Case Study: Mark Wilmer KW1A Transformer

Robert Hitchcock, Maintenance Control Manager

CAP Systems & Design Service Life

Asset	Age (Years)	Book Service Life (Years)	Description
Structures	30-40	50-100	15 Pumping Plants, 39 Checks and 50 Turnouts
Pumps/Motors	30-40	15-50	109 Main Units 700hp - 60,000hp
Substations Transmission	30-40	25-50	43 Main Transformers (230kV/13.8kV to 115kV/6.9kV)
Waterways	30-40	10-100	336 Miles Aqueduct, 36 miles of PCCP, PCP, Steel, Bar Wrap 36" – 252" diameter
Waddell Dam	30-40	50-100	Earthen Embankment Dam, 800,000 Acre-Ft Storage Reservoir
Waddell Pump Generating Station	30-40	15-100	40 MVA Pump Generating Station

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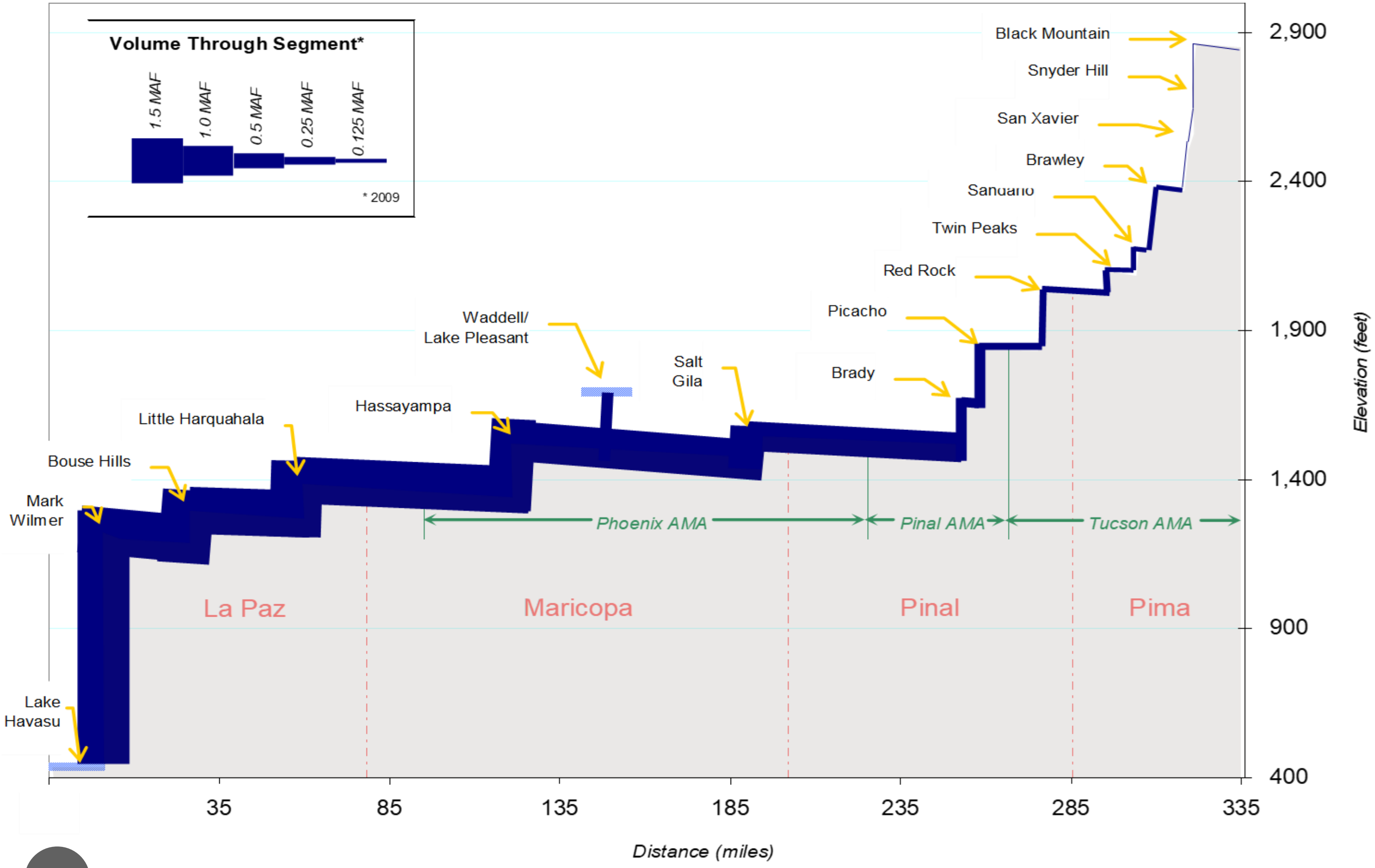
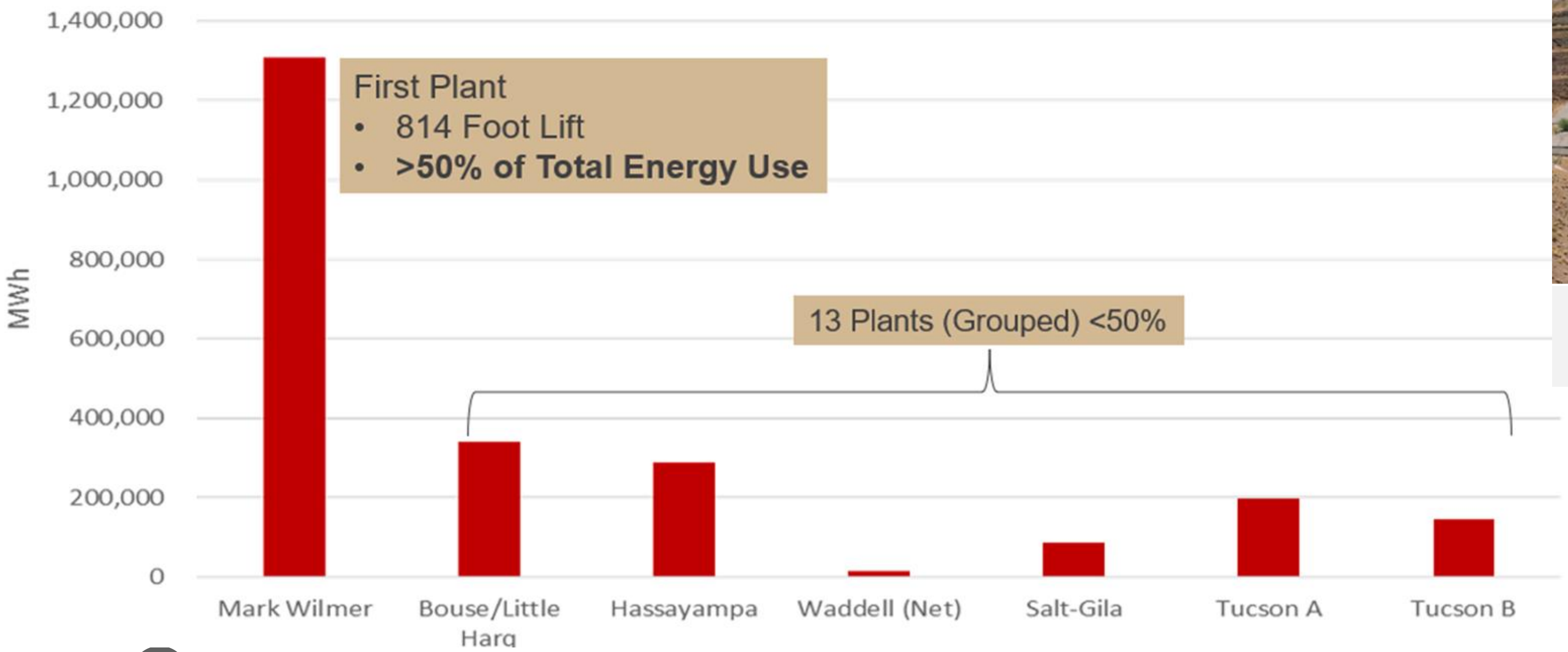
Elevation Profile and Volumes



