires removal of a few strips of paper from suspect sites. This procedure can conveniently be carried out during transformer repairs. The results of these tests will be a deciding factor in rebuilding or scrapping a transformer.

Note: Since it is usually not practical (and often dangerous to the transformer) to obtain a paper sample from a de-energised, in-service transformer an alternative method has been found.

When a cellulose molecule de-polymerises (breaks into smaller lengths or ring structures), a chemical compound known as a furan is formed.

Furan Analysis

By measuring the quantity and types of furans present in a transformer oil sample, the paper insulation overall DP can be inferred with a high degree of confidence. The types and concentration of furans in an oil sample can also indicate abnormal stress in a transformer, whether intense, short duration overheating or prolonged, general overheating. Furan analysis can be used to confirm Dissolved Gas Analysis where carbon monoxide present indicates problems with solid insulation.

Table 1

5-Hydroxymethyl-2-furaldehyde	5H2F	Oxidation
Furfuryl alcohol	2FOL	High Moisture
2-Furaldehyde	2FAL	Overheating, old faults
2-Furyl methyl ketone	2ACF	Rare, lighting
5-Methyl-2-furaldehyde	5M2F	Local, severe overheating

It has been shown that the amount of 2-furaldehyde in oil (usually the most prominent component of paper decomposition) is directly related to the DP of the paper inside the transformer.

Paper in a transformer does not age uniformly and variations are expected with temperature, moisture distribution, oxygen levels and other operating conditions. The levels of 2-furaldehyde in oil relate to the average deterioration of the insulating paper. Consequently, the extent of paper deterioration resulting from a "hot spot" will be greater than indicated by levels of 2-furaldehyde in the oil.

For typical power transformer, with an oil to paper ratio of 20:1, the 2-furaldehyde levels have the following significance:

Table 2

Furan Content (ppm)	**DP Value**	**Significance**
0-0.1	1200-700	Healthy transformer
0.1-1.0	700-450	Moderate deterioration
1-10	450-250	Extensive deterioration
>10	<250	End of life criteria

Other Diagnostic Compounds

The presence of phenols and cresols in concentrations greater than 1 ppm indicate that solid components containing phenolic resin (laminates, spacers, etc.) are involved in overheating.

INTERPRETATION

The “predicted” DP (degree of polymerisation) indicates an average paper condition over the whole transformer (subject to factors such as effective circulation). New Kraft paper has a DP in excess of 1200, and paper with a DP of 200 or less is considered to be unfit (subject to interpretation). (See Table 4)

The values can be optimistic if the oil has been regenerated within the last two years. This data should be evaluated in conjunction with routine chemical analysis and transformer history.

CASE STUDY: INSULATION FAILURE.

OVERIEW: The transformer failed in service while undergoing Power-On purification to remove moisture from the insulating oil.

TRANSFORMER DETAILS

Primary Voltage:	11 kV	Secondary Voltage:	500V	VA Rating:	500 KVA
Vector Group:	Dyn11	Impedence:	4.1%	Tap Changer:	Off Load
Make:	CAWSE & MALCOLM	Year Manufactured:	?	Conservator:	No
Breather Size:	CHG2	Oil Volume Litres:	600		

Transformer Oil Analysis-Diagnosis

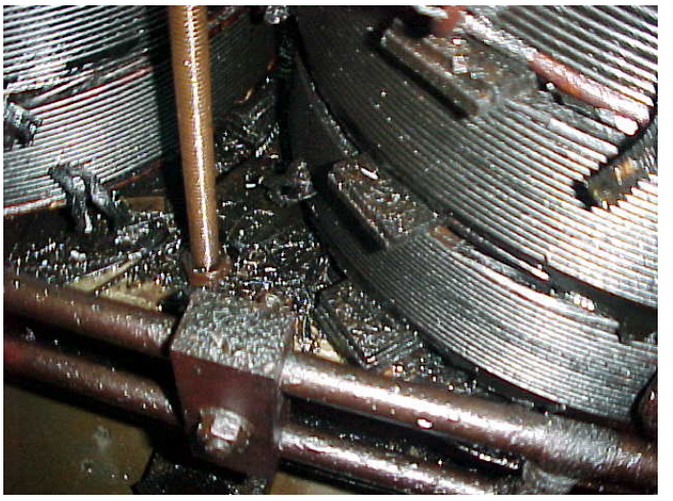
The Dissolved Gas analysis indicated a Partial discharge of low energy density (IEC 599) with the C02/C0 Ratio of 16. 5 indicating insulation paper degradation. (>3 and <11) Normal Ratio.

