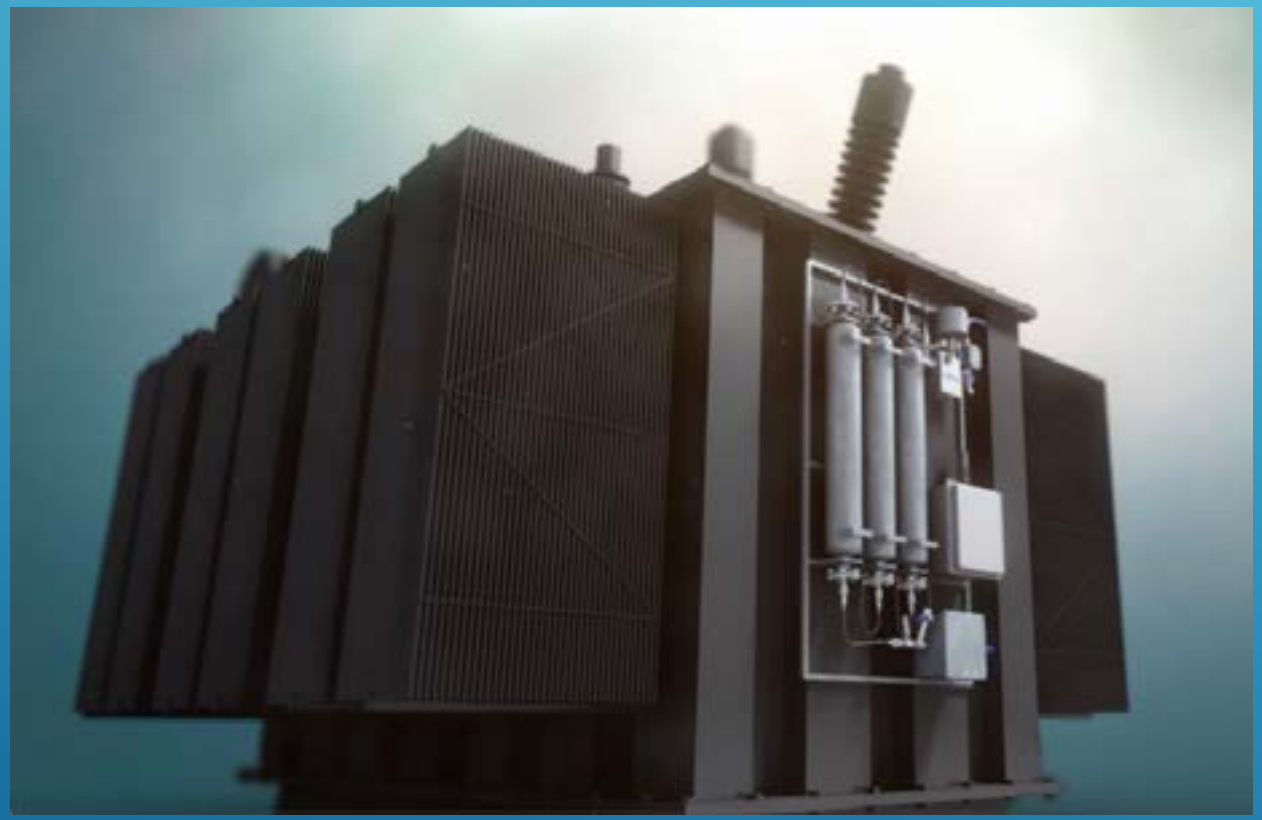
DryKeep® Transformer Moisture Management System



Critical Asset Management and Life Extension, Condition-Based Monitoring, and Real-Time Data Analytics
Manufactured by Ardry Trading Company in the USA.

ARDRY TRADING COMPANY

ESTABLISHED 1940

WWW.ARDRY.COM

WWW.DRYKEEP.COM

WWW.CABLEMATEPOWER.COM

- **Complete source for all substation, transmission and distribution equipment for underground and overhead systems, OEM transformer and switchgear components, tools, fault indicators, wire & cable, power transformer life extension, measurement & recording instruments, and C&I products.**

- **Serve the utility, industrial, commercial, contractor, government, NGO, military and OEM component markets throughout the world for over 75 years.**

- **Experienced electrical sales engineers that know the products they represent as well as the markets they serve.**

- **A marketing, engineering, specifying, logistics, stocking distributor and manufacturer.**

Power Transformers: Most Critical Asset

Power transformers are one of the most critical assets in the electric grid.

Life expectancy of 25-40 years. Can last longer with proper maintenance.

High cost of transformer failure and/or replacement.

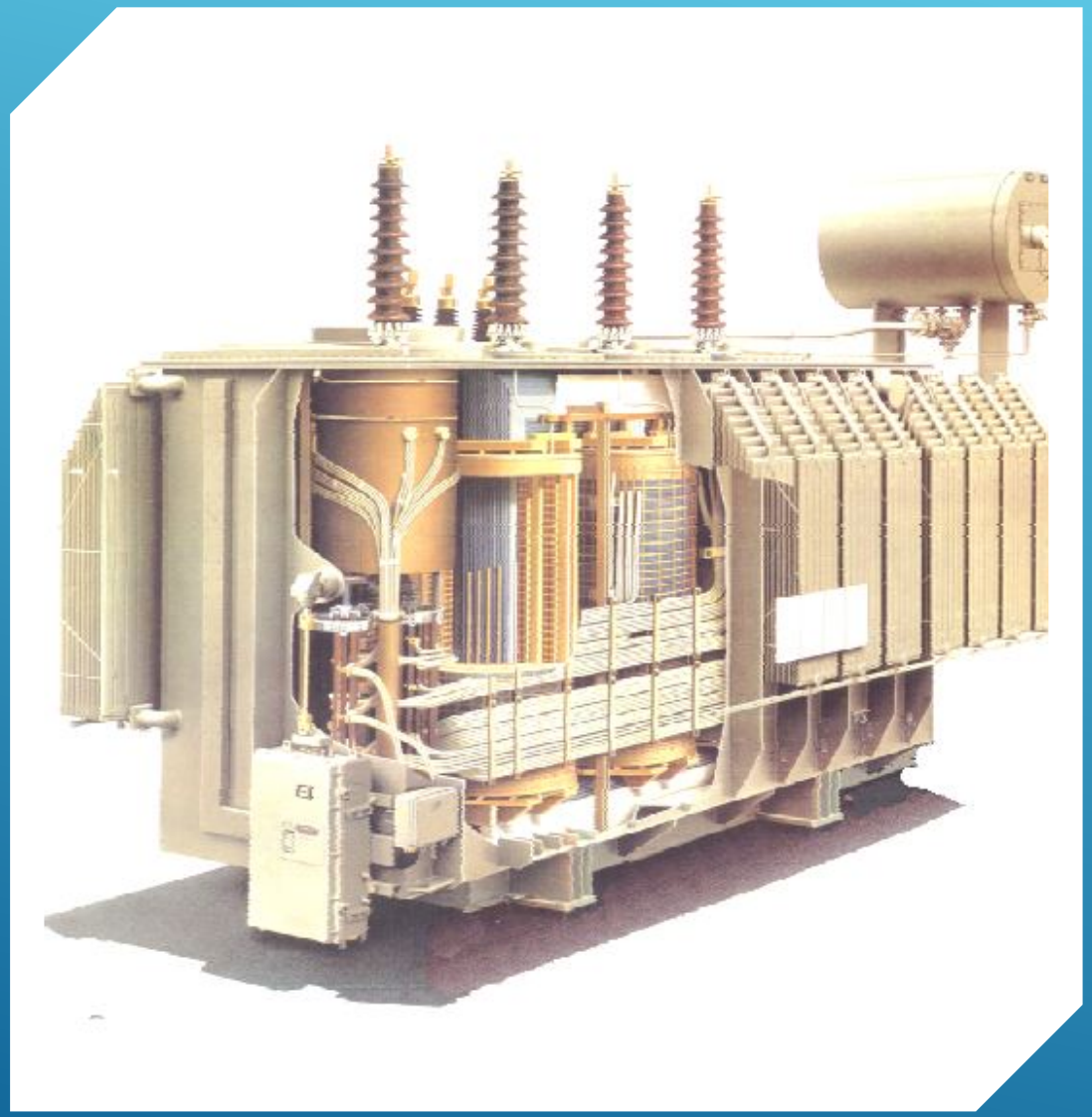
Utilities are faced with reducing capital and maintenance expenditures.

Extension of the power transformer life a key strategy in cost reduction.

Reactive asset management is inefficient and costly.

Too much focus on the oil and not the cellulose insulation!

THE PROBLEM



- A transformer consists mainly of copper, grain-oriented electrical steels (GOES), paper, wood and insulating oil.
- The copper and steel are not a problem. Will last a long time.
- While the oil ages more rapidly, it can be changed and treated.
- Temperature, oxygen and moisture cause the cellulose insulation to degrade and age.
- While temperature and oxygen are typically monitored and addressed, moisture in the cellulose insulation tends to be left unabated making it the single-greatest reason the cellulose inside a transformer ages, degrades and eventually causes the transformer to fail.
- It is unfortunate that the cellulose insulation cannot be renewed without major cost to the owner. Cellulose insulation preservation through proper dehydration needs to be addressed!

Sources of Water Contamination

1. Residual moisture after initial factory dry-out in cellulose (0.3 – 1.0%).

2. Ingress from atmosphere:
   a) Absorption of water from direct exposure of the insulation to the air (installation and repair works),

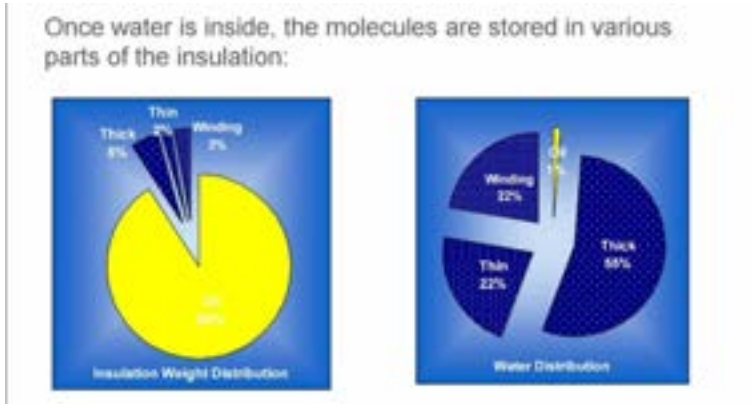
   b) Ingress of moisture in the form of molecular flow due to difference in the water concentration in the atmosphere and in the oil in the tank (minimal),

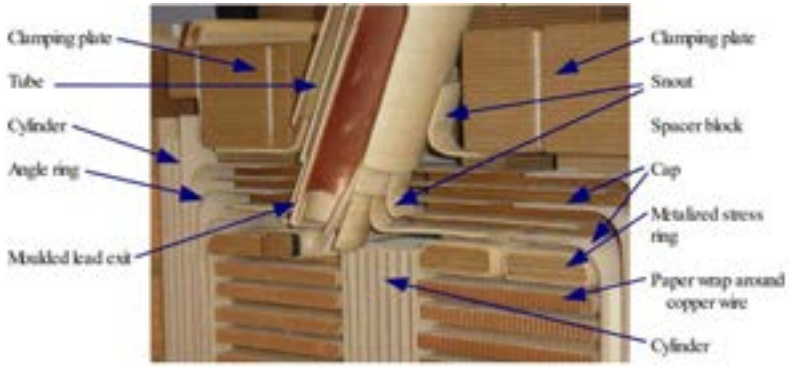
   c) Viscous flow of wet air into the transformer caused by the difference between the atmospheric pressure and the pressure in the tank (bad seals, leaks).

3. Aging decomposition of cellulose.

4. Aging decomposition of oil.

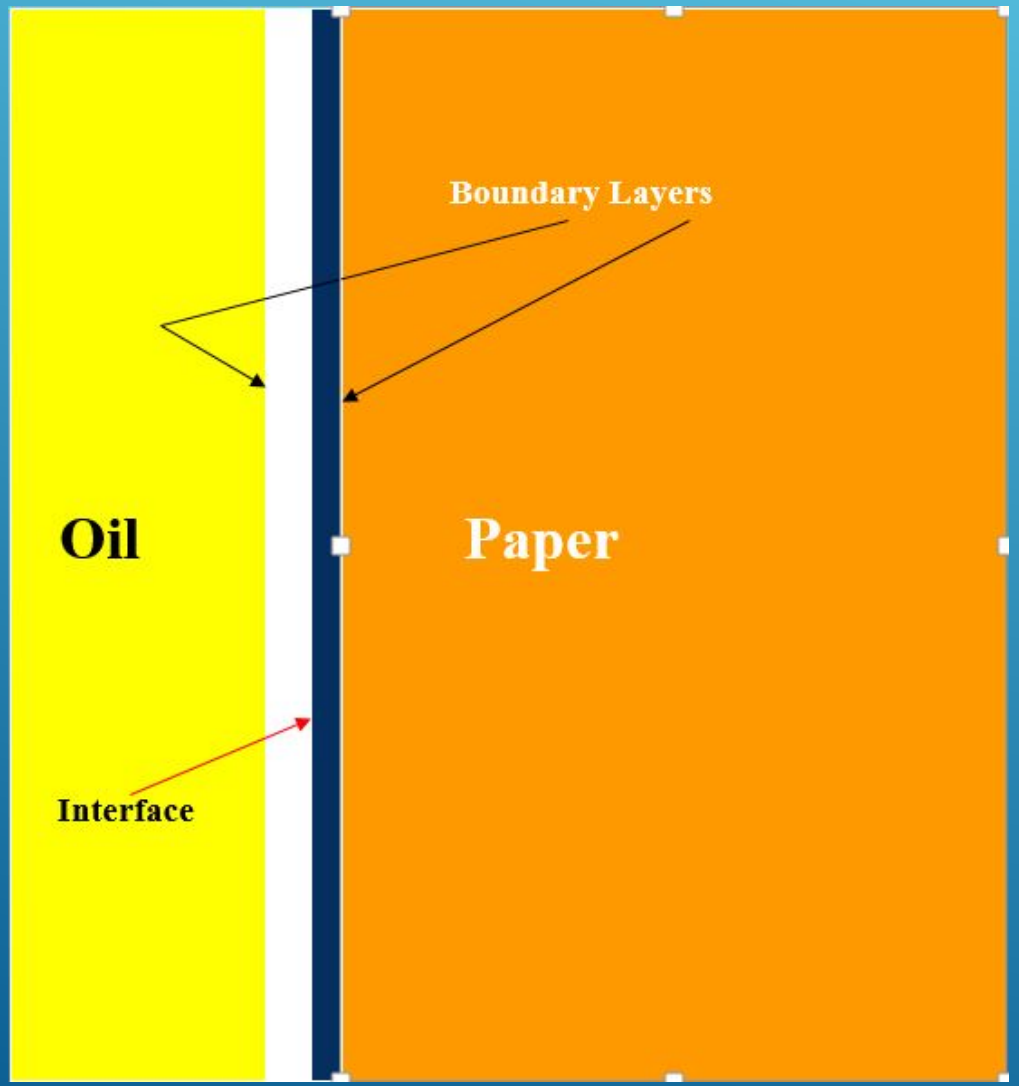
MOISTURE IN TRANSFORMERS





- Chemically-bound water: Paper glucose molecule that gives paper mechanical strength. Must remain. Must prevent over-drying.
- Free Water: Collects at bottom of tank. Continuous moisture removal prevents this.
- Suspended Water: Trapped in the oil decay byproducts.
- Dissolved Water: Moisture dissolved in oil and bound in the paper insulation. Presence reduces dielectric strength of paper and oil and accelerates aging of the paper which reduces mechanical strength. Only by removing this moisture continuously can we protect and extend the life of the transformer.

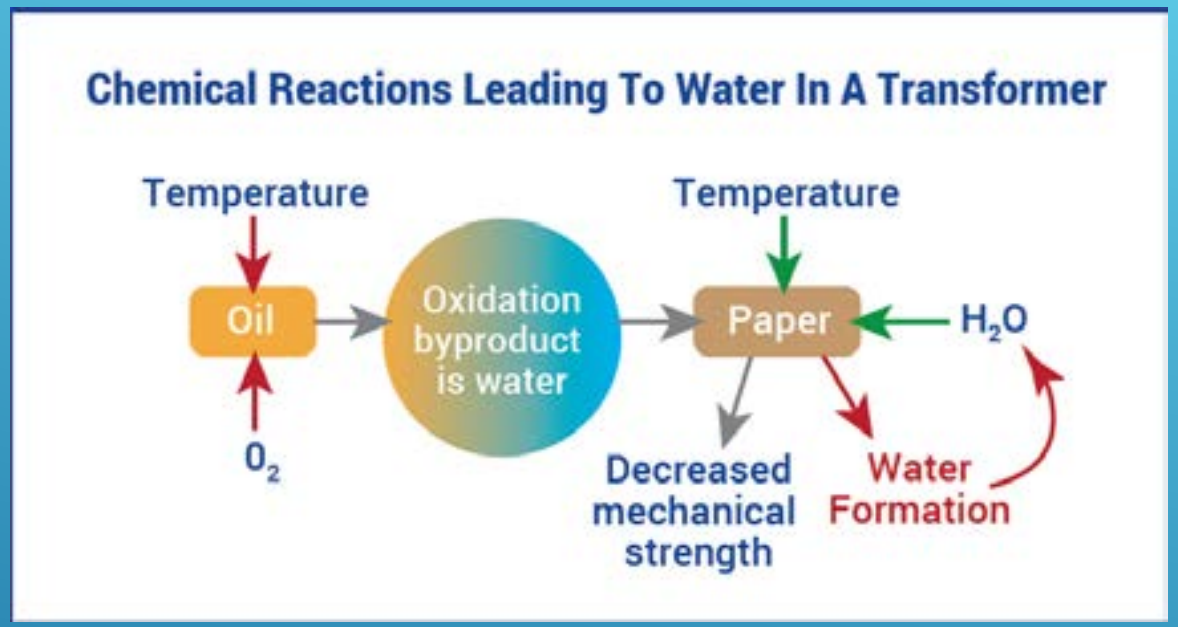
The Transfer Effect



During normal operation, any increase in operating temperature above 35 degrees C, will drive moisture out of the paper. This free moisture will either dissolve in the oil if the oil is dry enough, or it will “rain” down, in an energized field, between the interface of the oil and paper.

Similarly, with any decrease in temperature, the moisture will tend to migrate back into the paper but does so at a much slower rate than when it came out of the paper. Free water is the result.