Line Thickness Equates to Volume of Water That Flows Through That Section

Shows Elevation Profile Vertically

Energy Use by Pumping Plant



Mark Wilmer Pumping Plant

Intro to Failure Modes

- There was a belief that age/wear out/fatigue were the primary drivers of degrading conditions
- Physical asset performance can be optimized by overhaul or replacement at fixed time interval
- Based on premise that there is direct relationship between time in service and likelihood of failure

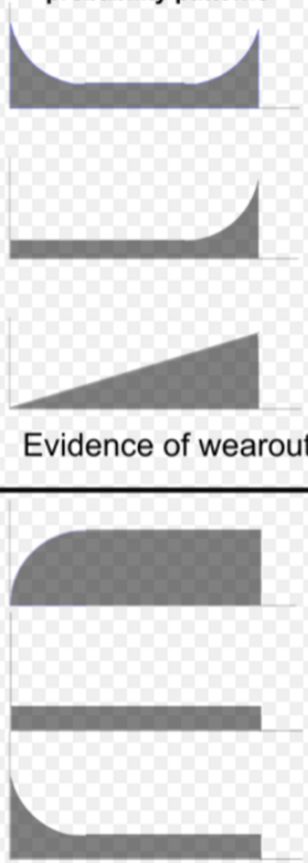
How Failures Actually Occur

Generally, less than 20% of failure modes of components are wear or age related. Time or usage-based strategies can actually decrease reliability and introduce new issues.

This is why CAP has chosen to follow a condition driven Maintenance, Refurbishment, and Refurbish/Replacement strategy.

Time based intrusive maintenance causes more problems than it solves.

Condition monitoring and no planned maintenance with critical spares & procedure on hand are most effective for random FM's.



The six conditional failure probability patterns	UAL 1978	Broberg 1973	MSDP Studies 1983	SSMD 1993
Age Related \ Wearout				
A.	4%	3%	3%	6%
B.	2%	1%	17%	0%
C.	5%	4%	3%	0%
Evidence of wearout	11%	8%	23%	6%
Random \ No wearout				
D.	7%	11%	6%	0%
E.	14%	15%	42%	60%
F.	68%	66%	29%	33%
No evidence of wearout	89%	92%	77%	93%

- Pattern A; High incidence of failure at the beginning followed by a constant or increasing conditional probability of failure then a wear-out (*Bathtub* curve)
- Pattern B; Classic wear-out, shows constant or increasing conditional probability of failure then a wear-out.
- Pattern C; Gradual aging wear out age is not identifiable
- Pattern D; Best new, low conditional probability of failure
- Pattern E; Totally random, constant conditional probability of failure at all ages
- Pattern F; High rate of failure probability at the beginning but decreasing and getting constant after coming into service

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Risk Management

RISK = LIKLIHOOD X CONSEQUENCE

- Any time a piece of equipment is relied upon for production, there is risk associated with its ability to meet its design intent.
- In order to reduce the risk of operation, an organization can either work to reduce the likelihood of failure or reduce the consequence of the failure.

2003 Infrastructure Risk Assessment

Transformer Risk Assessment Findings

Although the probability of a catastrophic transformer failure is low, the consequence is so significant that CAP needs to implement Methods to reduce the risk associated with this failure.

The recommendation of a fire wall reduces the consequence of failure but does not decrease the probability. A failure of this type would still be highly consequential.

Transformer Risk Assessment Recommendation

CAP determined rather than just focus on reducing the consequence of failure, CAP would focus on reducing the likelihood of failure.

One of the implemented recommendations was to install online dissolved gas analyzers at Pumping Plants to reduce the probability of transformer failure.