The Furan analysis of 8.97 ppm indicated Extensive paper deterioration. The maintenance history of the transformer revealed that oil replacement and purification took place on 12-03-2000. The Furan production rate was 160 ppb (parts per billion) per month (ppb/month). The Morgan Schafer Company reports that a furan production rate of 25 ppb/month is cause for concern.

The transformer oil analysis indicated a case of advanced paper insulation deterioration. (See Table 3)

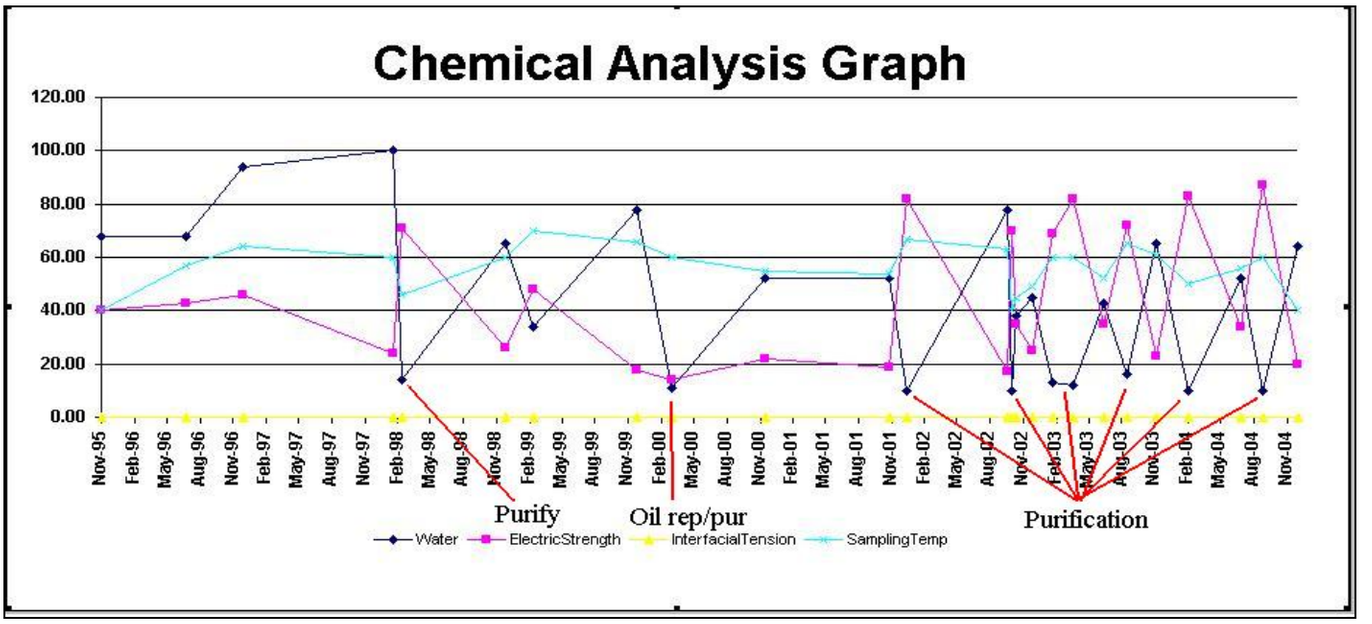
Findings

The transformer was removed to a works facility and inspected. The paper insulation clearly was at End of life criteria.



Review of Maintenance History.

The transformer had undergone oil purification on ten occasions since 1995 in an attempt to remove moisture and improve the dielectric. With oil replacement on 12-03-2000. The oil purification had no effect in improving the oil condition