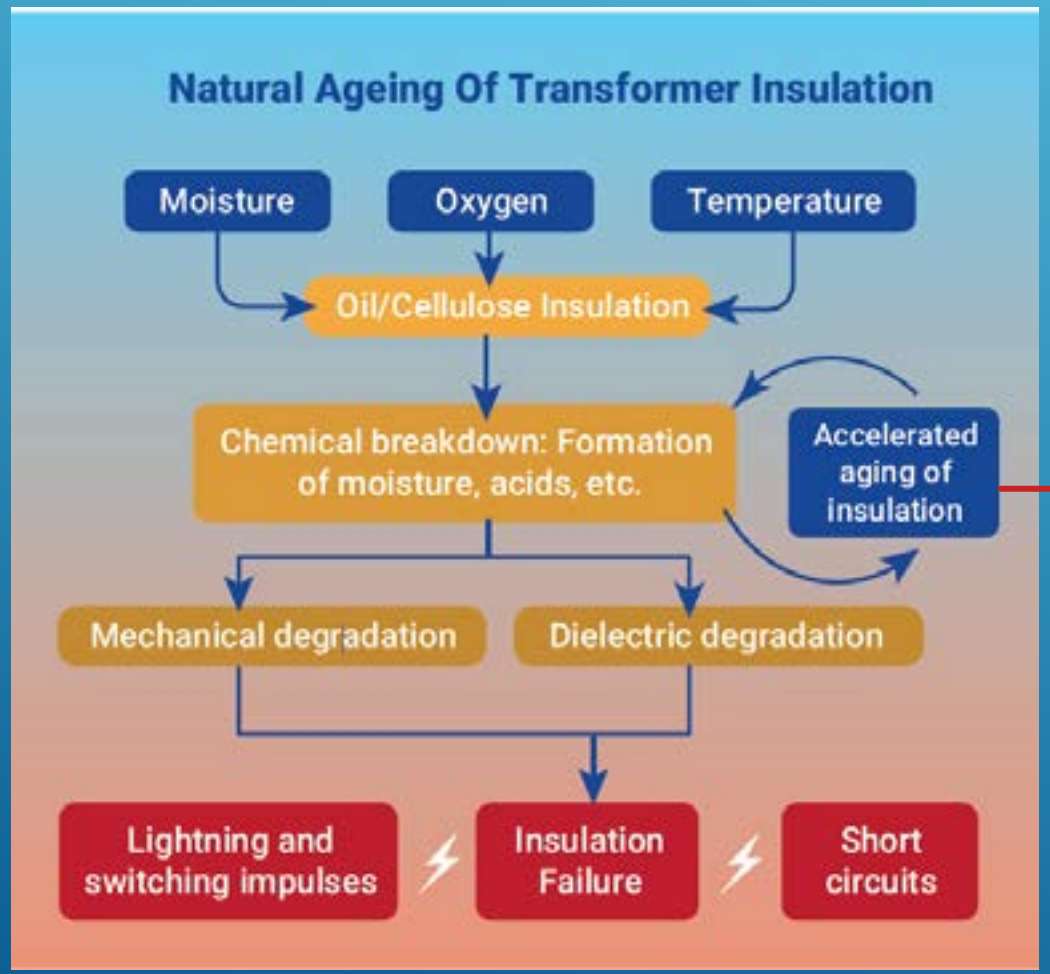
Chemical Decomposition of Paper and Oil



The eventual breakdown of the base oil molecules due to the oxidative processes is inevitable. H_2O is formed.

Paper has an affinity for moisture much greater than oil. Moisture replaces the oil in the paper. The presence of moisture in paper promotes acid-hydrolysis by causing carboxylic acids to dissociate, ageing the paper more rapidly then if moisture was abated and more moisture is formed. Ageing becomes auto-acceleratory.

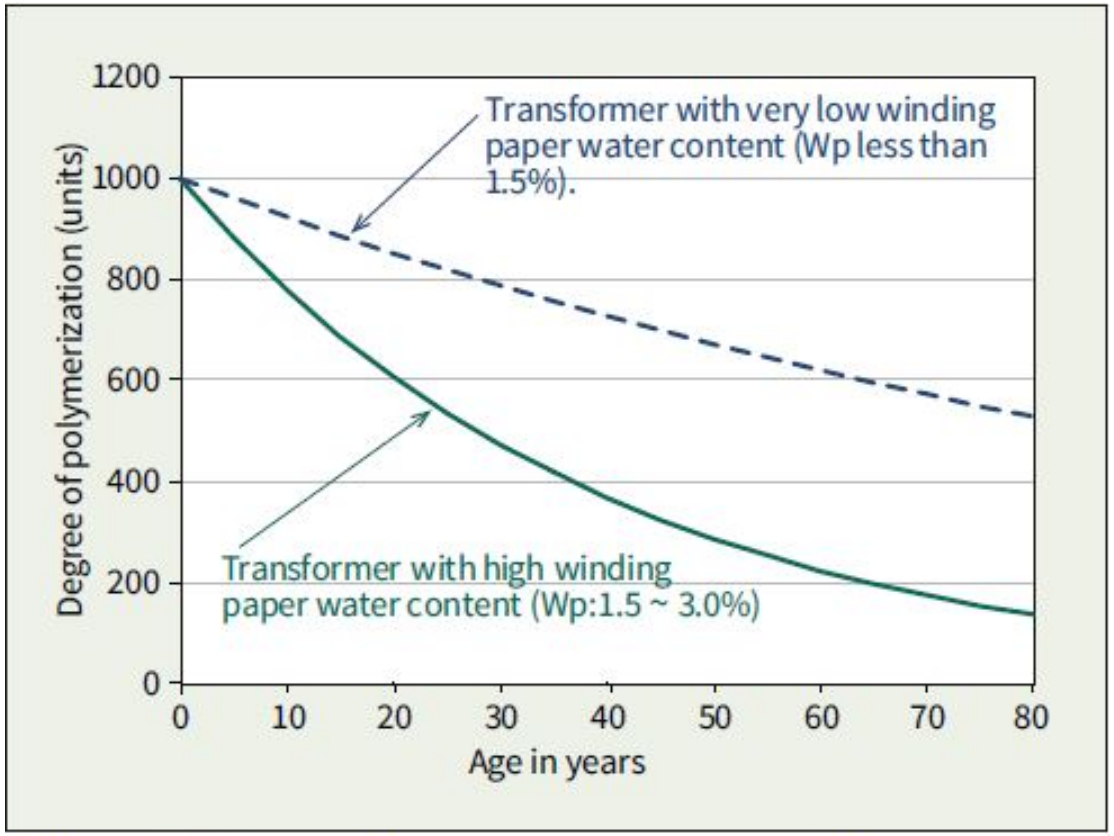
Why Moisture is Bad for Transformers



Presence of moisture in a transformer leads to:

- Chemical decomposition of paper and oil.
- Deterioration of dielectric properties of paper and oil.
- Irreversible deterioration of mechanical properties of paper.
- **The problem is auto-acceleratory**

MOISTURE VS PAPER AGING

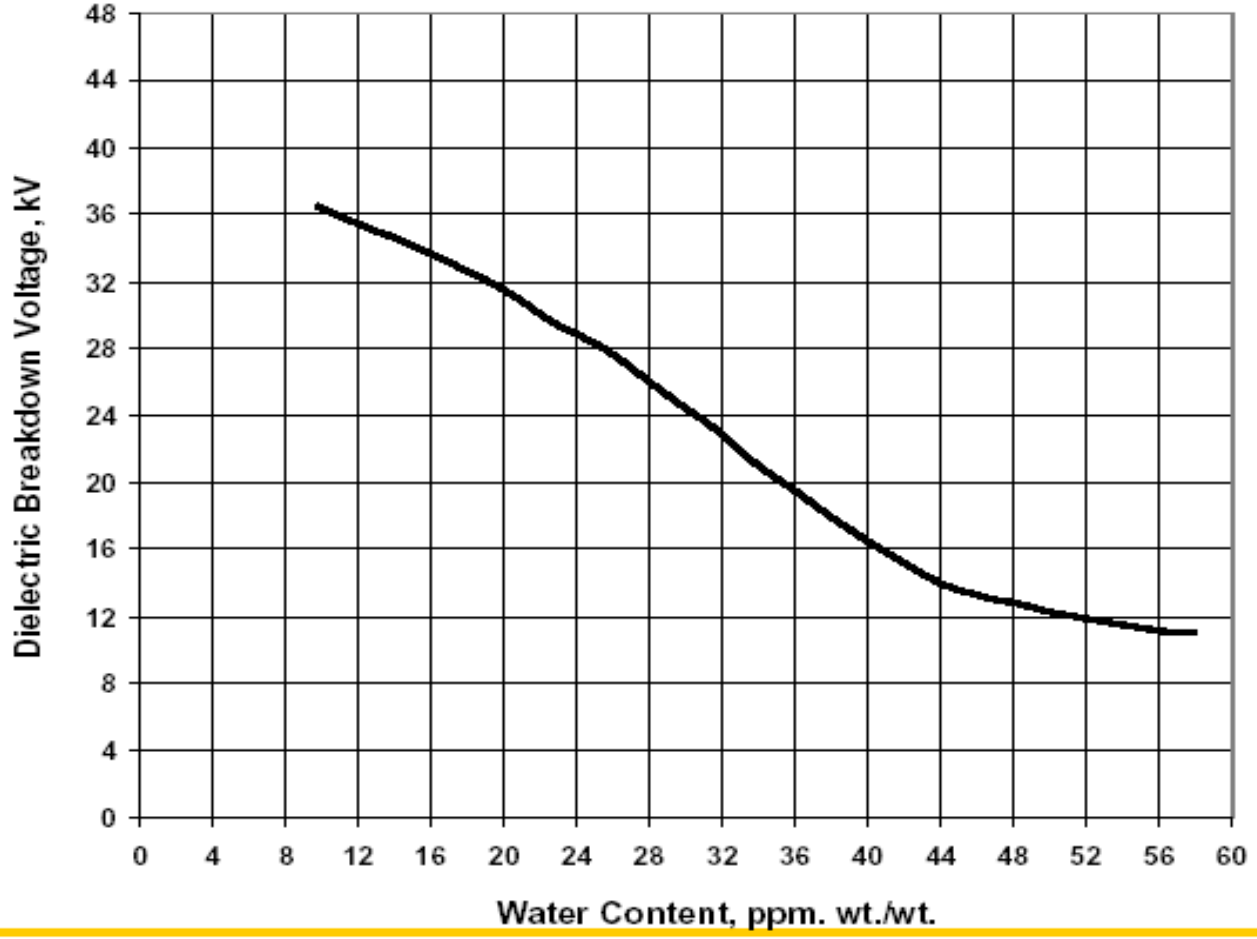


Relationship between elapsed years and degree of polymerization.

- At low moisture, aging is slow and potential life is long.
- As moisture level rises above 1.5%, the rate of decay begins to seriously accelerate.
- Paper with 3.5% moisture degrades 20 times faster than at 0.5%…insulation viable for only a short period of time.

Moisture-Induced Dielectric Breakdown: Chain of Events

Dielectric Strength & Water Content



Deterioration of Mechanical Properties of Paper

As the paper ages, tensile strength decreases.

Temperature and moisture are the two main causes

“Degree of Polymerization” quantities degradation.

Calculated using the Carothers Equation. Wallace Carothers invented Nylon.

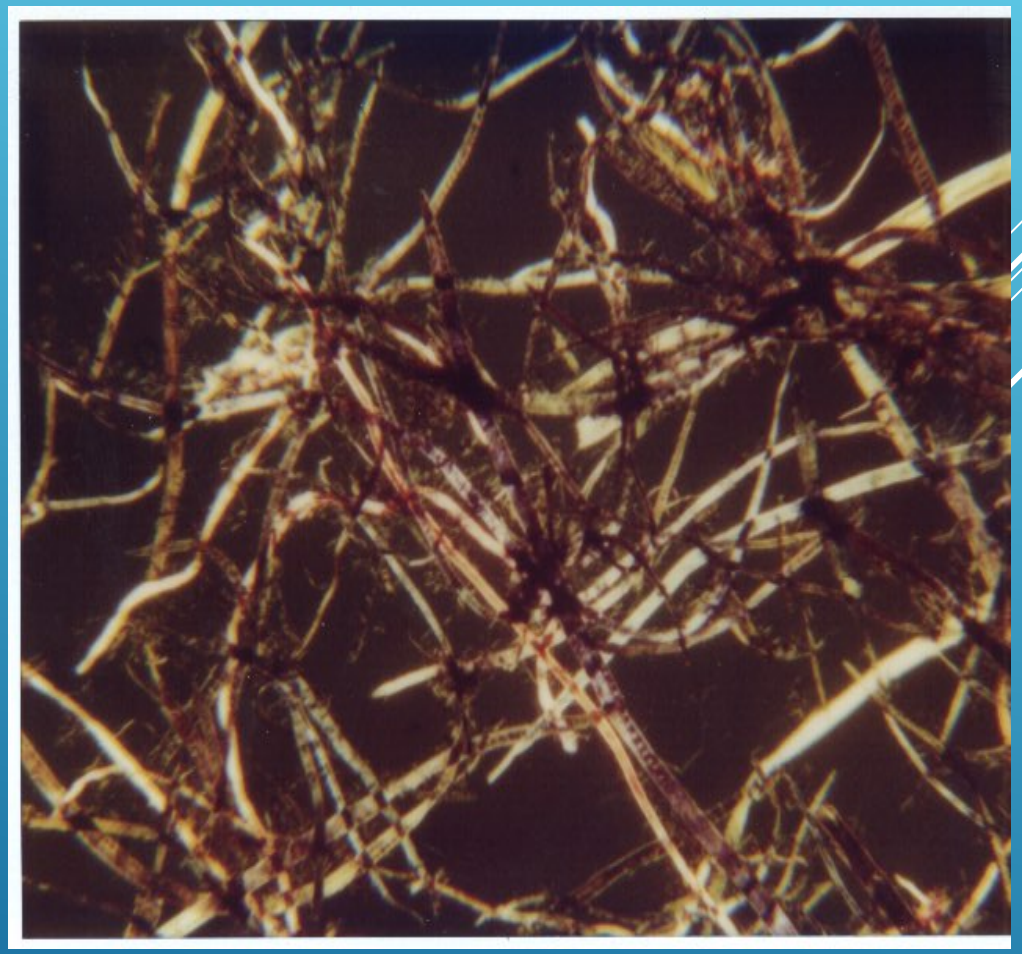
DP is a measure of the fiber bonding strength and is the average length of the cellulose chains, in glucose units, that make up the paper insulation.

Aging of the paper is a chemical reaction.

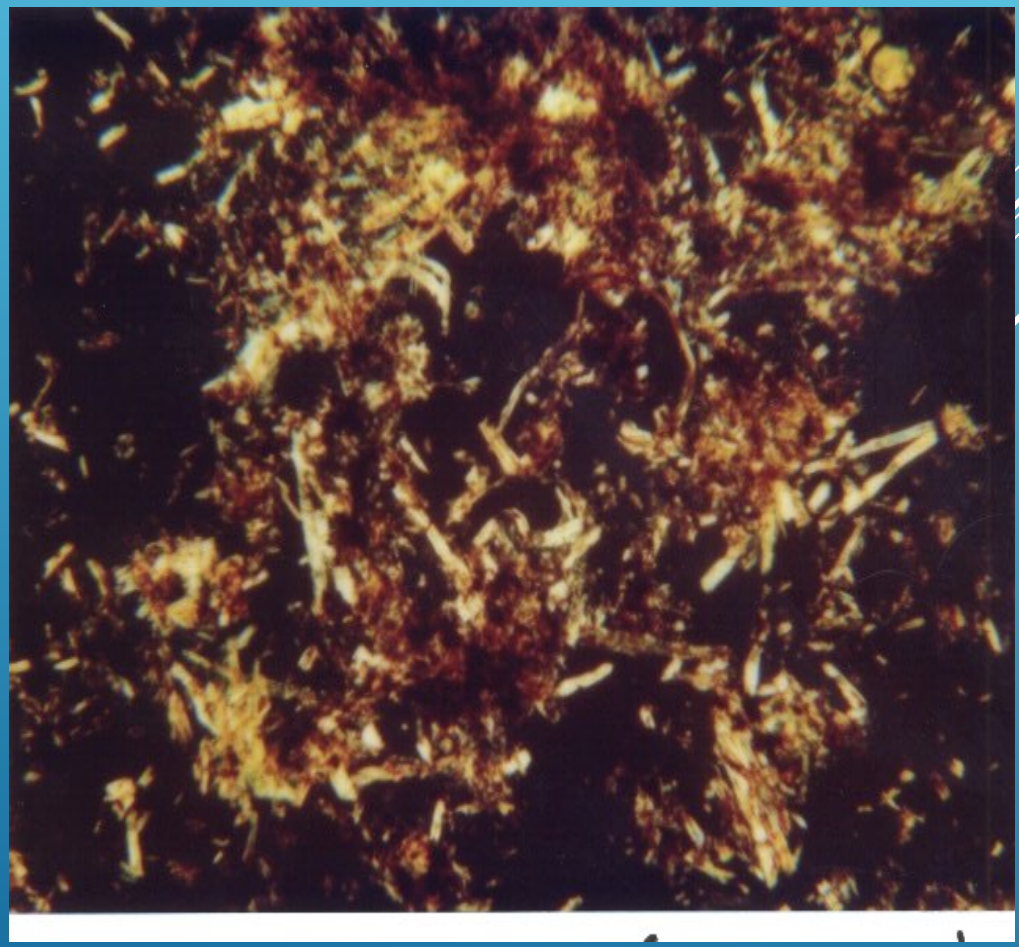
Shortens the molecules of the paper fibers and reduces molecular bonding causing paper to lose mechanical properties/strength.

New

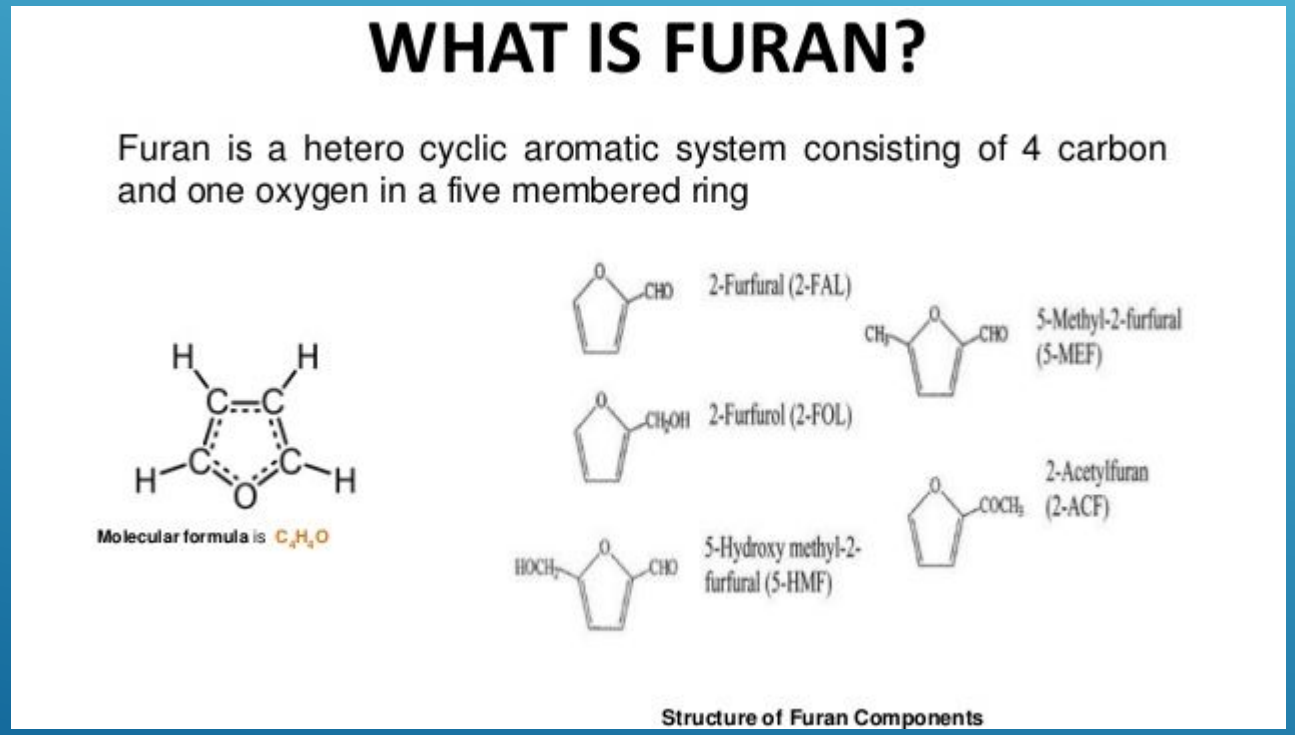
LOW OXYGEN & MOISTURE CONTENT



Aged



Furan Analysis to Estimate DP



- When cellulose degrades, the bonds that hold the glucose molecules together break apart, releasing glucose into the oil. Glucose is an unstable molecule so it is quickly converted into furan. Furan is a stable molecule, soluble in oil, and only produced in a transformer by the degradation of cellulose, so it is an ideal substance to measure in order to gain information about the condition of the paper insulation.
- Taking a sample for Furan Analysis is a non-invasive procedure that requires a relatively small amount of oil and is easy to test using routinely gathered oil samples.