Prevention-Failure (P-F) Curve

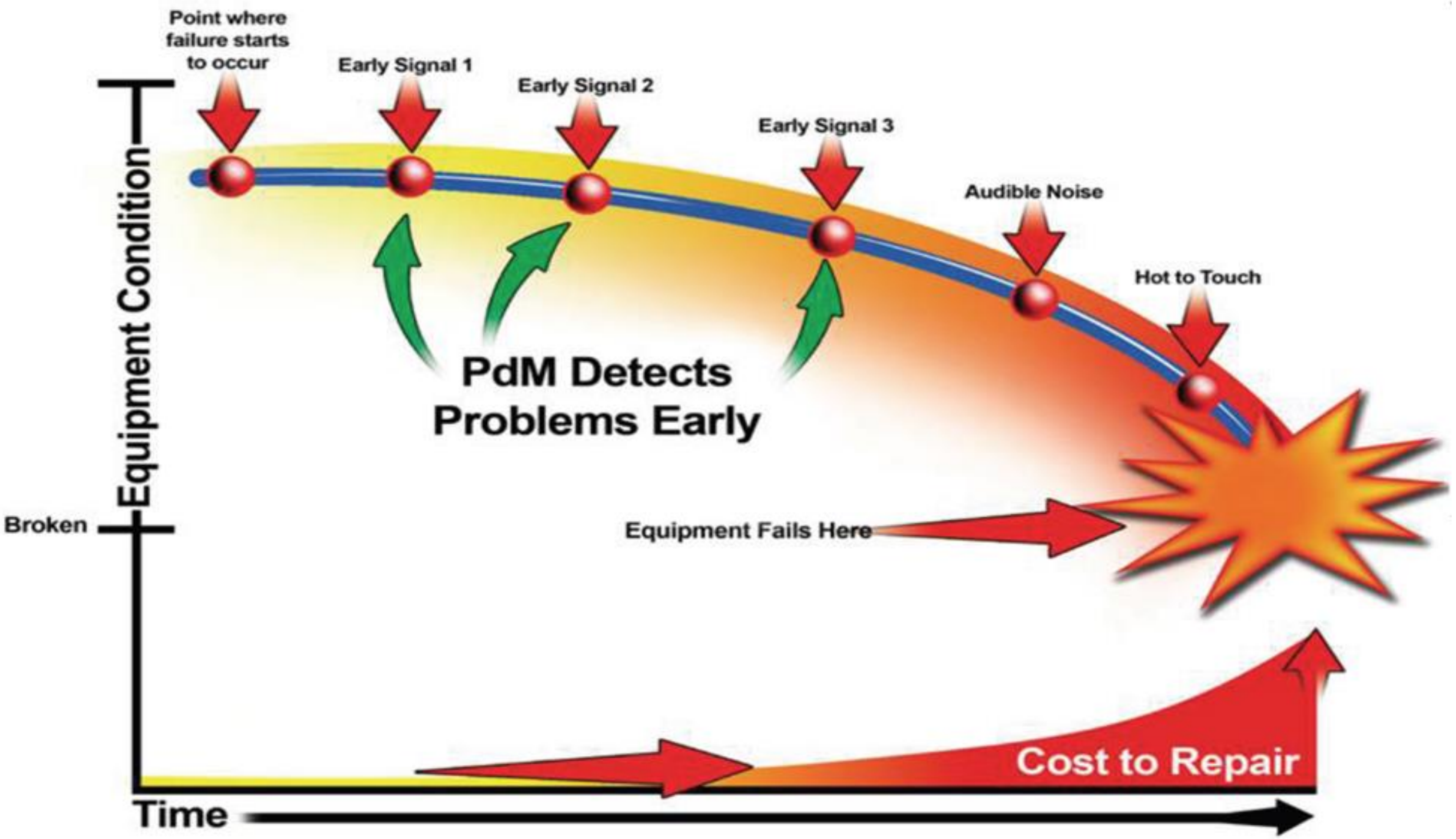


Figure 3: P-F curve

Courtesy of Allied Reliability

Transformer – Assessed Gasses

Offline measurements evaluated against set criteria:

- H_2
  - Indicates partial discharging and sustained arcing
- CH_4
  - Indicates partial discharging, and degrading thermal condition of oil
- C_2H_6
  - Indicates partial discharging, and degrading thermal condition of oil
- C_2H_4
  - Indicates sustained arcing and degrading thermal condition of oil
- C_2H_2
  - Indicates partial discharging sustained arcing and degrading thermal condition of oil
- CO
  - Indicates degrading thermal condition of paper
- CO_2
  - Indicates degrading thermal condition of paper
- Total Dissolved Combustible Gas
  - Includes hydrogen, methane, ethane, ethylene, acetylene, and carbon monoxide. Gassing rate increases as fault conditions worsen
- Total Dissolved Gas
- Water in oil
  - Indicates rate of paper aging, bubble formation during overloads, has an inverse relationship with dielectric strength

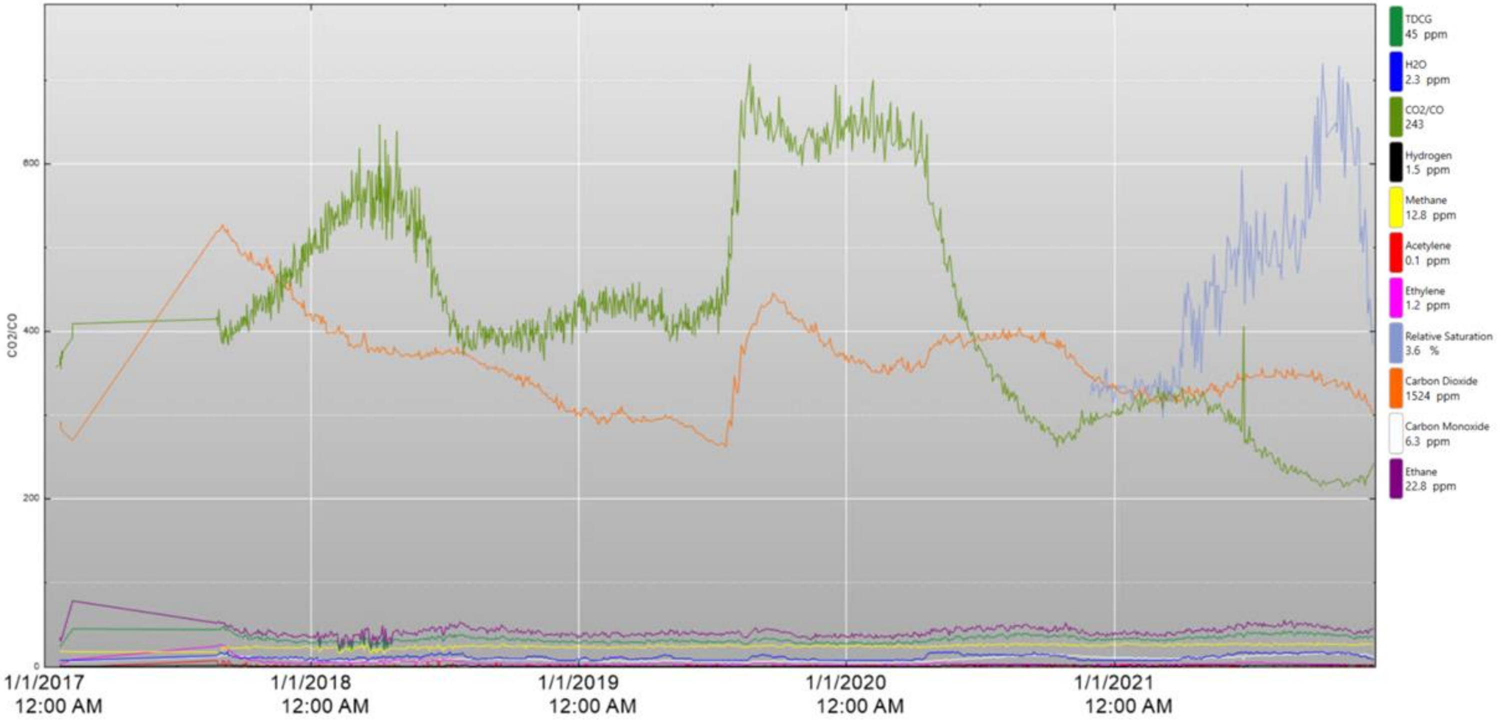
- Interfacial Tension
  - Indicates oil ageing and oxidative breakdown
- Acid Number
  - Indicates oil ageing and oxidative breakdown
- Dielectric Breakdown
  - Indicates oil ageing and oxidative breakdown
- Power Factor
  - Measures dielectric loss in oil and indicates ageing and oxidative breakdown