Spreadsheet of Transformer oil analysis and Maintenance History

SampleDate	H_2	0_2	N_2	CH_4	CO	CO_2	C_2H_4	C_2H_6	C_2H_2	%Gas	H_20	kV	Acidity	Temp	Furan	SampleType
13-Dec-2004	434	2340	64873	16	355	5863	15	0	0	8.63	64	20	0.10	40	8.97	
7-Sep-2004	0	0	0	0	0	0	0	0	0	0	10	87	0.09	60		Purification
9-Jul-2004	167	2500	55983	15	324	6322	0	0	0	8.01	52	34	0.09	56		
15-Feb-2004	0	0	0	0	0	0	0	0	0	0	10	83	0.09	50		Purification
19-Nov-2003	40	8547	70970	9	351	4259	17	19	0	8.38	65	23	0.09	61		
28-Aug-2003	0	0	0	0	0	0	0	0	0	0	16	72	0.07	65		Purification
23-Jun-2003	21	19370	65345	5	114	2116	0	0	0	8.53	43	35	0.07	52		
31-Mar-2003	0	0	0	0	0	0	0	0	0	0	12	82	0.08	60		Purification
3-Feb-2003	0	0	0	0	0	0	0	0	0	0	13	69	0.08	60		Purification
9-Dec-2002	120	21162	73130	7	124	2601	0	10	0	8.63	45	25	0.08	49		
23-Oct-2002	23	20525	56656	0	55	1189	0	0	0	8.01	38	35	0.09	45		
11-Oct-2002	24	5878	46760	1	63	4297	0	0	0	6.22	10	70	0.09	40		Purification
2-Oct-2002	45	9531	61661	11	237	4833	15	17	0	8.74	78	17	0.08	63		Suspect Fault
27-Dec-2001	0	0	0	0	0	0	0	0	0	0	10	82	0.07	67		Purification
6-Nov-2001	102	11165	53340	10	236	3729	11	11	0	7.03	52	19	0.07	54		
28-Nov-2000	0	24042	59971	9	207	2281	19	0	0	8.58	52	22	0.05	55		
12-Mar-2000	0	0	0	0	0	0	0	0	0	0	11	14	0.05	60		Oil rep/pur
9-Dec-1999	53	13284	59226	7	159	3754	18	19	0	8.8	78	18	0.05	66		
23-Feb-1999	0	0	0	0	0	0	0	0	0	0	34	48	0.18	70		Purification
8-Dec-1998	50	8079	69484	5	429	4872	10	0	0	8.49	65	26	0.18	60		
26-Feb-1998	0	0	0	0	0	0	0	0	0	0	14	71	0.17	46		Purification
30-Jan-1998	19	18445	68637	7	359	6250	9	0	0	10.97	100	24	0.17	60		
9-Dec-1996	58	15222	72938	17	425	9269	18	15	0	9.71	94	46	0.15	64		
4-Jul-1996	19	19031	67861	10	244	6588	5	0	0	9.5	68	43	0.13	57		
14-Nov-1995	16	4377	44646	6	351	6777	8	2	0	5.99	68	40	0.13	40		

Economic Consideration.

Accessing the state of the paper insulation is vitally important when considering a maintenance plan for a transformer. In this case a more cost effective maintenance plan would be to remove the transformer to a works facility for Refurbishment.

The assumed average maintenance cost for this transformer was R 25 000 since 1995 with no benefits i.e. there had been no improvement in fluid insulation condition with a deterioration in solid (paper) condition. The end result being in service failure amounting to significant losses.

Case Study: Predicated Insulation Failure

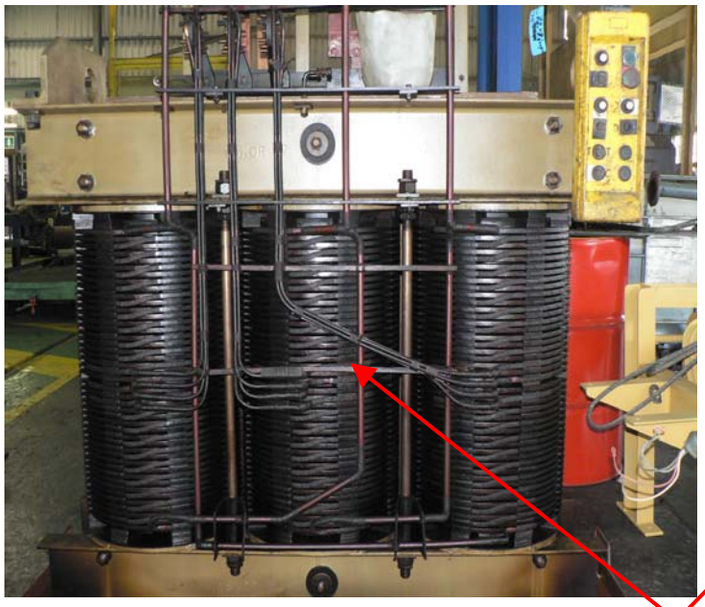
Substation:	POWER STATION NO.2	Transformer No:	TE 43	Serial No:	5292
Sample Point:	MAIN TANK	Sample Date:	14/01/2006	Analyses Date:	24/01/2006
Primary Voltage:	6.6 kV	Secondary Voltage:	550 V	VA Rating:	1500 KVA
Vector Group:	Dyn11	Impedance:	5.41%	Tap Changer:	On Load
Make:	JOHNSON & PHILLIPS	Year Manufactured:	1965	Conservator:	Yes
Breather Size:	None	Oil Volume Liters:	1967	Report Number:	MONDI-105651