Furan Analysis ⇒ Degree of Polymerization

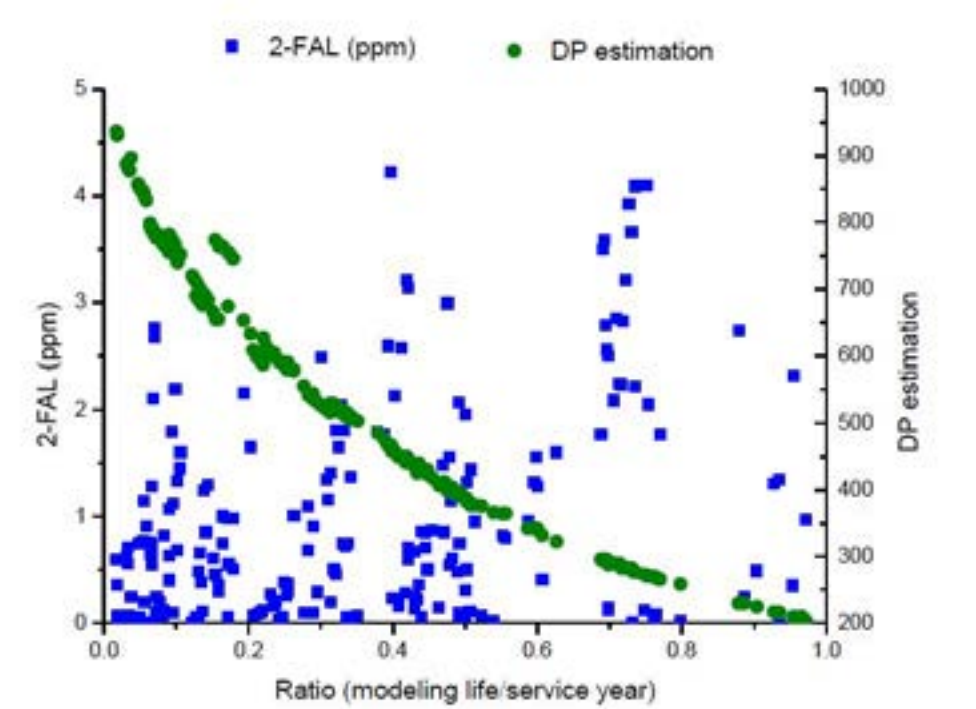
- To run a Furan Analysis, the oil is analyzed with high-pressure liquid chromatography and the concentrations of the five main derivatives of furan are measured:
    1) 2-Furfural (2-FAL)
    2) 2-Furfurol (2-FOL)
    3) 2-Acetylfuran (2-ACF)
    4) 5-Methyl-2-furfural (5-MEF)
    5) 5-Hydroxy methyl-2-furfural (5-HMF)
- The concentrations are reported as an estimated Degree of Polymerization. Correlation studies indicate that the DP value resulting from tests on paper samples is very close to the estimated DP from furan analysis.

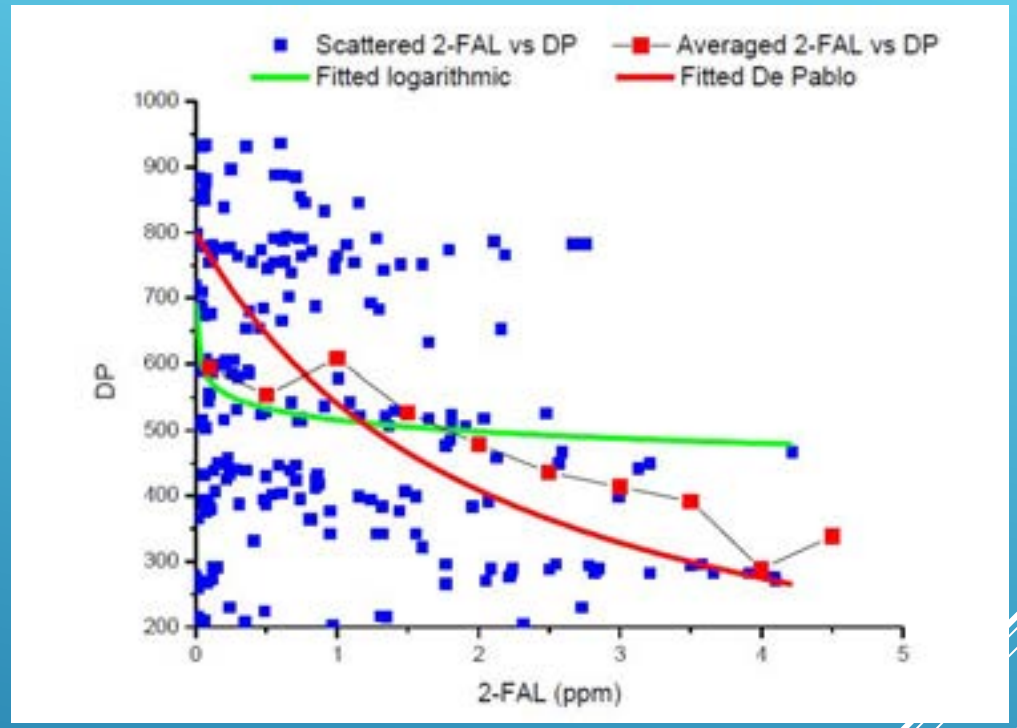
Lab Accelerated Ageing to Correlate Furan Analysis with Degree of Polymerization

Proposer	Ageing conditions†	Derived 2FAL-DP correlation		2FAL prediction (ppm) at:		
				DP_{800}	DP_{400}	DP_{200}
Chendong [152]	24/1, 140 and 148°C, Dried oil/paper, up to 40 days	$\log(2FAL) = 1.51 - 0.0035 \times DP$	(2-33)	0.05	1.29	6.46
De Pablo et al. (collaboration work lead by CIGRE TF 15.01.03) [136, 147]	100/1, 120°C, 2%W, air, 56 days	$\log(2FAL) = 3.41 - 0.00264 \times DP$	(2-34)	0.2	2.25	7.62
	100/1, 150°C, 0.5%W, N_2, 30 days	$\log(2FAL) = 3.57 - 0.00355 \times DP$	(2-35)	0.05	1.41	7.24
	100/1, 120°C, 0.5%W, N_2, 56 days	$\log(2FAL) = 1.82 - 0.00166 \times DP$	(2-36)	0.03	0.14	0.3
	100/1, 120°C, 0.5%W, N_2/air, 56 days	$\log(2FAL) = 3.61 - 0.00356 \times DP$	(2-37)	0.06	1.53	7.91
	100/1, 105°C, 0.5%W, air, 240 days	$\log(2FAL) = 3.4 - 0.00287 \times DP$	(2-38)	0.13	1.79	6.7
Kachler et al. [90]	100/1, 85°C. 3.8%W, air, 150 days, non-inhibited oil	$\ln(2FAL) = 7.09 - 0.01 \times DP$	(2-39)	0.40	21.98	162.39
	100/1, 85°C, 3.8%W, air, 150 days, inhibited oil	$\ln(2FAL) = 6.49 - 0.01 \times DP$	(2-40)	0.22	12.06	89.12
	100/1, 85°C, 3.8%W, absence of air, 150 days, non-inhibited oil	$\ln(2FAL) = 8.75 - 0.013 \times DP$	(2-41)	0.19	34.81	468.72
Pahlavanpour et al.[153]	625/1, 70-180°C in 10°C steps, dried, sealed, 1 day per temperature step, inhibited oil	$\log(2FAL) = 1.4394 - 0.0046 \times DP$	(2-42)	0.005	0.4	3.31
Dong et al. [149]	With the aid of oil-paper model to simulate in-field transformers	$\log(2FAL) = 1.82 - 0.0025 \times DP$	(2-43)	0.66	6.61	20.89
De Pablo [154]	Derived based on cellulose chain scission theory	$2FAL = 7100/DP - 8.88$ *	(2-44)	0.01	8.87	26.62
De Pablo [154]	As above, assuming 20% of cellulose ages faster	$2FAL = 4301/DP - 5.38$ *	(2-45)	0.00	5.37	16.13
Burton		$\log(2FAL) = 2.5 - 0.005 \times DP$	(2-46)	0.03	3.16	31.62

When plotted, scattering shows uncertainty. This would be exaggerated in the field.

National Grid Field Study of Furan Analysis





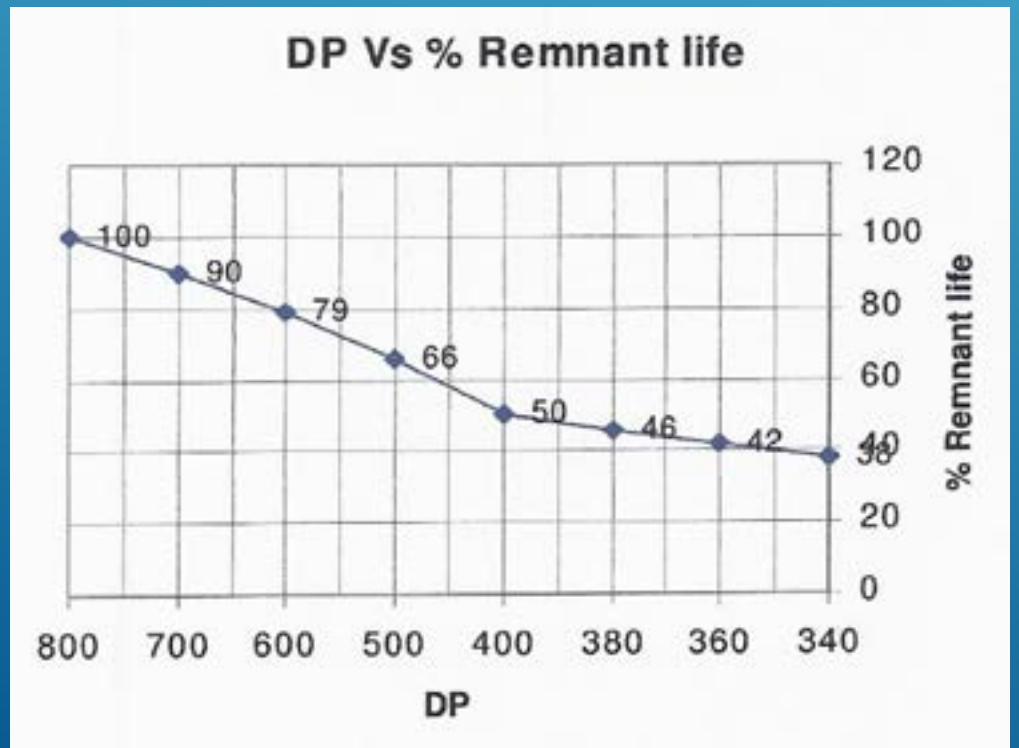
$$DP_{\text{Fitted De Pablo}} = \frac{1674}{(2\text{-FAL})+2.09}$$

Furan to DP example

FURAN ANALYSIS EXPRESSED IN PPB

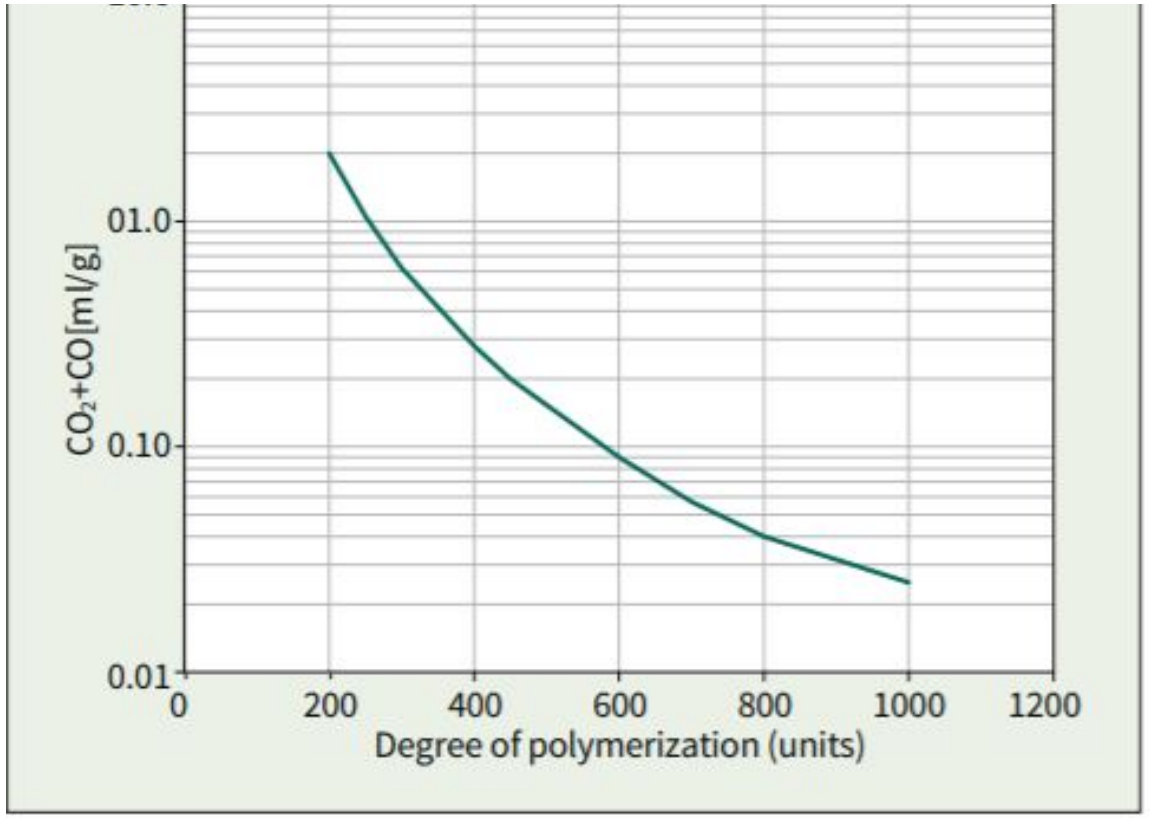
DATE	5H2F	2FOL	2FAL	2ACF	5M2F	TOTAL
12/10/12	ND	ND	333	ND	ND	333
07/07/14	ND	ND	231	ND	ND	231
01/23/15	ND	ND	227	ND	ND	227
08/20/15	ND	ND	416	ND	7	423
11/20/15	ND	ND	422	ND	ND	422

$$DP_{\text{Fitted De Pablo}} = \frac{1674}{(2\text{-FAL})+2.09}$$



$$DP = \frac{1674}{(.416+2.09)} = 668$$

TEPCO STUDY SHOWS CORRELATION BEWTWEEN CO2+CO CONTENT AND DP.



Relationship between degree of polymerization and carbon monoxide and carbon dioxide.

Using DP to Estimate % of Remaining Life

2FAL (ppb)	DP Value	Estimated percentage of remaining life	Suggested Interpretation
58	800	100	Normal Ageing Rate
130	700	90	
292	600	79	
654	500	66	Accelerated Ageing Rate
1464	400	50	
1720	380	46	
2021	360	42	
2374	340	38	Excessive Ageing Danger Zone
2789	320	33	
3277	300	29	
3851	280	24	High Risk of Failure
4524	260	19	
5315	240	13	End of expected life of paper Insulation and Transformer
6245	220	7	
7337	200	0	

“We Already Prevent Moisture”

We have “sealed” transformers.

We use a nitrogen blanket.

We have silica gel breathers.

Only limits ingress from atmosphere or the moisture content of the air that comes into the transformer.

Preventing moisture from entering the transformer from external sources will not inhibit production of moisture from the oil and cellulose breakdown. Moisture will build up internally due to the normal aging and degradation of the oil and paper insulation.

For example, a 10 year old completely sealed transformer will still contain a minimum 1.5% moisture by weight… (0.5% factory level plus 1% internal build up every 10 years).

“We Don’t Have Moisture Issues”

We process the oil and have the moisture removed.

We use portable dry-out units already.

Our oil samples show very low moisture PPM levels.

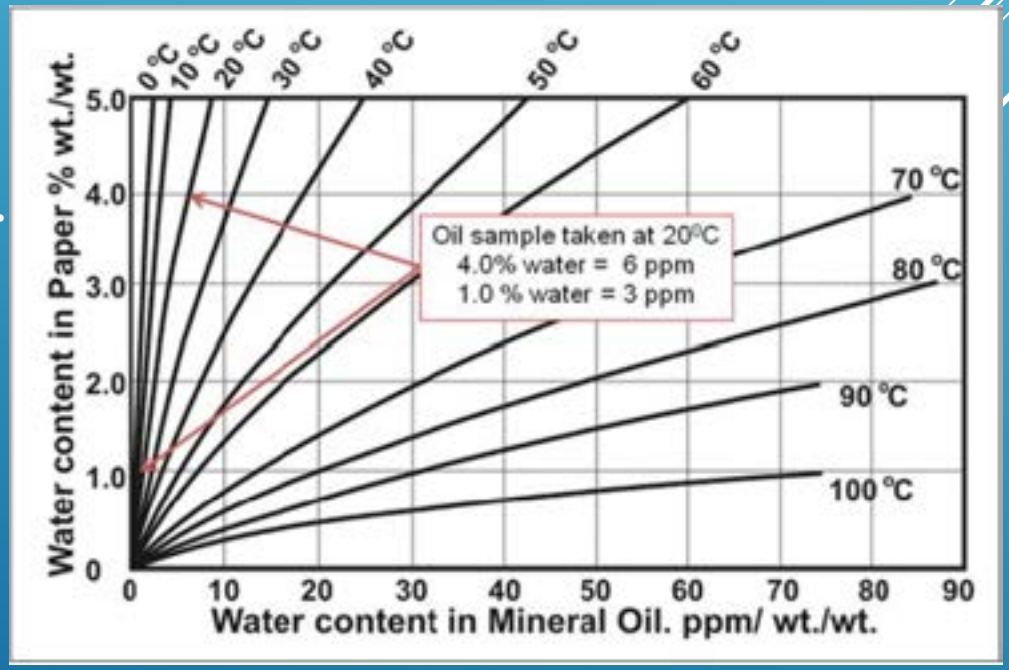
Never had a transformer fail because of moisture.

95-98% of moisture is in the paper, not the oil.

Moisture is a byproduct of the aging of the oil and the paper. Always increasing. Mechanical degradation to cellulose is irreversible.

6PPM at 40°C = 1.83%.....6PPM at 20° C = 3.83%

Cellulose insulation deterioration accounts for 20% of all transformer failures, second only to line surges, according to Hartford Steam Boiler Inspection and Insurance Company.