Transformer – Data Trending

Monitored gasses in ppm:

- CO2/CO Ratio
  - Indicates rapid deterioration of paper insulation
- Hydrogen
- Methane
- Acetylene
- Ethylene
- Ethane
- Carbon Monoxide
- Carbon Dioxide
- Oxygen
- Total Dissolved Combustible Gast Content
- Water

- Online monitoring of concentration of gasses in ppm
- System monitors multiple parameters and sends notification to engineers if any gasses pass established notification points.



Plant Transformers

- Each pumping plant has electrical substations with transformers to step the power down from the distribution system to the plant system.
- Each plant has sufficient redundancy to run the full plant with one transformer out of service for inspection, repair, or breakdown.
- Mark Wilmer has 3 transformers that step the power from the 230kV distribution down to 13.8kV

2018/2019 - MWP KW1A Investigation

- From May to December 2018, CAP Engineers Monitored increasing dissolved gasses in MWP Transformer KW1A.
- From May to December total combustible gasses (TCG) increased 15ppm/day which is above the Doble investigate recommendation at 10ppm/day.
- In January 2019, MWP KW1A was taken out of service and detailed analysis was performed to determine the root cause of the increase in dissolved gasses.

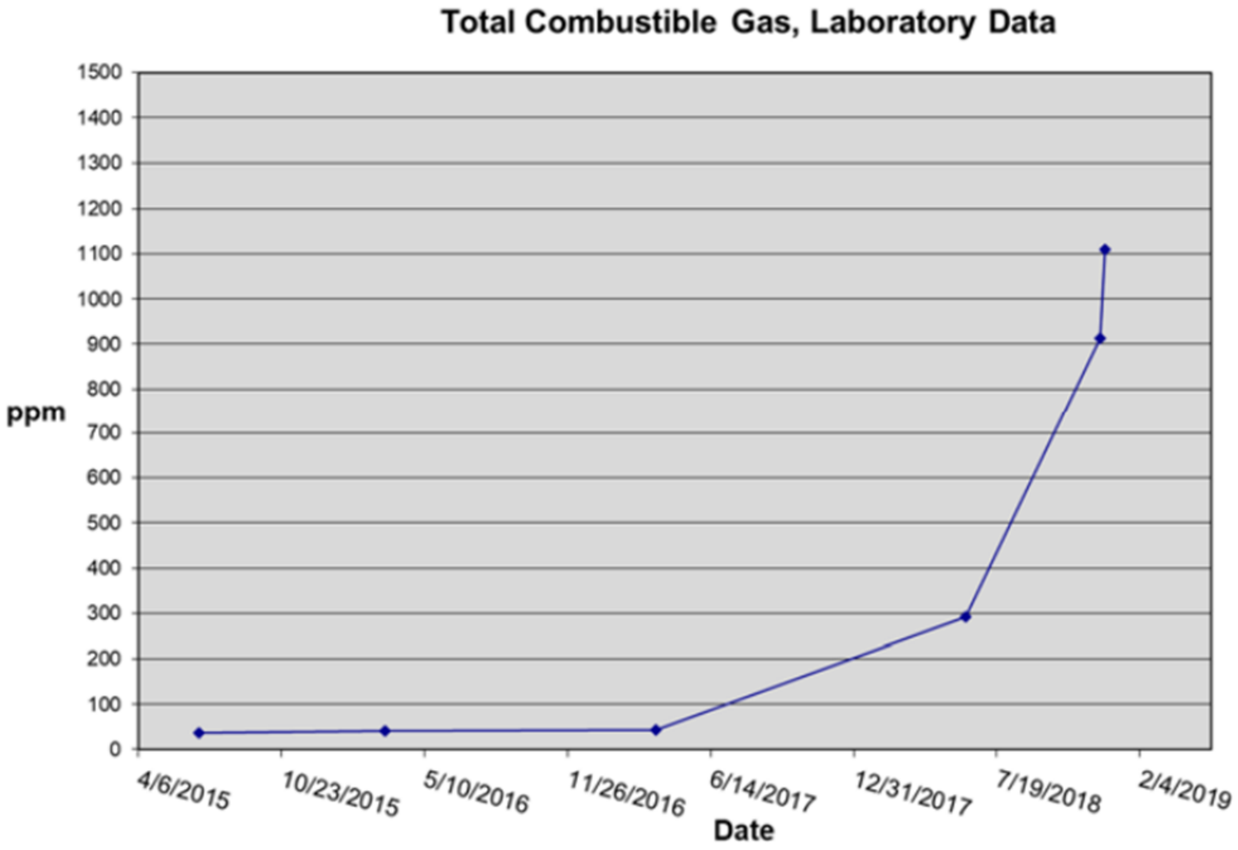
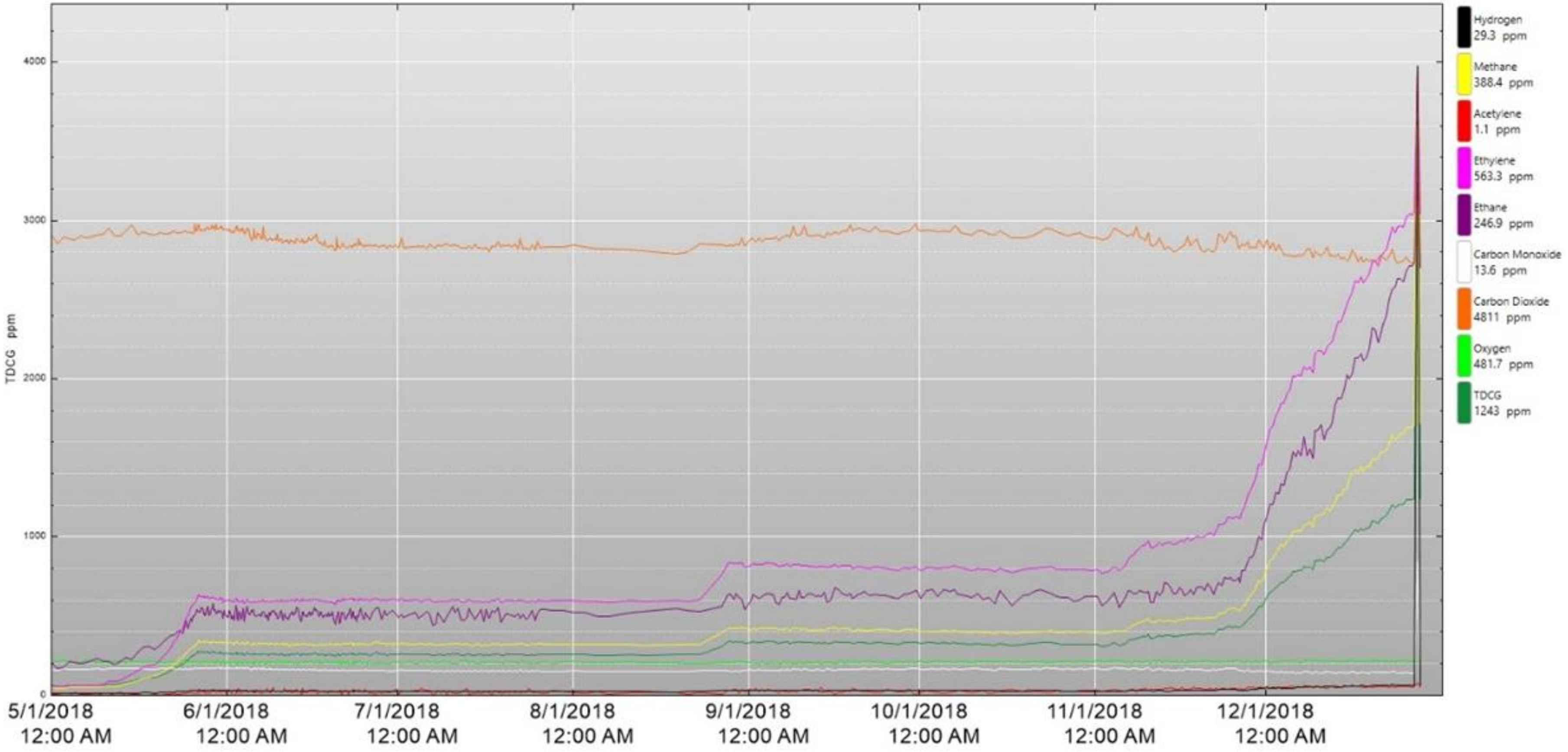