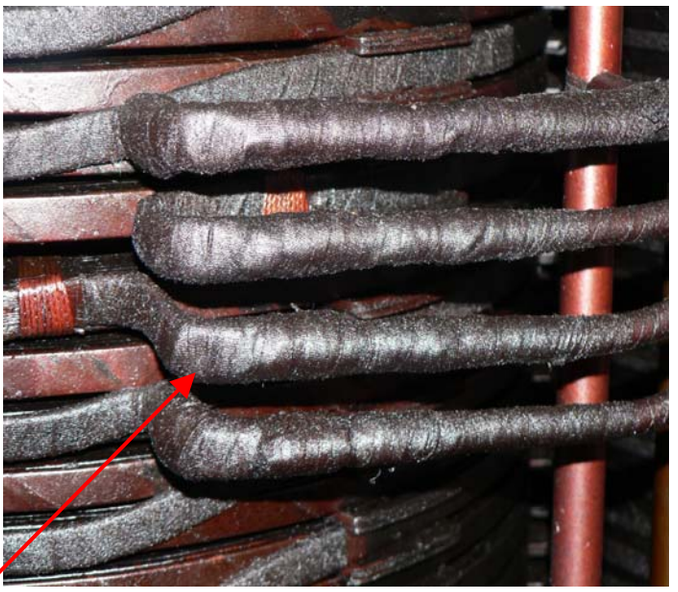
TRANSFORMER INSULATING PAPER CONDITION

Furan ppm (mg/L)	9.90	>10 End of life criteria
Predicted Degree of polymersation	218	< 250 End of life criteria
Water in paper: % Dry Weight	3.08	2.0 (max)
Water in paper: Total Litres	7.87	

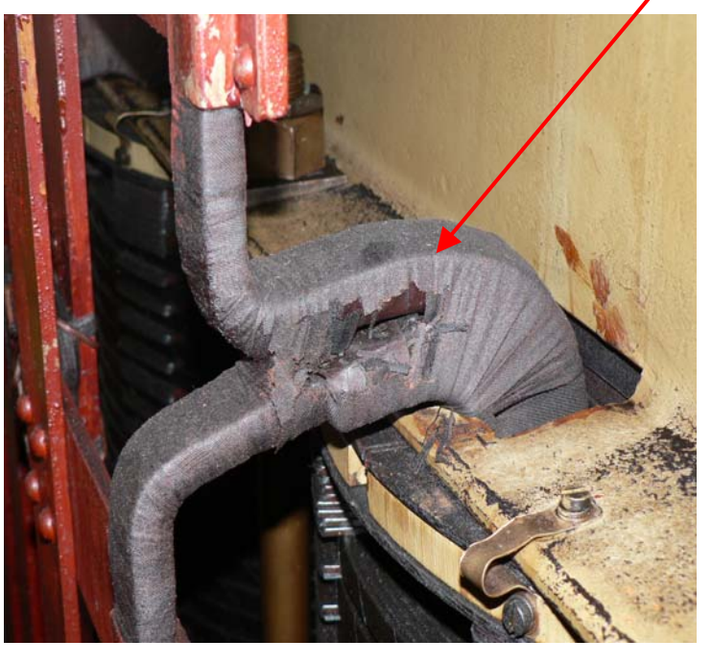
Paper insulation: Extensive deterioration-Serious production rate-316 ppb/month (see Furan). > 25 ppb/month(cause for concern)