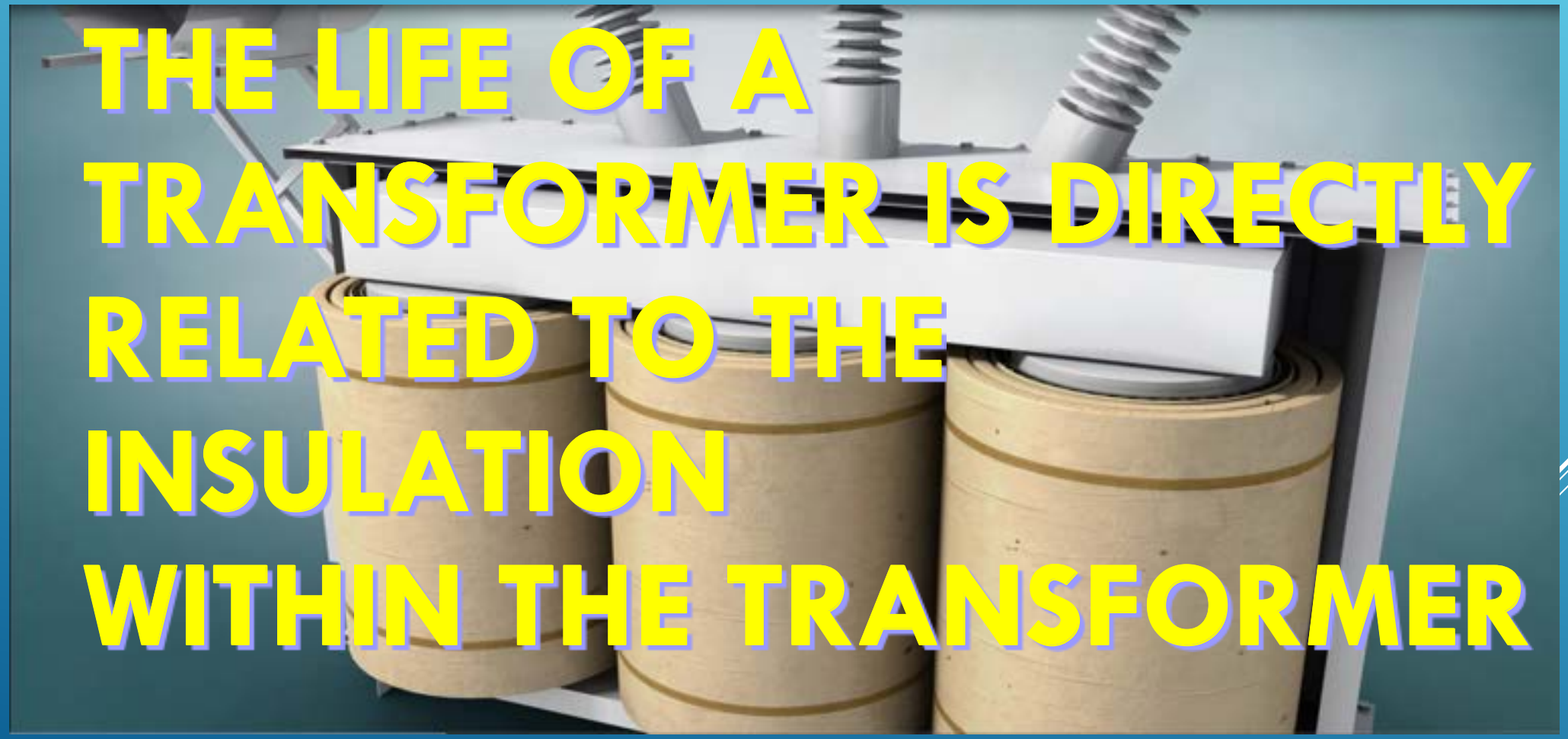


The Problem With Moisture

- Moisture always accumulates-unless constantly abated.
- Detrimental even at low levels.
- Weakens dielectric strength of oil and paper insulation.
- Weakens mechanical strength of cellulose insulation.
- Accelerates aging of cellulose insulation.
- Can result in arcing and short circuits within the windings.
- Presence creates more moisture.
- Ultimately will cause cellulose insulation to fail.
- Reduces potential service life.
- Damage to the mechanical strength of the paper is irreversible, rendering reactive/portable dry-outs ineffective.

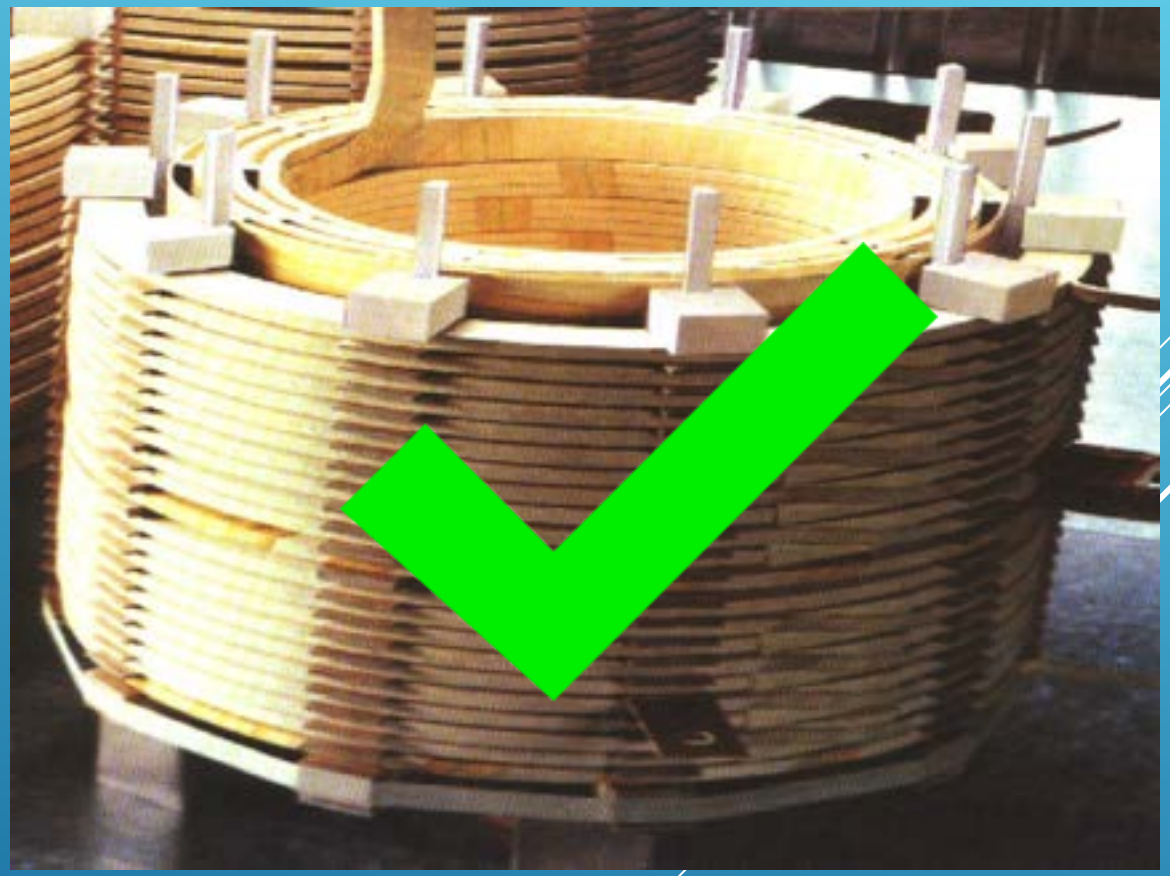
The Big Picture

We have seen the implications of moisture as a catalyst for adverse change in the transformer… how it sets the stage for the decomposition of the winding insulation, and in the process limits the potential life and performance of the transformer.



Moisture Strategies

- Ideally, keep the insulation factory dry.
- Remove moisture that has accumulated and don't allow further accumulation to build up and degrade insulation with reactive measures.



Portable Units Are Corrective, Not Proactive or Preventative.

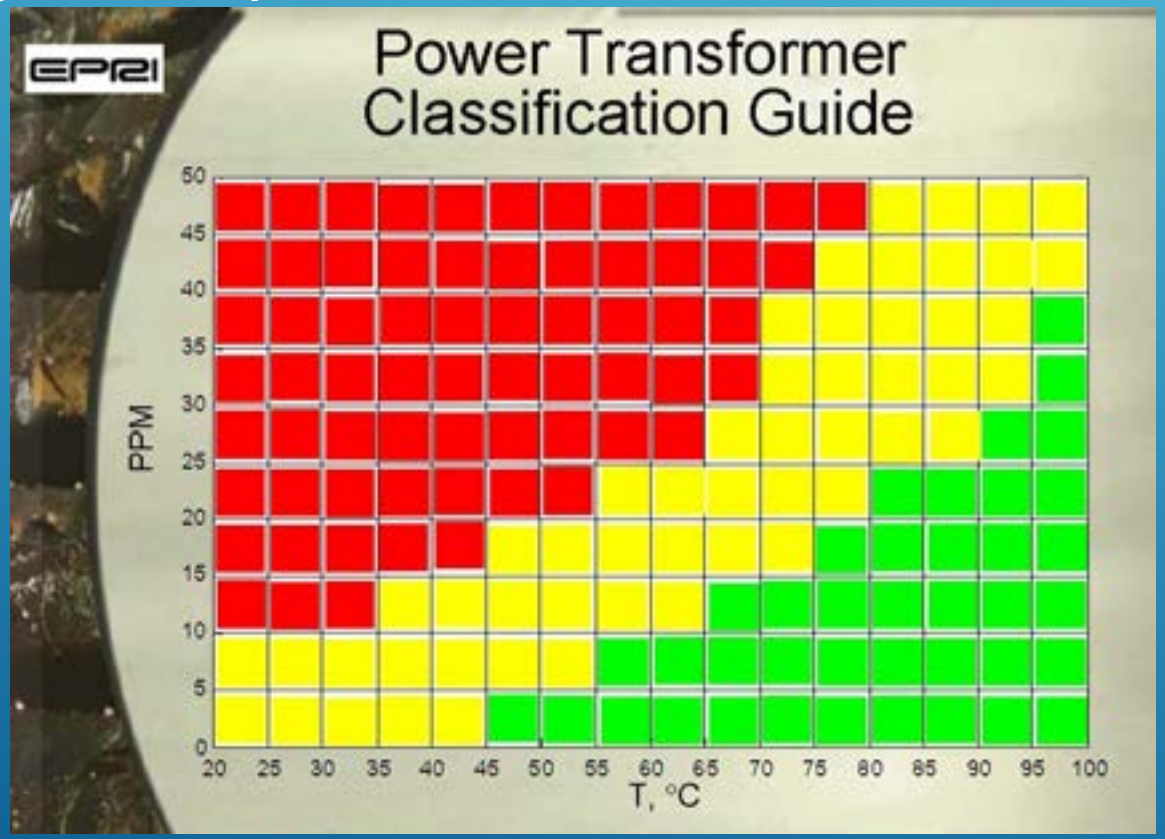




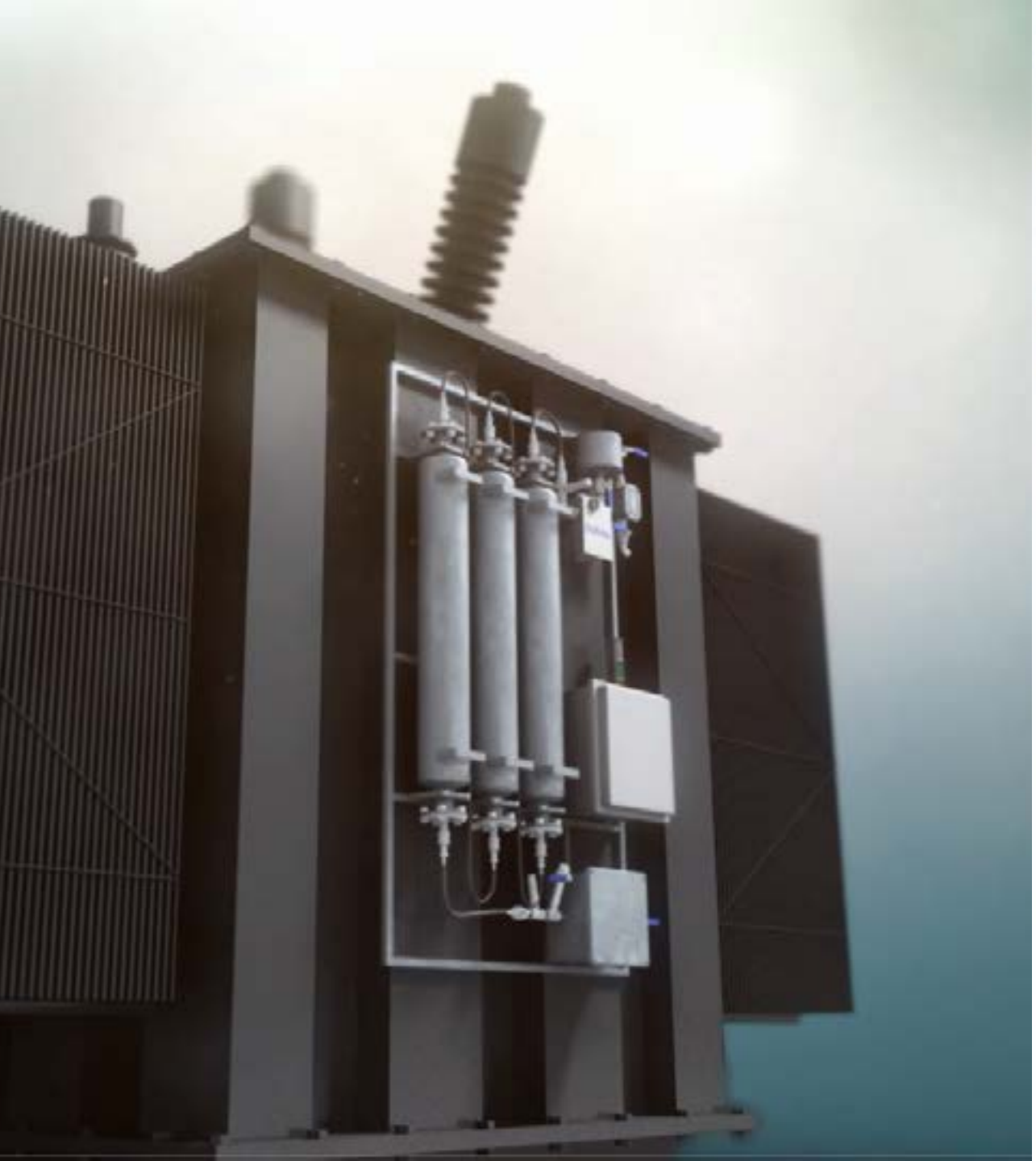

Developing Your Moisture Management Plan of Action

- Step One: Revise your power transformer specifications so that a proactive moisture management system is included with your transformer from the factory.

- Step Two: Rank the transformers in your current fleet to plan and budget for moisture reduction and management for existing assets based on priority and need.
  - Critical loads go to the top!



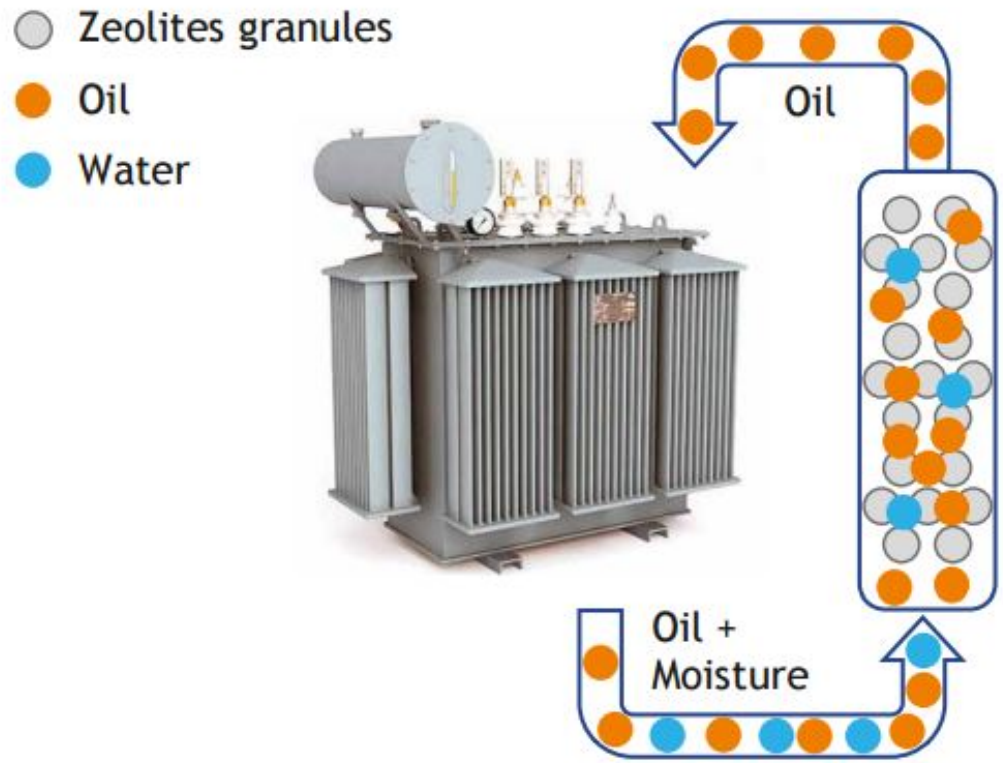

DryKeep IS THE SOLUTION



DryKeep® System Components

1 De-aerator valve
2 Air bleeder hose
3 De-aerator tank
4 Oil Flow Meter
5 Outlet solenoid safety isolation valve
6 Manual outlet valve
7 Outgoing moisture in oil/oil temperature sensor
8 Oil Sampling Port
9 1-micron particle filter
10 Quick couplers
11 Drying cylinders
12 LED status indicating light stack
13 RTU cellular antenna
14 WLAN access point
15 SMART system display and HMI
16 SMART system RJ45 Ethernet interface
17 Overdry prevention bypass valve
18 Incoming moisture in oil/oil temperature sensor
19 Oil Sampling Port
20 Pump/Motor
21 Inlet Solenoid Safety Isolation Valve
22 Manual Inlet Valve

DryKeep® Technology



Molecular sieves are used as drying agents throughout the world in many industries. Extensive research in the 1990's lead to the identification of the proper molecular sieve adsorption technology used by DryKeep today.

DryKeep® adsorption technology is properly sized and coated to capture moisture molecules to the exclusion of anything else.

DryKeep® cannot remove oil inhibitors.

DryKeep® cannot destroy the transformer's DGA signature.

DryKeep® Technology

DryKeep® technology includes two Vaisala MMT162 moisture-in-oil sensors that read the PPM of moisture in the oil and the oil temperature coming into and out of the DryKeep® system. The MMT162 incorporates the latest generation of the Vaisala HUMICAP® Sensor. The sensor is developed for demanding moisture measurement in liquid hydrocarbons and has been successfully used in oil applications for over a decade.

Permanently installed sensors provide a repeatable engineering-based process that continuously measures the water content and temperature of the oil. DryKeep® SMART technology uses this real-time data to estimate the percent moisture in the paper insulation, control the drying process, communicate data to responsible personnel, log historical data, and provide trend analysis.