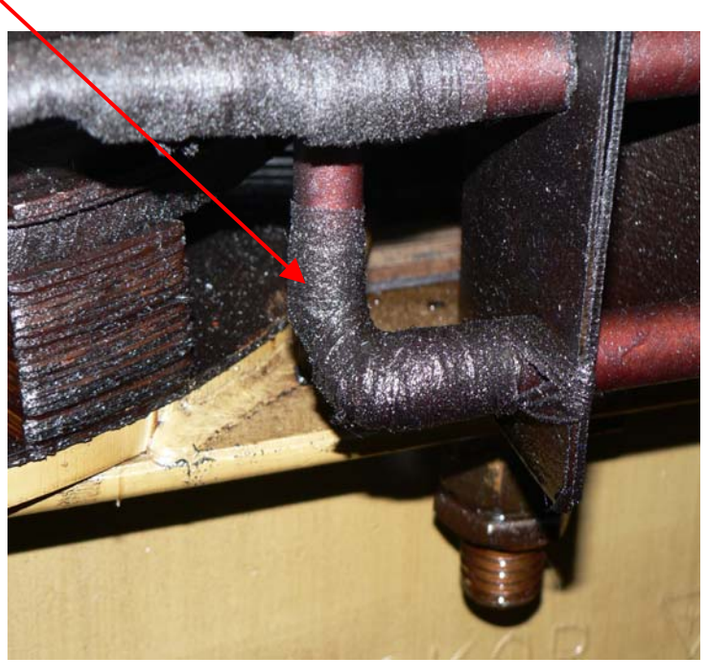
RECOMMENDED: Remove from service for Inspection/Repairs to paper insulation.





FINDINGS: Extensive solid (paper) insulation deterioration



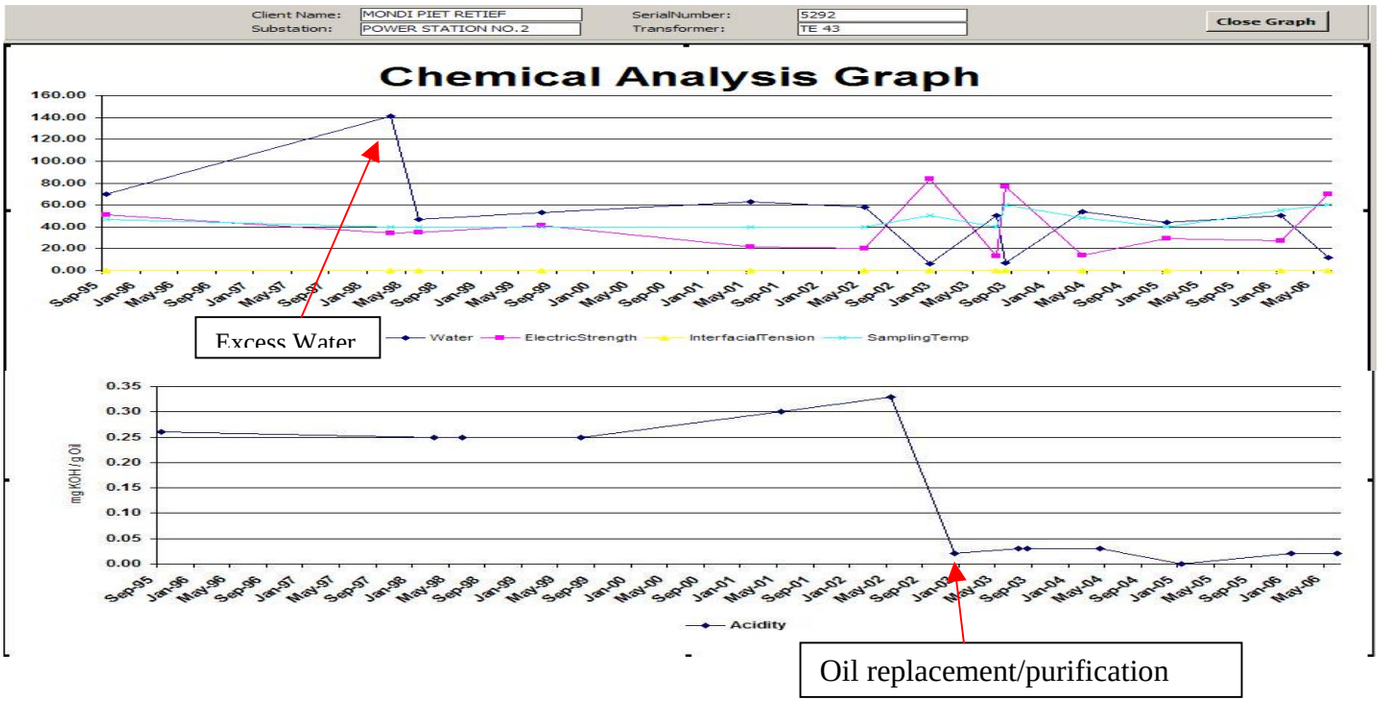


CONCLUSION:

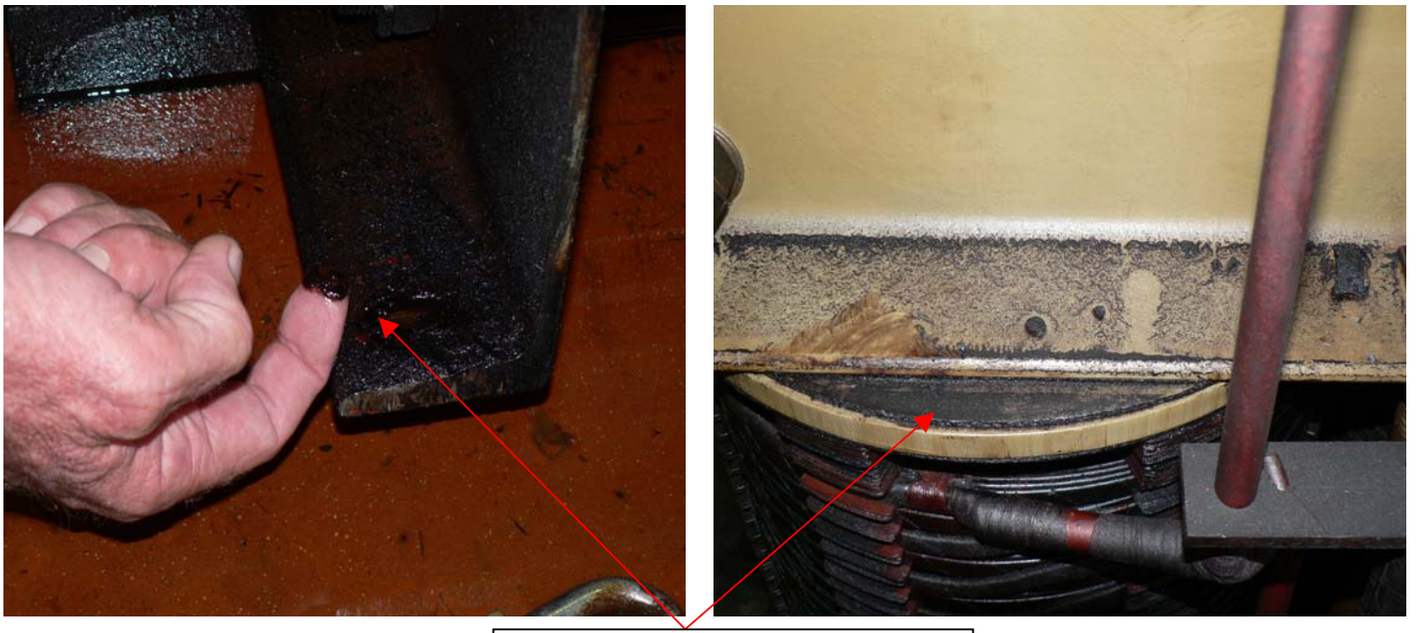
The transformer was rewound/remanufactured at a works facility and then returned to service under planned conditions avoiding costly in service failure.

Cause of Insulation paper deterioration.

To understand the cause the maintenance history of this unit was reviewed. The graph trends show typical high moisture in oil and acid contents, which cause the paper insulation deterioration. (See table 3)



The oil replacement/purification at January 2003 was not done with any internal flushing with sludge remaining in this unit.



Conclusion.

The use of furan in oil analysis has a significant cost benefit in planning a maintenance program. This data needs to viewed in conjunction with Dissolved Gas Analysis, fluid insulation tests and the maintenance history.

When the transformer reaches the end of its reliable, cost effective life, the solid insulation is longer strong enough to continue to keep it in service. One of the things that can be done with the transformer as it is taken out of service is to rewind or remanufacture it. This involves reusing the core steel, the case, and other structural components while rewinding with new insulation wrapped conductor and new solid insulation

A furan test should be included with yearly maintenance and trends developed to monitor the condition of the paper.

TABLE 3

The progression towards insulation failure.