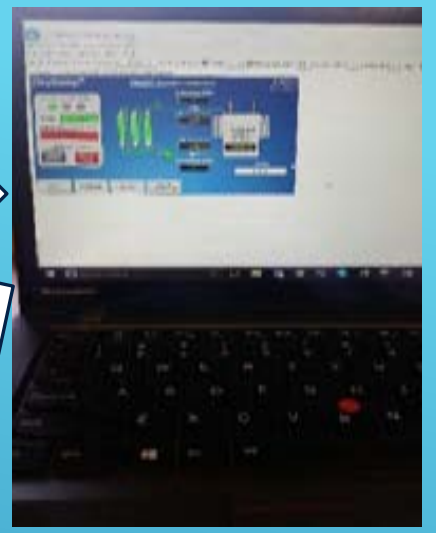
SMART: SCADA Monitoring Analysis Reporting Technology

PPM + Temp

Oil Flow

Local Display

Ethernet



VPN over cellular

RTU

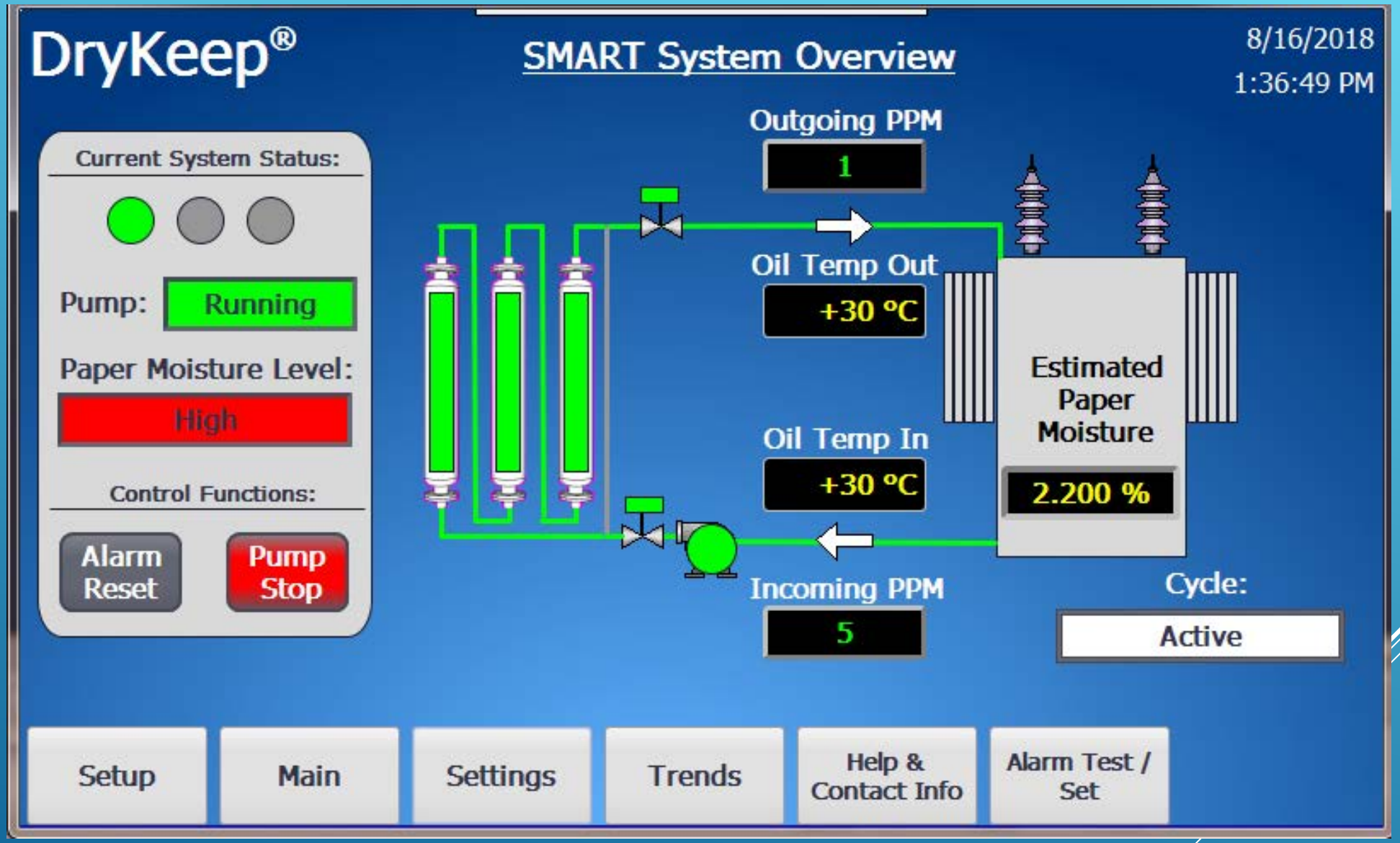
SCADA

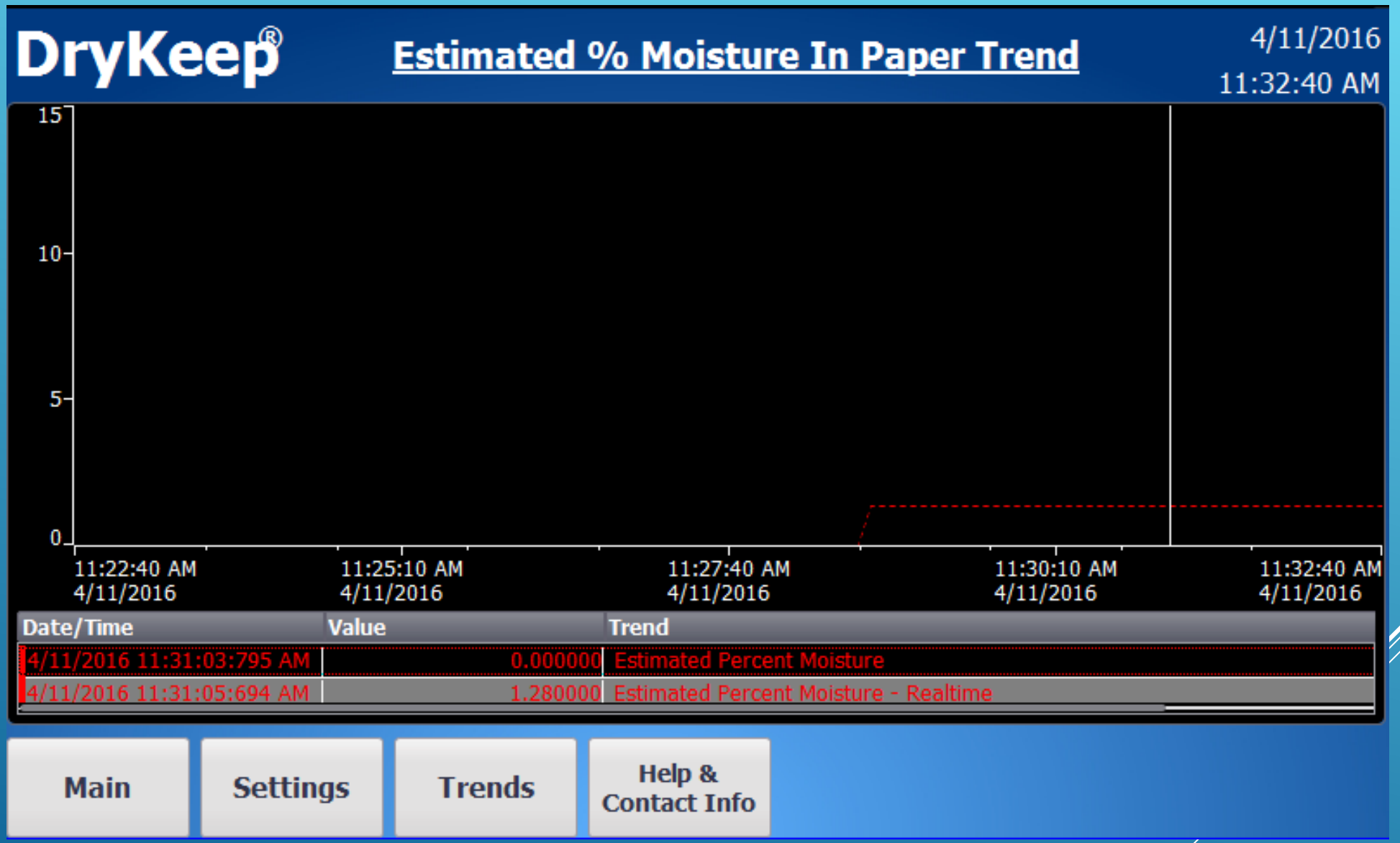
WLAN Access Point

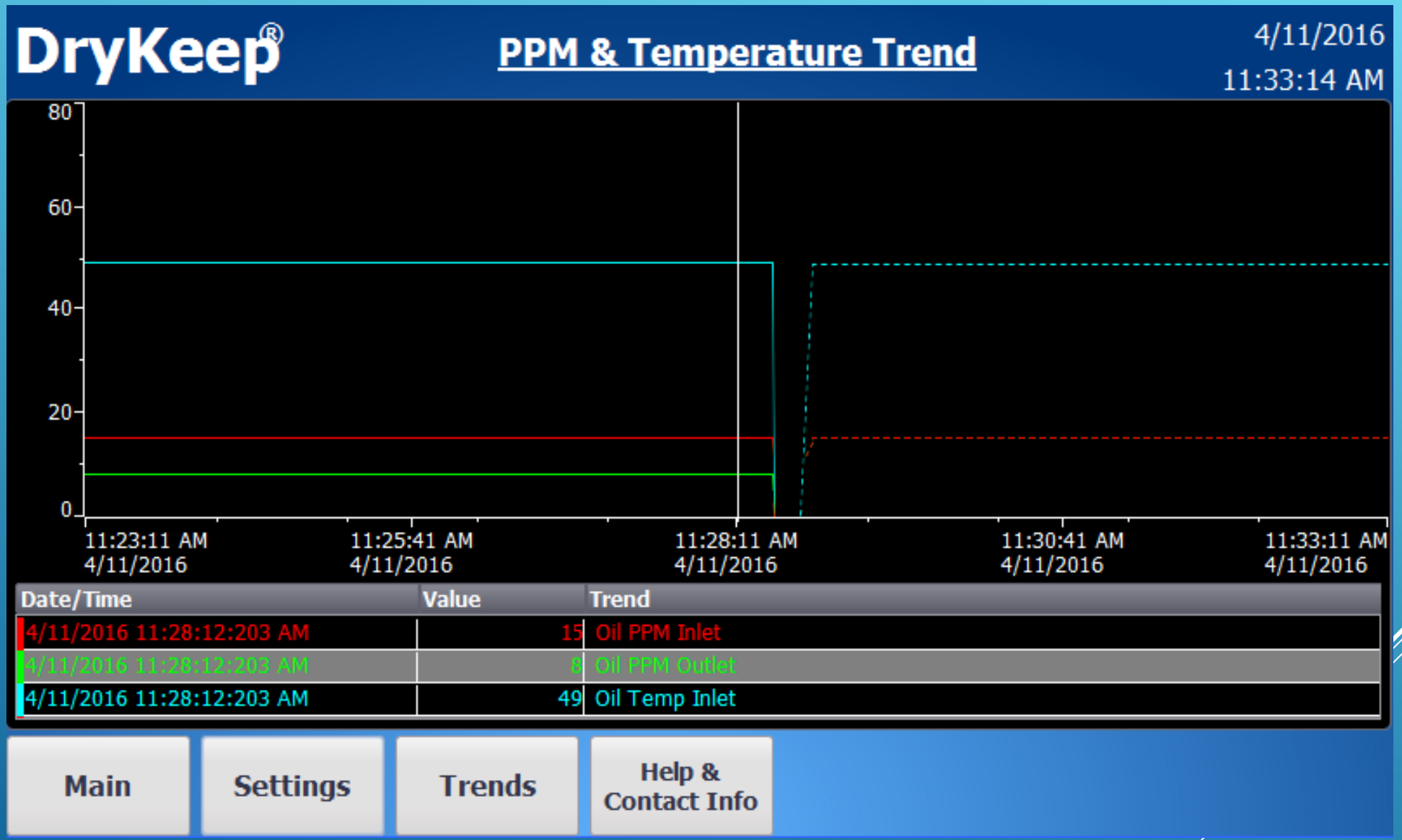
SCADA

Cellular

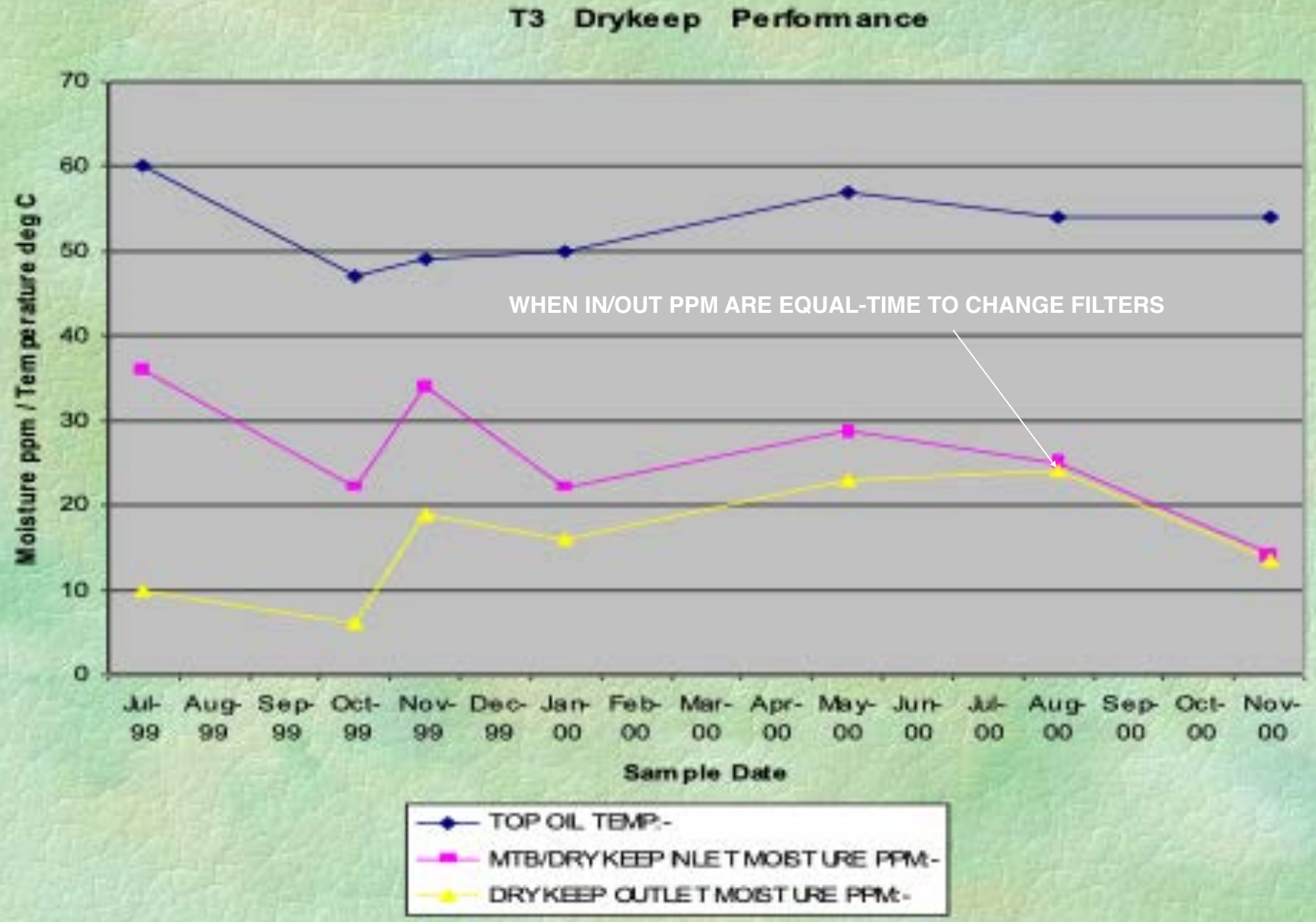
Overdrying protection

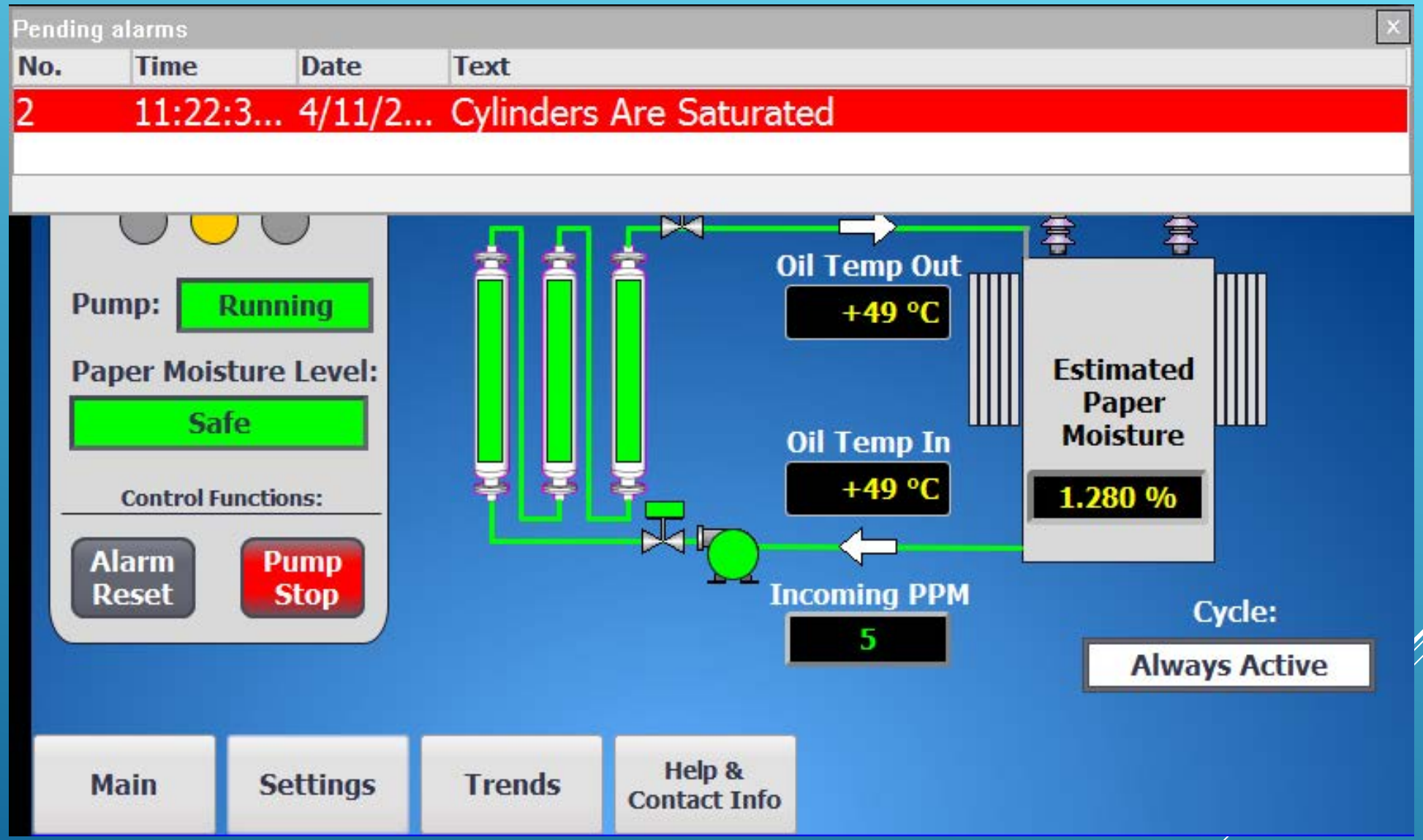

DryKeep®
SMART System Overview
8/16/2018
1:36:49 PM
Current System Status:
Pump:
Running
Paper Moisture Level:
High
Control Functions:
Alarm Reset
Pump Stop
Outgoing PPM
1
Oil Temp Out
+30 °C
Oil Temp In
+30 °C
Incoming PPM
5
Estimated Paper Moisture
2.200 %
Cycle:
Active
Setup
Main
Settings
Trends
Help & Contact Info
Alarm Test / Set


DryKeep®
Estimated % Moisture In Paper Trend
4/11/2016
11:32:40 AM
15
10
5
0
11:22:40 AM
4/11/2016
11:25:10 AM
4/11/2016
11:27:40 AM
4/11/2016
11:30:10 AM
4/11/2016
11:32:40 AM
4/11/2016
Date/Time
Value
Trend
4/11/2016 11:31:03:795 AM
0.000000
Estimated Percent Moisture
4/11/2016 11:31:05:694 AM
1.280000
Estimated Percent Moisture - Realtime
Main
Settings
Trends
Help & Contact Info


DryKeep®
PPM & Temperature Trend
4/11/2016
11:33:14 AM
80
60
40
20
0
11:23:11 AM
4/11/2016
11:25:41 AM
4/11/2016
11:28:11 AM
4/11/2016
11:30:41 AM
4/11/2016
11:33:11 AM
4/11/2016
Date/Time
Value
Trend
4/11/2016 11:28:12:203 AM
15
Oil PPM Inlet
4/11/2016 11:28:12:203 AM
8
Oil PPM Outlet
4/11/2016 11:28:12:203 AM
49
Oil Temp Inlet
Main
Settings
Trends
Help & Contact Info

90 MVA Transformer, 133/33 kV. Manufactured in 1978




Pending alarms
No.
Time
Date
Text
2
11:22:3...
4/11/2...
Cylinders Are Saturated
Pump:
Running
Paper Moisture Level:
Safe
Control Functions:
Alarm Reset
Pump Stop
Oil Temp Out
+49 °C
Oil Temp In
+49 °C
Incoming PPM
5
Estimated Paper Moisture
1.280 %
Cycle:
Always Active
Main
Settings
Trends
Help & Contact Info

DryKeep® is Safe!