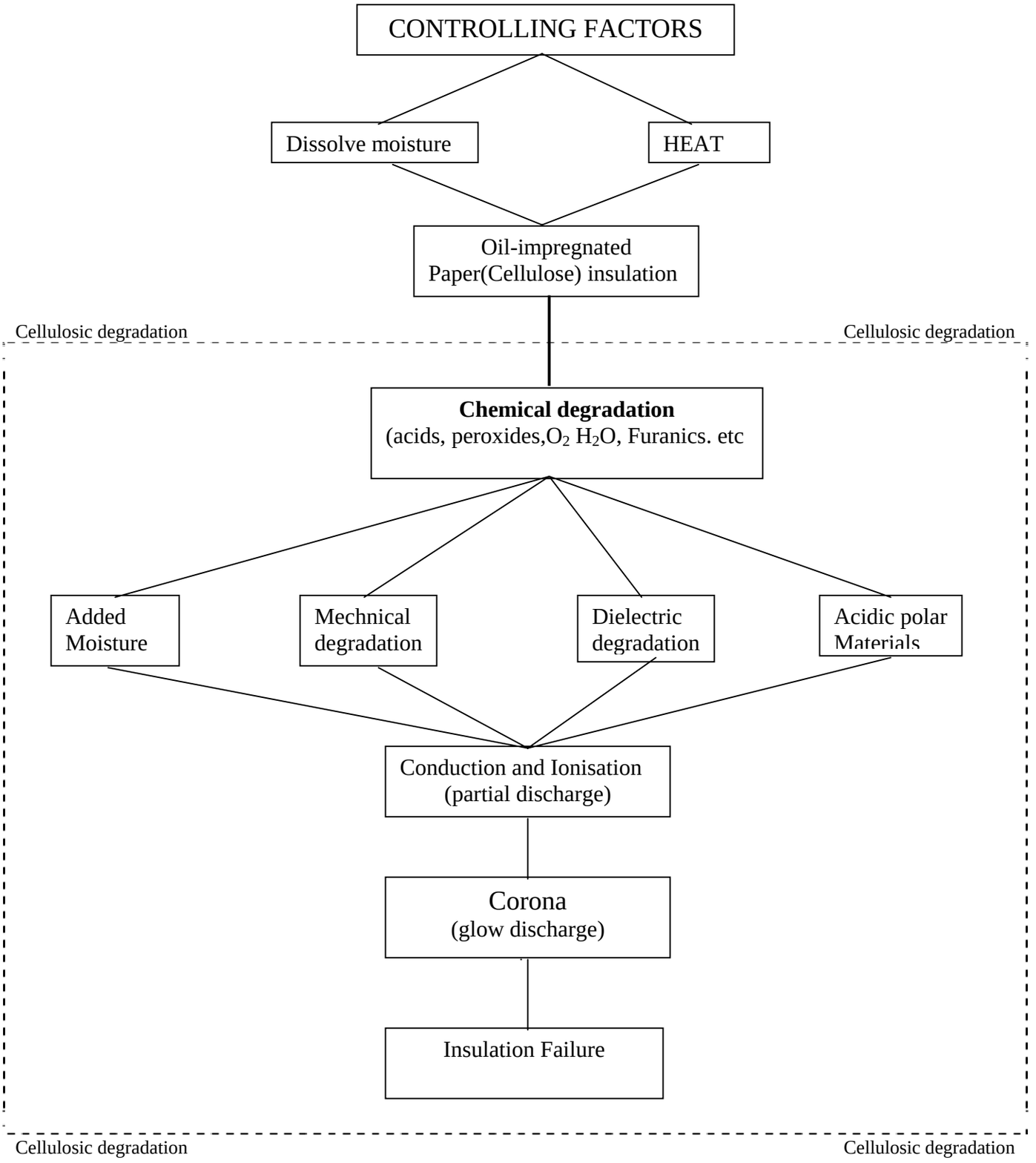


Table 4

DP Range	Remark
<200	Test indicates extensive paper degradation exceeding the critical point. Strongly recommend that the transformer be taken out of service immediately and visually inspected.
200-250	The paper is near or at the critical condition. Recommend that the transformer be taken out of service as soon as possible and thoroughly inspected. Paper samples can be taken for direct DP testing.
260-350	The paper is approaching the critical condition. Suggest inspection be scheduled and/or re-sample within 1 year to reassess condition.
360-450	The paper is starting to approach the critical condition. Suggest a re-sample in 1-2 years time.
460-600	Significant paper deterioration but still well away from the critical point.
610-900	Mild to minimal paper ageing.
>900	No detectable paper degradation