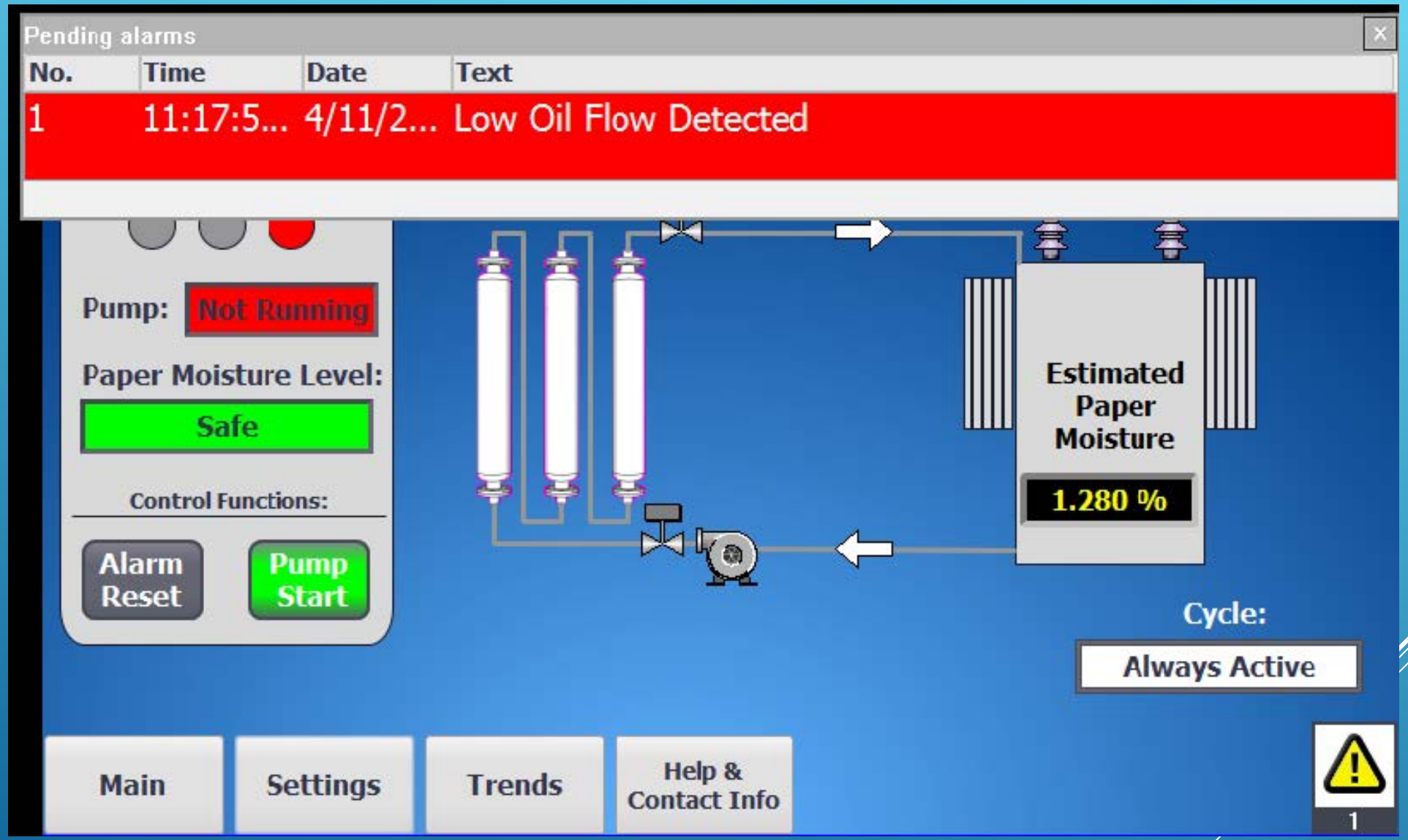
The pump is the only active component. Presents no electrical risk to the transformer.

DryKeep® is Safe!

Normal operation and system powered will show Green,

Cylinders saturated will show Amber,

Problem detected with the system itself will show Red. System will automatically shut the pump down and isolation safety valves will close to completely isolate system from the transformer.

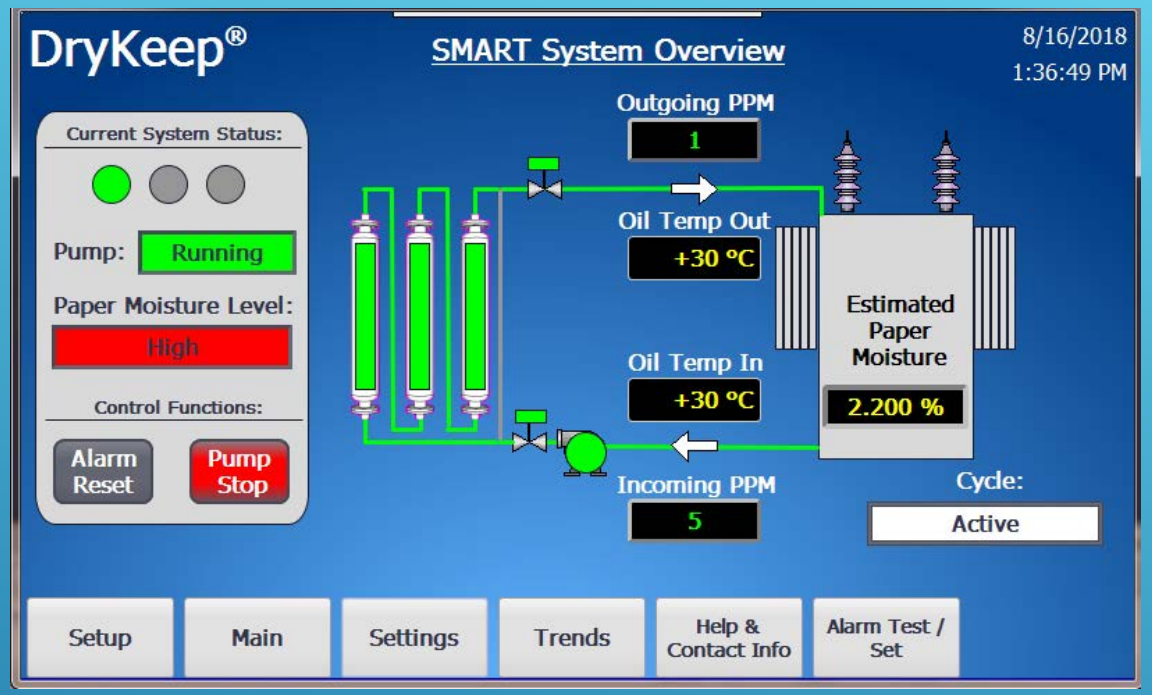

Pending alarms
No.
Time
Date
Text
1
11:17:5...
4/11/2...
Low Oil Flow Detected
Pump:
Not Running
Paper Moisture Level:
Safe
Control Functions:
Alarm Reset
Pump Start
Estimated Paper Moisture
1.280 %
Cycle:
Always Active
Main
Settings
Trends
Help & Contact Info
1

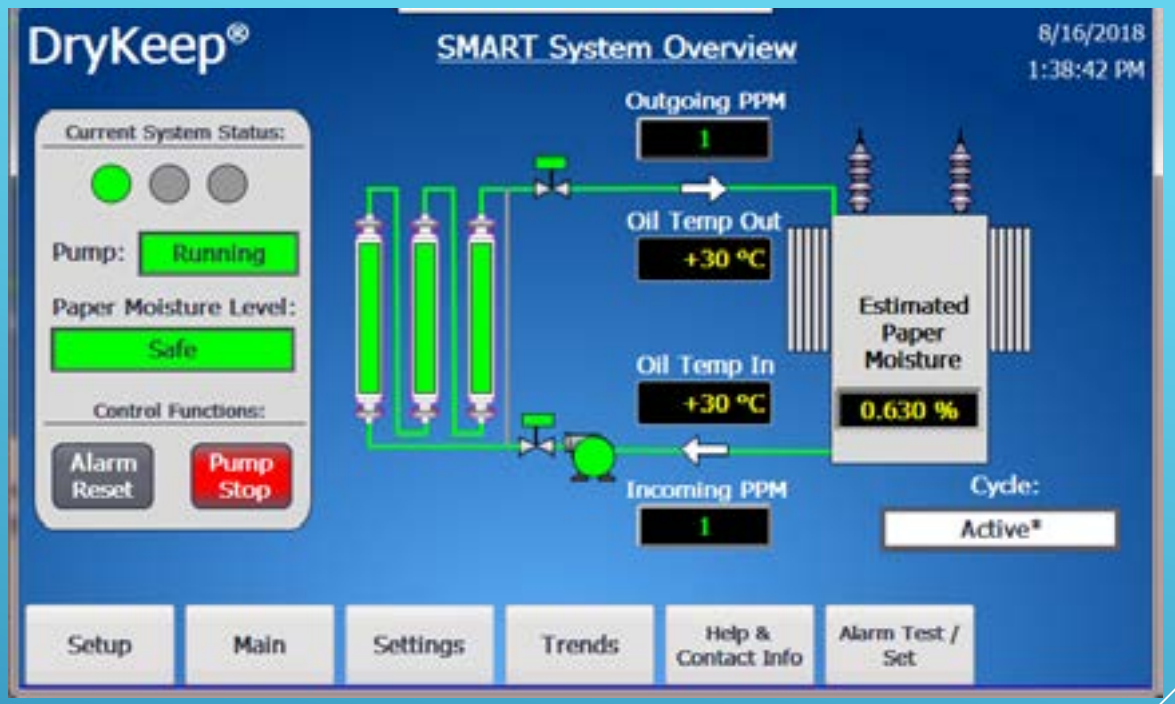
DryKeep® Moisture Management

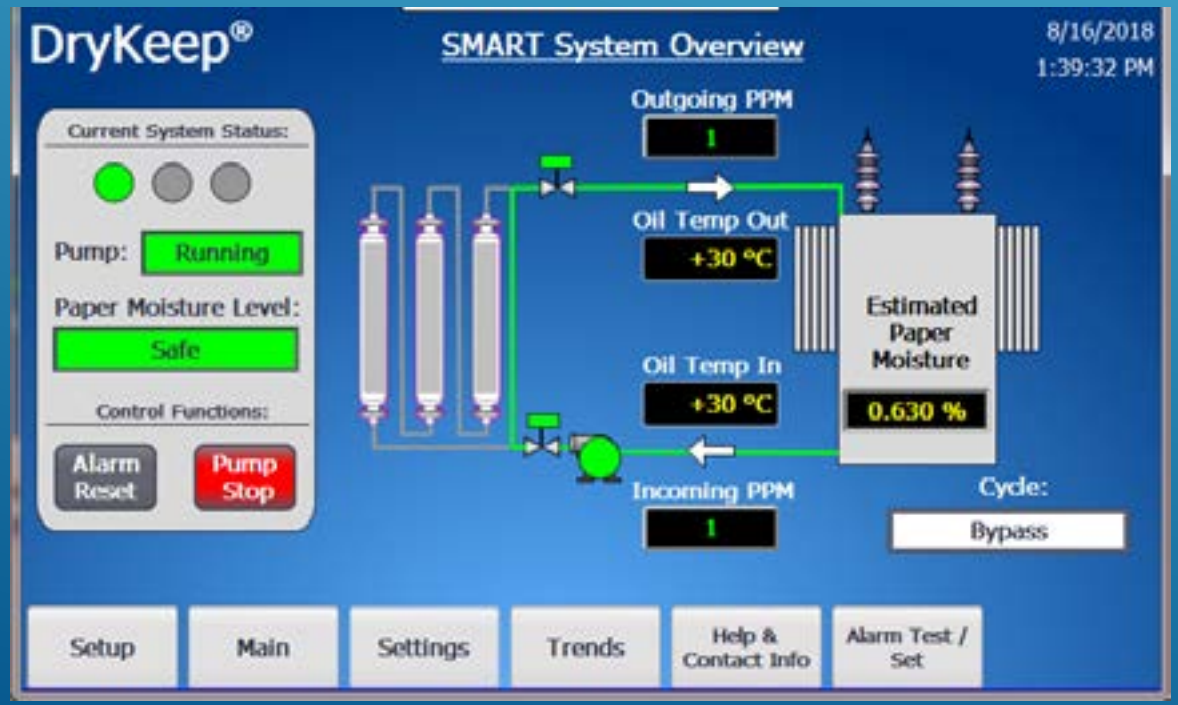
- Power transformer windings are designed to withstand high axial forces which result from short circuit events.
- To withstand these forces, the winding assembly is clamped to a predetermined pre-load pressure during manufacture.
- As long as the transformer clamping system maintains pre-load pressure, the windings will remain tight during a short circuit event and should therefore not sustain any damage.
- The thickness of the conductor material will not change except for the thermal expansion and contraction during load cycles.
- Cellulose insulation that was allowed to adsorb moisture will swell.
- As moisture is removed, swelling will subside.
- Over-drying can cause the windings to come loose.
- DryKeep® SMART technology prevents over-drying.

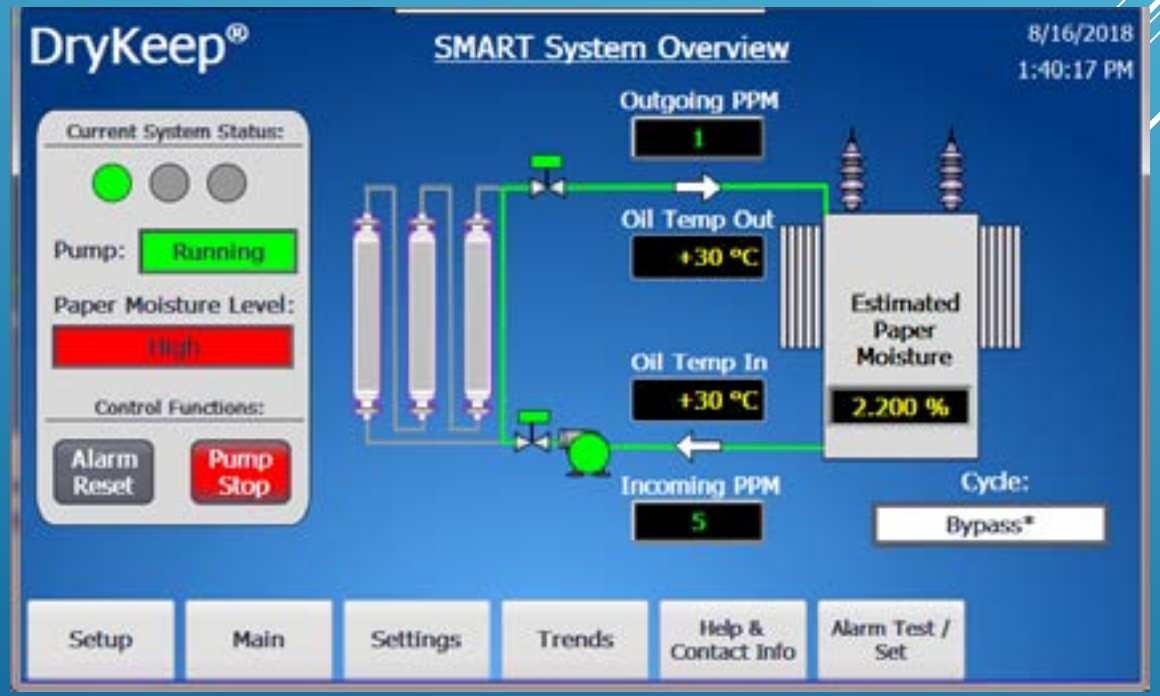
- DryKeep's SMART technology continuously monitors the estimated percent moisture in the paper.
- When moisture removal is required, oil flows through the drying cyinders.
- When the transformer has reached a safe level, the system automatically actuates the divertor valve to bypass the drying cylinders.
- Continuous pump operation ensures constant condition-based monitoring and provides all data 24/7/365

DRYKEEP® TECHNOLOGY PREVENTS OVERDRYING


DryKeep®
SMART System Overview
8/16/2018
1:36:49 PM
Current System Status:
Pump: Running
Paper Moisture Level:
High
Control Functions:
Alarm Reset
Pump Stop
Outgoing PPM
1
Oil Temp Out
+30 °C
Oil Temp In
+30 °C
Incoming PPM
5
Estimated Paper Moisture
2.200 %
Cycle:
Active
Setup
Main
Settings
Trends
Help & Contact Info
Alarm Test / Set


DryKeep®
SMART System Overview
8/16/2018
1:38:42 PM
Current System Status:
Pump: Running
Paper Moisture Level:
Safe
Control Functions:
Alarm Reset
Pump Stop
Outgoing PPM
1
Oil Temp Out
+30 °C
Oil Temp In
+30 °C
Incoming PPM
1
Estimated Paper Moisture
0.630 %
Cycle:
Active*
Setup
Main
Settings
Trends
Help & Contact Info
Alarm Test / Set


DryKeep®
SMART System Overview
8/16/2018
1:39:32 PM
Current System Status:
Pump: Running
Paper Moisture Level:
Safe
Control Functions:
Alarm Reset
Pump Stop
Outgoing PPM
1
Oil Temp Out
+30 °C
Oil Temp In
+30 °C
Incoming PPM
1
Estimated Paper Moisture
0.630 %
Cycle:
Bypass
Setup
Main
Settings
Trends
Help & Contact Info
Alarm Test / Set


DryKeep®
SMART System Overview
8/16/2018
1:40:17 PM
Current System Status:
Pump: Running
Paper Moisture Level:
High
Control Functions:
Alarm Reset
Pump Stop
Outgoing PPM
1
Oil Temp Out
+30 °C
Oil Temp In
+30 °C
Incoming PPM
5
Estimated Paper Moisture
2.200 %
Cycle:
Bypass*
Setup
Main
Settings
Trends
Help & Contact Info
Alarm Test / Set

DryKeep® USA

A brand brought to you by The Andry Group

Power Transformer Dry-Out System

www.drykeep.com

POWER TRANSFORMER MOISTURE AND AGEING ANALYSIS

CUSTOMER:	ATI Metals	OIL TEMPERATURE (c)	35
SUBSTATION/TX NAME:	Melt Shop	MOISTURE IN OIL (ppm)	28
SERIAL NUMBER:	184874	EST. % MOISTURE IN PAPER	4.85%
MVA RATING:	13.6	% OVER SAFE LEVEL	3.5500%
HV RATING:	25.7kV	LITERS OF H20 TO REMOVE	23
MANUFACTURER:	Penn	2-FAL (ppb)	n/a
YEAR MADE:	n/a	EST. D.P.	n/a
OIL CAPACITY (L)	9085	CURRENT RATE OF AGEING	HIGH
SPECIFIC GRAVITY:	0.87		

CALCULATED LITERS OF MOISTURE IN OIL:

0.25 liters of moisture in the oil

CALCULATED MOISTURE IN INSULATION:

28 ppm at 35 ° C equals 4.85%

30.67 liters of moisture in the insulation

CALCULATED TOTAL MOISTURE IN TRANSFORMER:

30.92 liters of moisture in the transformer

TRANSFORMER LIFE EXTENSION AND MOISTURE MANAGEMENT PROGRAM

A brand new transformer has a typical moisture content of 0.5% of the weight of the insulation but transformers that have been in service should not be dried out below ~1.3% to avoid having to reclamp the windings in the field.

MOISTURE THAT SHALL REMAIN IN TRANSFORMER AFTER REDUCED TO ~1.3%

8 liters of moisture to be left

MOISTURE TO REMOVE TO REDUCE CONTENT DOWN TO ~1.3%

23 liters of moisture to be removed

NUMBER OF CYLINDER SETS REQUIRED TO DRY OUT TRANSFORMER:

2 sets of cylinders required

After the original cylinders that come on the SMART RT-9 plus 1 changeout(s) of saturated cylinders (all 3 become saturated at the same time), your transformer will be dried out to a safe level. Thereafter, DryKeep will keep it at this safe level to ensure a normal rate of ageing and transformer life extension

---

The SMART investment.....DryKeep®

195 Industrial Blvd., Rincon, Georgia, 31326 USA Telephone: 912-754-2474

DryKeep® Is Simple To Install

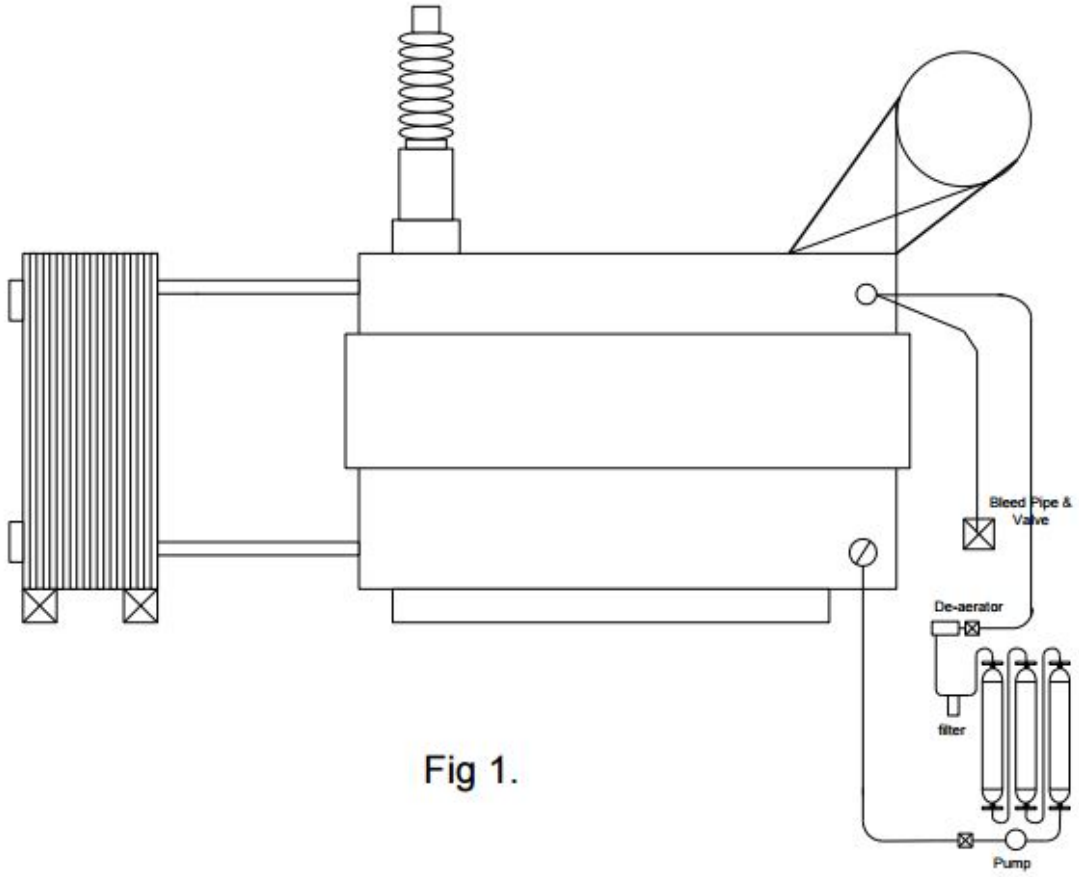
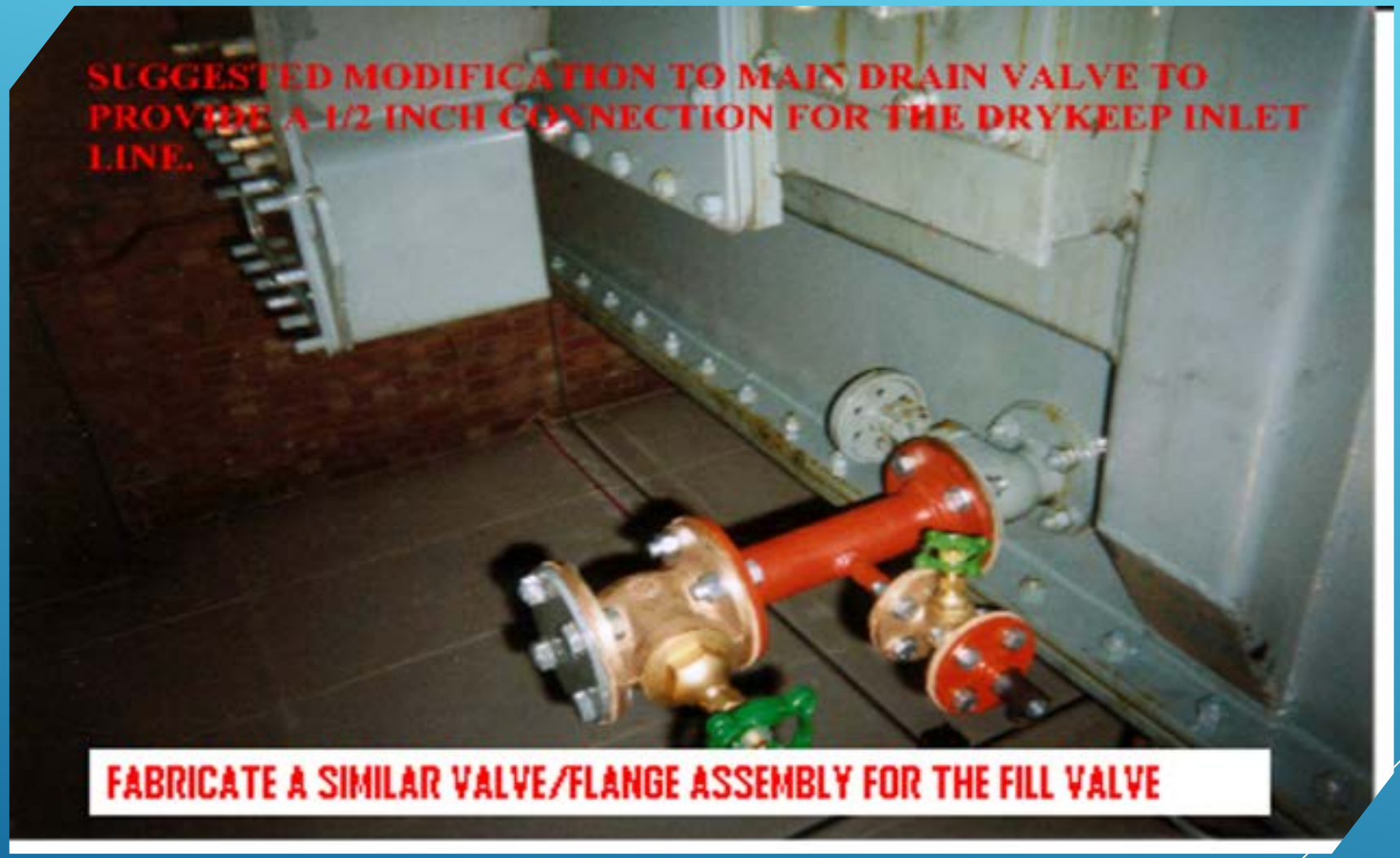


Fig 1.


TV3 BSP


SUGGESTED MODIFICATION TO MAIN DRAIN VALVE TO PROVIDE A 1/2 INCH CONNECTION FOR THE DRYKEEP INLET LINE.
FABRICATE A SIMILAR VALVE/FLANGE ASSEMBLY FOR THE FILL VALVE


DryKeep


DryKeep

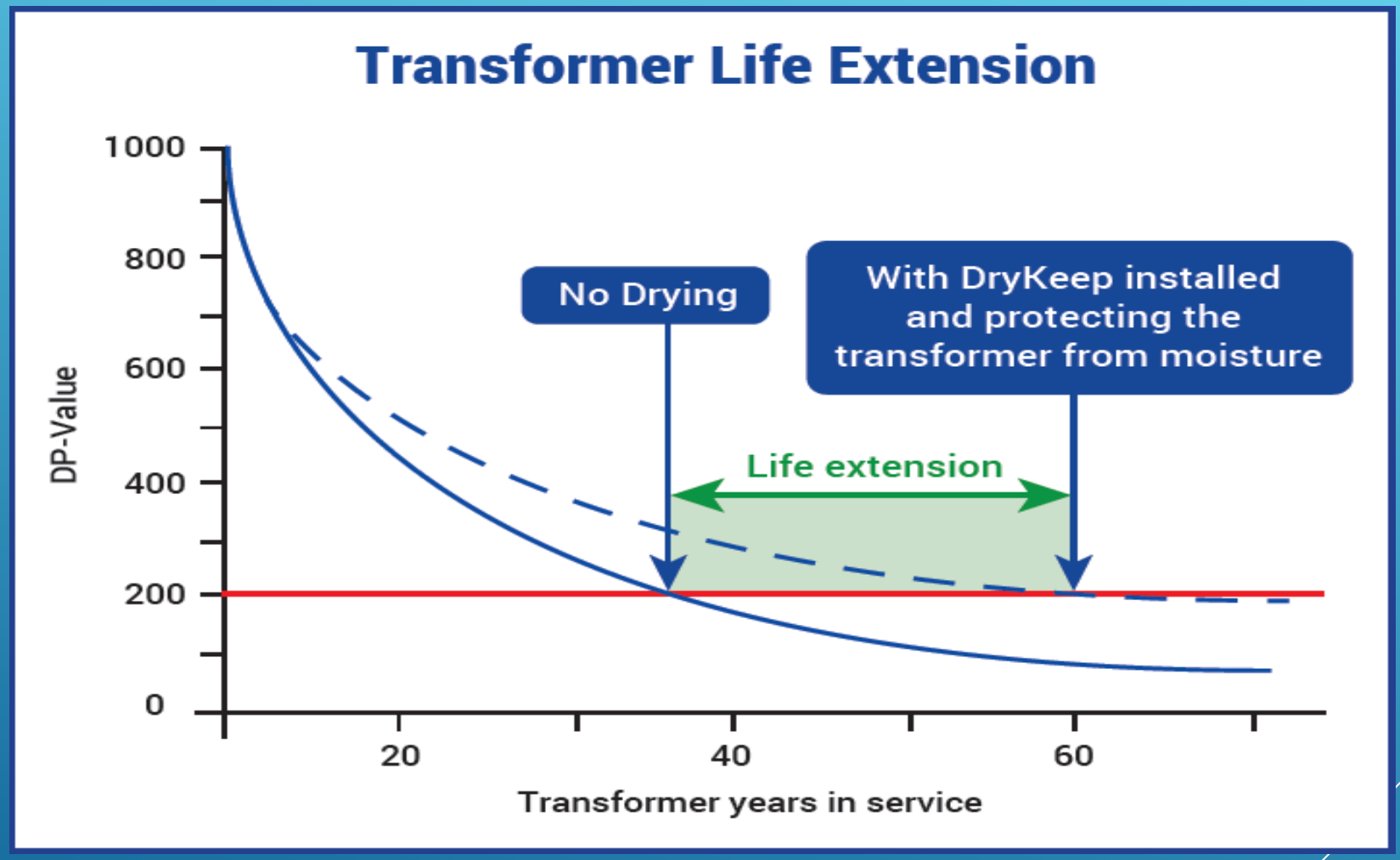
SERIE: G1510-04
IDAD DEL REACTOR: 6,330 KVAR
PEDIDO: 4540000615
RE DE LA INSTALACION: DURANGO SUR AMPL. + MVAR
ON: N_2 5 LBS. A 22 °C A 540 M.S.N.M.
RESIDUAL : 0.3 %
DE EMB. 03/2005

R1ØC

Technological Benefits with DryKeep

- Prevents premature failure.
- Slows the auto-acceleratory aging effects by PERMANENTLY removing moisture from the cellulose insulation system.
- Increases the service life and reliability.
- Preserves the dielectric and mechanical properties of cellulose insulation.
- Enables transformers to be run on higher load cycles with reduced risk of failure.
- May enable lower insurance cost of transformer.
- Reduces maintenance costs.
- Proactive and preventative versus corrective and reactive.
- Simple to install with unattended operation and remote monitoring and control.
- Safety is built-in with automatic shutdown, isolation and alarming.
- Provides real-time assessment and condition-based monitoring of insulation under actual operating conditions.
- Transformer remains online and loaded during operation.

Transformer Life Extension with DryKeep



Adapted from Cigré Brochure 323 – Ageing of cellulose in mineral-oil insulated transformers, Figure 33: Simulation of maintenance action of cellulosic insulation and its effect on retarding ageing.

Financial Benefit of with DryKeep

Example of Minimum Financial Benefit with DryKeep®

Initial Purchase Price of a three-phase 80 mVA 115/13.2kV transformer	US$ 540,000.00
Transformer Oil Capacity	16,630 liters
Moisture in Oil from Oil Test Lab Results, Year 8	22ppms at a top oil temp of 47°C
Estimated Total Amount of Moisture in the Transformer	40 liters
Estimated Percent Moisture in the Paper	2.5%
Moisture to be removed to bring transformer to safe level and keep dry	23 liters
Replacement Cost of the Transformer at End of Useful Life (C) *(keep constant for simplicity)*	US$ 540,000.00
Transformer Useful Life without DryKeep	35 years
Transformer Useful Life with DryKeep Installed in Year 8	60 years
Years of Deferred CAPEX from Life Extension by Investing in DryKeep (n)	25 years
Interest Rate on Investments (IR)	4%
Formula for interest earned by Investing Deferred CAPEX	$C((1+IR)^n-1)$
Interest Earned over 25 years US$ 540,000 $((1+0.04)^{25}-1)$	US$ 899,551.62
Minimum Financial Benefit with DryKeep	**US$ 899,551.62**

Financial Benefit with DryKeep

Example of Net Cost Savings with DryKeep®

	Without DryKeep®	With DryKeep®
Life Expectancy	35 years	60 years
Initial Transformer Cost	US$ 540,000.00	US$ 540,000.00
Annual Straight-Line Depreciation	US$ 15,428.57	US$ 9,000.00
Present Value Cost of Transformer *(depreciated over full life expectancy)*	US$ 179,813.34	US$ 111,388.97
Present Value Savings on Initial Purchase		US$ 68,424.37

System Selection Criteria

- Should be a simple, low maintenance product.
- Easy to install and maintain.
- Efficient at removing moisture from oil and more importantly the cellulose insulation.
- Should be a low-cost, proactive, permanent installation.
- Should be robust, substation quality.
- Have built-in safety features.
- Self-regulating to prevent over-drying.
- Offers local and remote reporting, monitoring and control.
- Have a track record of successful installations and customer references.
- Local after-sales support service.
- Saturated cylinders are simple to regenerate locally.
- Complies with relevant industry standards. IEEE Standard C57-140-2017

DryKeep® vs competitors

Competitor	DryKeep
Less Experience	Over 20 years, over 1000 installed units
Drying done offlline. Saturated drying media replaced offline.	Transformer remains energized
Saturated cartridges must be returned to factory	Saturated cylinders regenerated on site/locally
Pump not suitable for transformer oil	Pump made specifically for transformer oil
No self-regulation to prevent over-drying or must shut down pump to prevent over-drying.	SMART system with divertor valve prevents over-drying while providing continuous, real-time, condition-based data
Insufficient pump flow/head	DryKeep pump flow rate optimized for maximum drying of oil. DryKeep pump head suitable up to 60 feet with constant flow rate
Pump not rated for outdoor use; must have cover.	Rated for outdoor use
Does not control ESD.	Static dissipative hoses prevents breakdown from ESD.
Improper gaskets	TD 1049 cork compounded with Nitrile (NBR) rubber cylinder gasket suited for mineral and silicone oil according to ASTM D3455 "Test Methods for Compatibility of Construction Materials with Electrical Insulating Oil of Petroleum Origin" and ASTM D5282 "Test Methods for Compatibility of Construction Materials with Silicone Fluid used for Electrical Insulation" •
No data logging	All data logged for historical and trend analysis
Doesn't provide estimated % moisture in paper or total moisture removed.	SMART system algorithm provides real-time, average, and historical estimated % moisture in paper and total moisture removed.
Minimal outputs for remote communications, SCADA.	Ethernet, fiber optic, cellular, and WLAN communications for simple SCADA and remote control, monitoring and alarming.

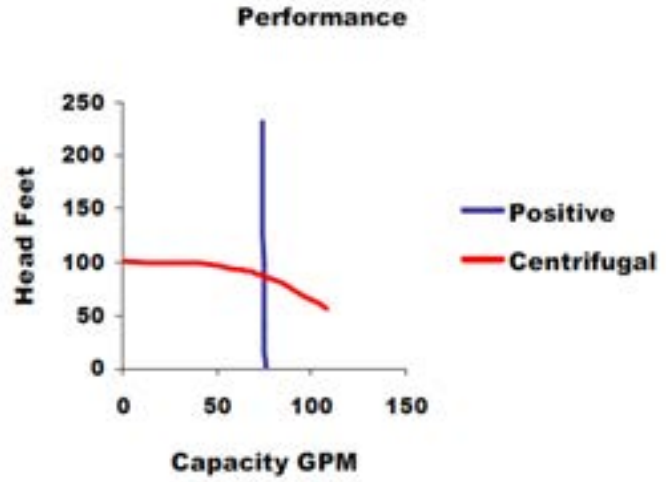
DryKeep® Offers Superior Performance

Competitor's pump:

- Not rated for transformer oil
- Inefficient and not powerful enough

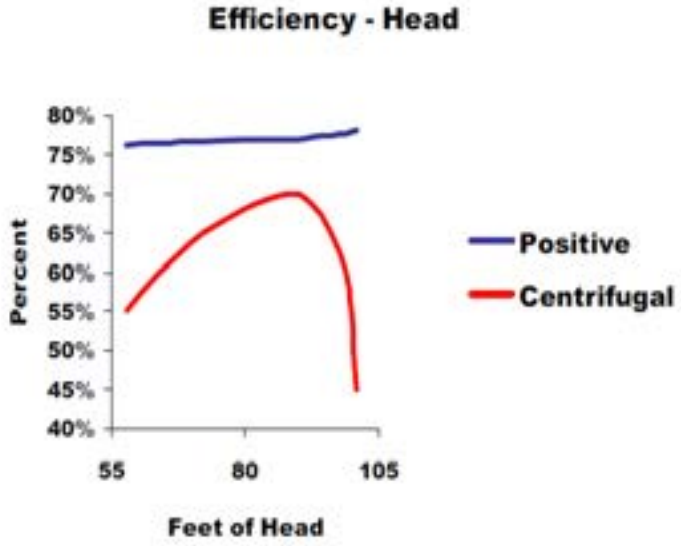
Flow rate versus pressure

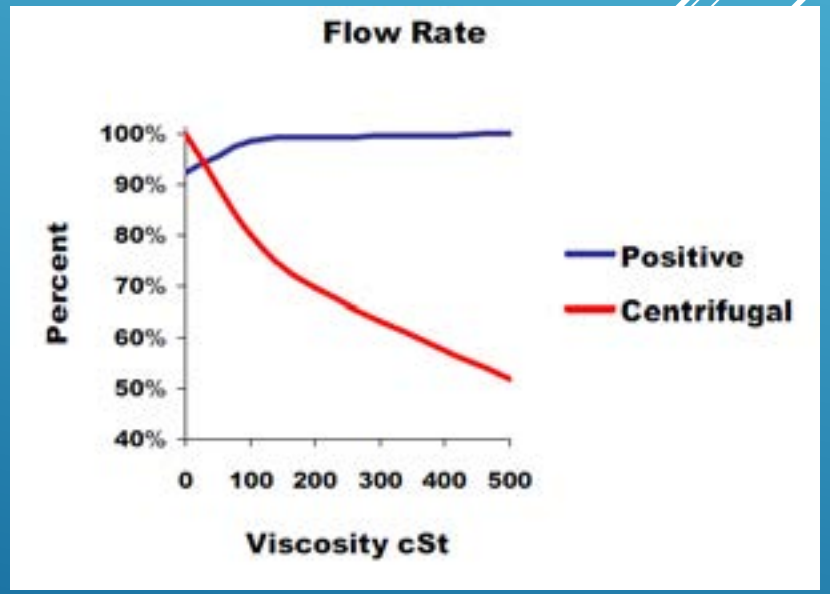
By looking at the performance chart to the right you can see just how different these pumps are. The centrifugal has varying flow depending on pressure or head, whereas the PD pump has more or less constant flow regardless of pressure.



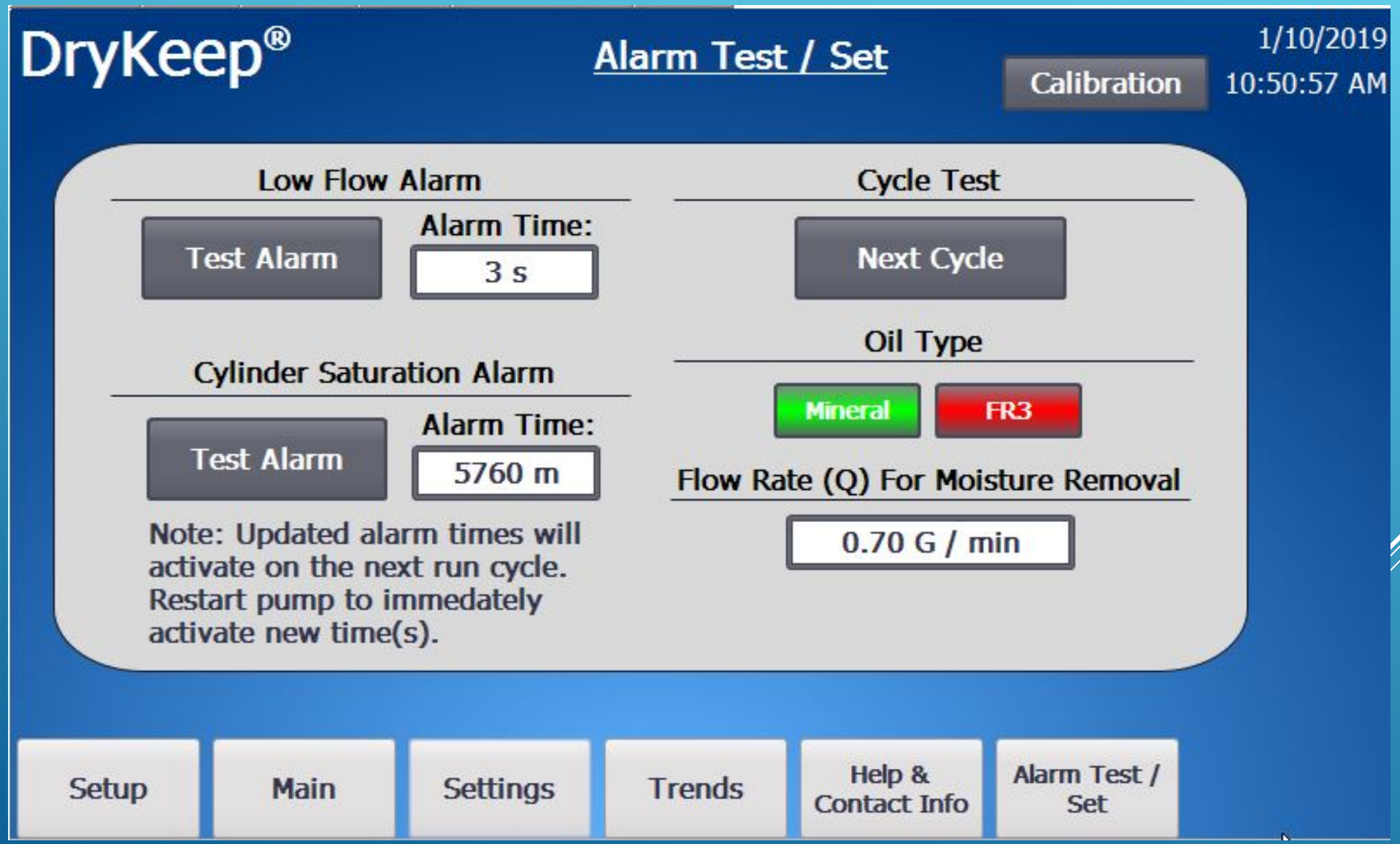
Efficiency versus pressure

The pumps behave very differently when considering mechanical efficiency as well. By looking at the efficiency chart to the right you can see the impact of pressure changes on the pump's efficiency. Changes in pressure have little effect on the PD pump but a dramatic one on the centrifugal.

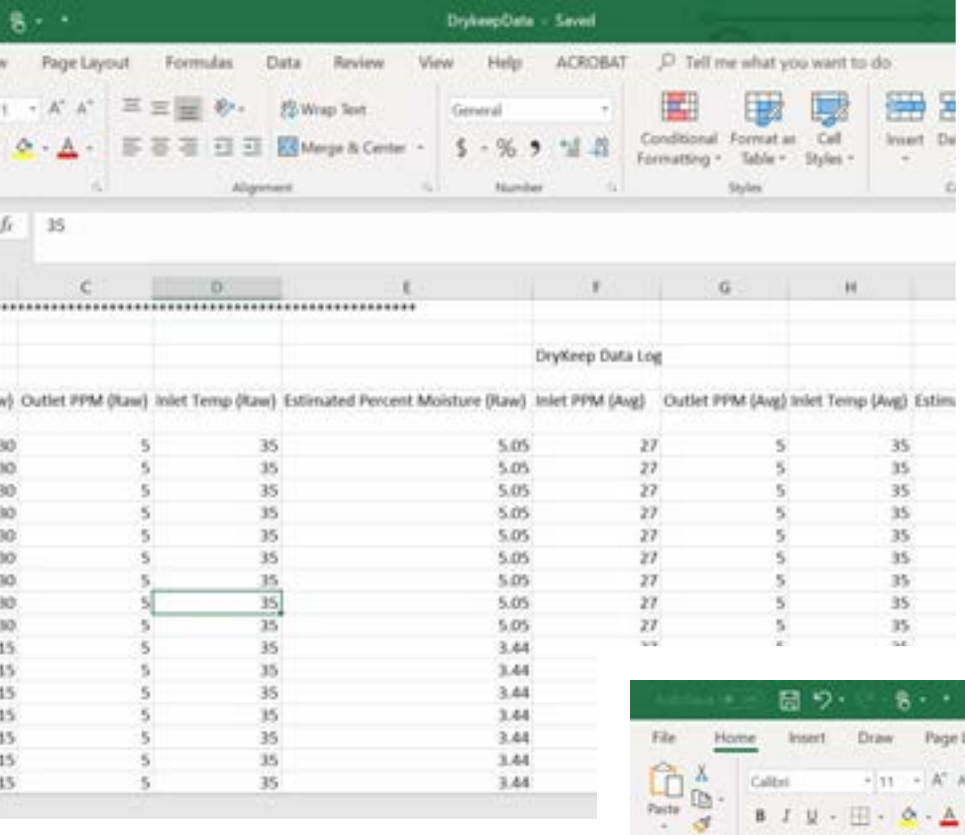


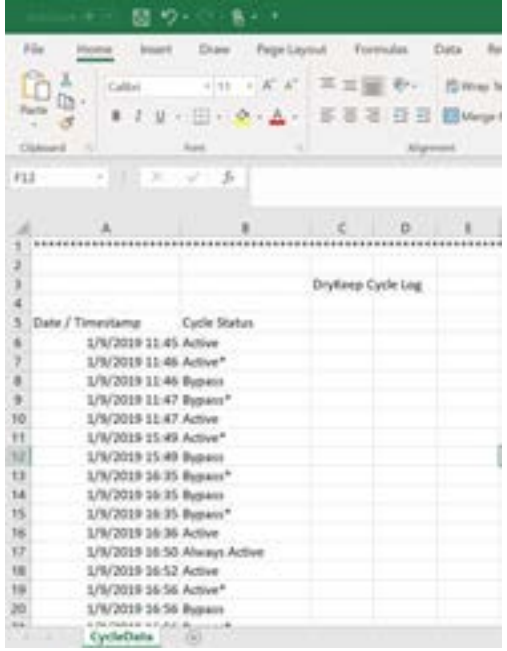


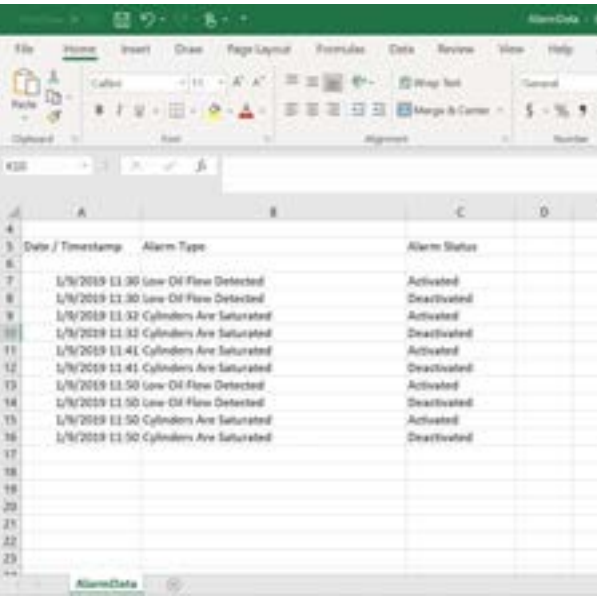
Customization and System Testing

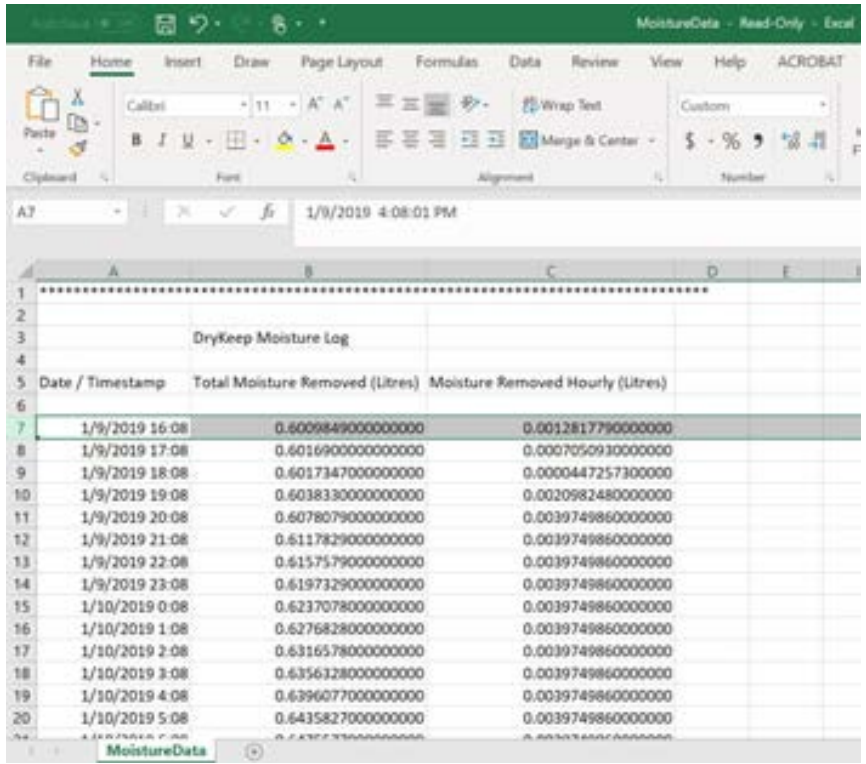


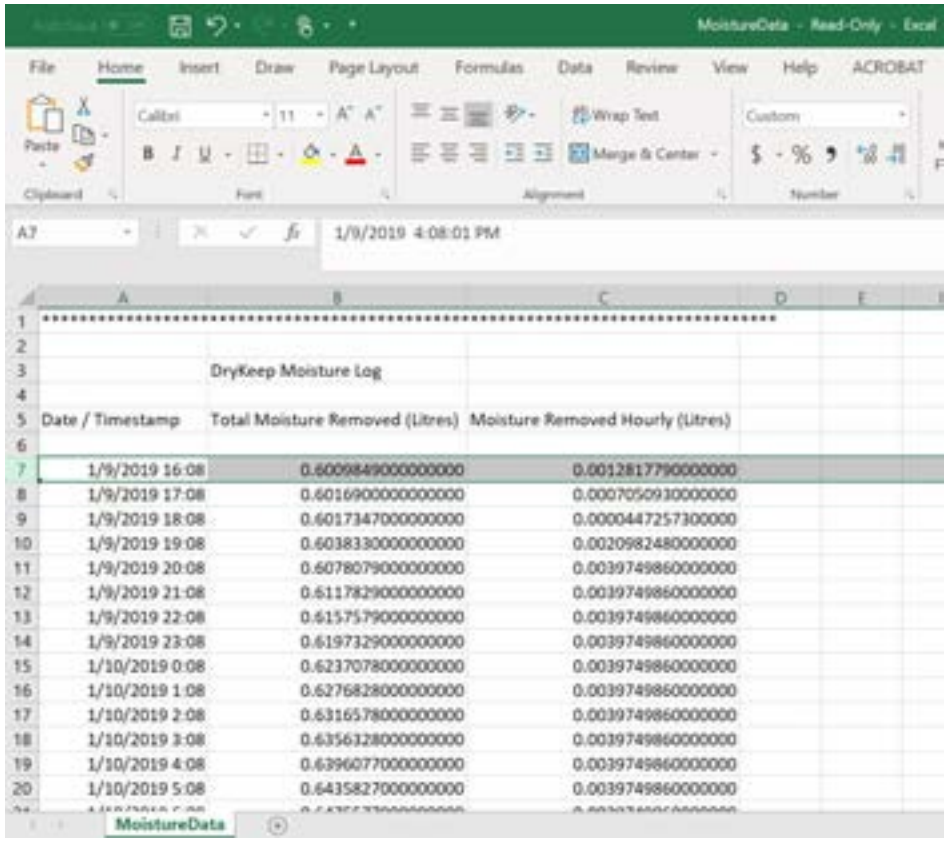
LOGGED DATA PROVIDES HISTORICAL TREND ANALYSIS











DRYKEEP SMART TECHNOLOGY PROVIDES RESULTS-BASED FEEDBACK

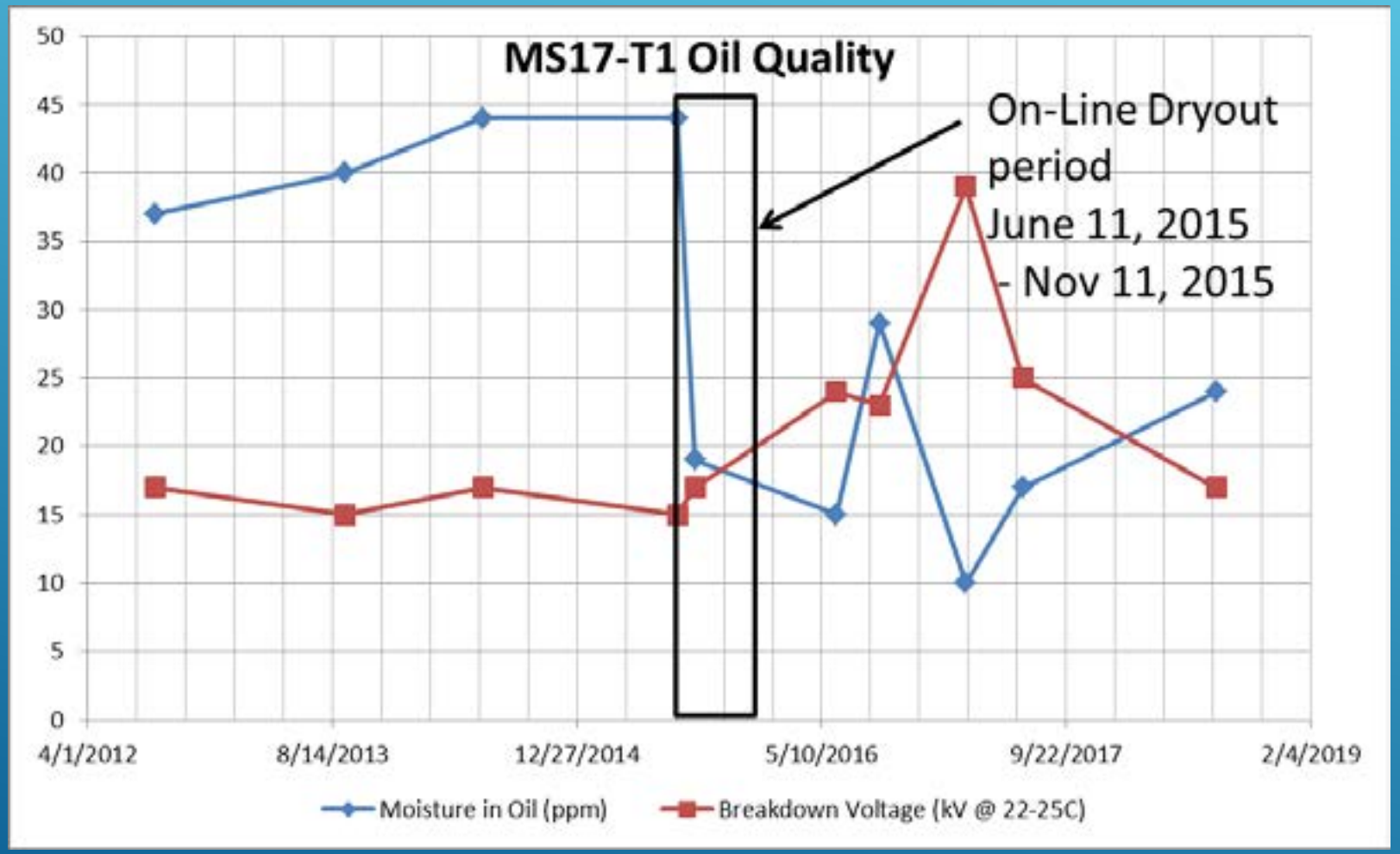
Moisture Removal Options

Advantages per method	DryKeep®	Portable Mobile/Dryout	Field Dehydration	Factory Dry Out
Dries the oil	✓	✓	✓	✓
Dries the paper	✓	?		✓
All work is done on-site	✓	✓	✓	
Transformer remains energized	✓	✓	✓	
Remote monitoring	✓	✓		
Improves other oil qualities	✓	✓		
Prevents moisture build-up	✓			
Permanent solution	✓			
Proactive	✓			
Condition-based monitoring	✓			
Historical data logging/trend analysis	✓			
SCADA-ready	✓			
Remote access & control	✓			
Verifiable financial benefit & cost savings	✓			
Extends transformer life	✓			
Estimated days out of service	0	0	1-2	30-45

- Reduce moisture content
- Improve breakdown voltage
- Reuse On-Line Dry-out unit after Pilot

UTILITIES KINGSTON ON-LINE DRY-OUT PILOT

Outcome of Pilot



5.5 liters of moisture removed over 5 month period (June 2015 – Nov 2015). Verified by weighing the cylinder before and after replacing molecular sieve material.

Conclusions

- The life of a transformer is directly related to the life of the cellulose insulation.
- Moisture pervasive; more serious liability than thought.
- Limits acceptance of load and stress.
- Reduces dielectric and mechanical strength.
- Shortens potential service life.
- Paper and oil aging are substantial source of moisture.
- Using portable dry-out systems is reactive. Does not extend life of the asset.
- Cellulose insulation aging reduction must be a driving consideration rather than a short term challenge.
- Avoidance of moisture build-up in cellulose is key to asset management of power transformers.
- DryKeep® technology provides proactive critical asset management that extends the life of a transformer with clear technological and financial benefits and is the SMART solution to moisture in power transformers.

Further Resources

- IEC 60422 – Supervision and maintenance guide for mineral insulating oils in electrical equipment
- IEEE C57.106-2015 Guide for Acceptance and Maintenance of Insulating Oil in Equipment
- IEC 60076-7 - Loading Guide for oil-immersed power transformers
- CIGRE Brochure 248 – Guide on economics of transformer management
- Cigré brochure 227 "Life management techniques for power transformers"
- T.V. Oommen and L.N. Arnold, "Cellulose insulation materials evaluated by degree of polymerization measurements"
- A.M. Emsley, R.J. Heywood, M. Ali, X. Xiao: "Degradation of cellulosic insulation in power transformers .4. Effects of ageing on the tensile strength of paper",
- A.M. Emsley, "The kinetics and mechanism of degradation of cellulosic insulation in power transformers"
- H.Yoshida, Y.Ishioka, T.Suzuki, T.Yanari, T.Teranishi,: "Degradation of insulating materials of transformers"
- Takayuki Kobayashi, Takayuki Kido, Kojiro Shimomugi of TEPCO Power Grid Inc, "How Transformers Age" T&D World, January 2019

Thank you!

contact Ed Vance, DryKeep USA Sales Manager at edv@ardry.com.

www.drykeep.com