Figure 3: Total Combustible Gas – Lab Data

2018/2019 - MWP KW1A Investigation

- Specifically, CAP identified increases in ethylene, ethane, and methane.
- These increases indicate heating of the transformer oil.
- The ratio of gasses indicated that the overheating of oil was not occurring on a bare metal surface and was more likely taking place at a paper-wrapped location.



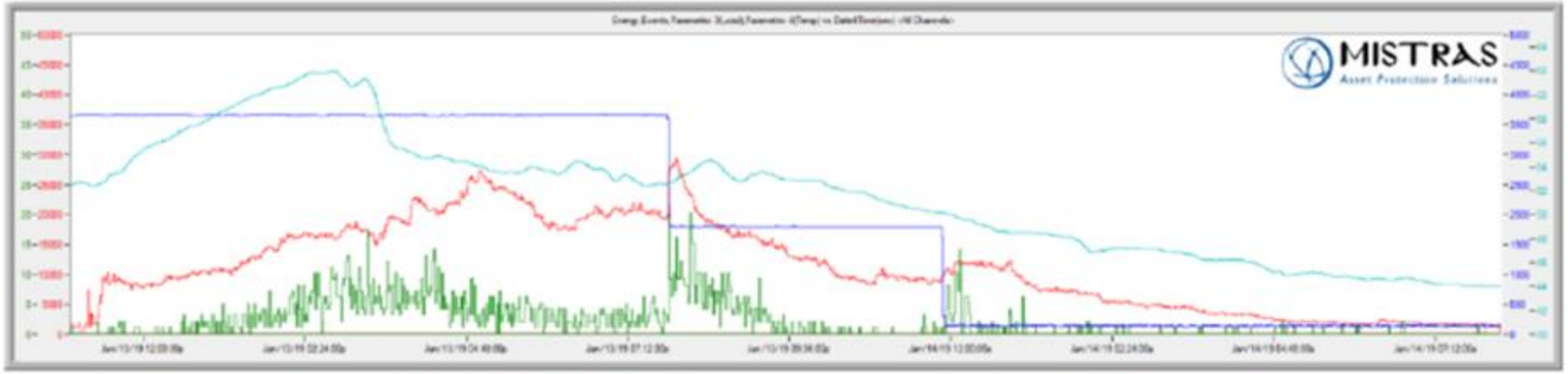
2019 - MWP KW1A Investigation

- In January 2019, CAP worked with Doble to perform a detailed investigation to determine the overheating source in the transformer.
- The investigation included visual inspection, acoustic emission and partial discharge testing (online), vibration and Infrared screening (online), and off-line transformer electrical testing.

Figure 1b: Right Side

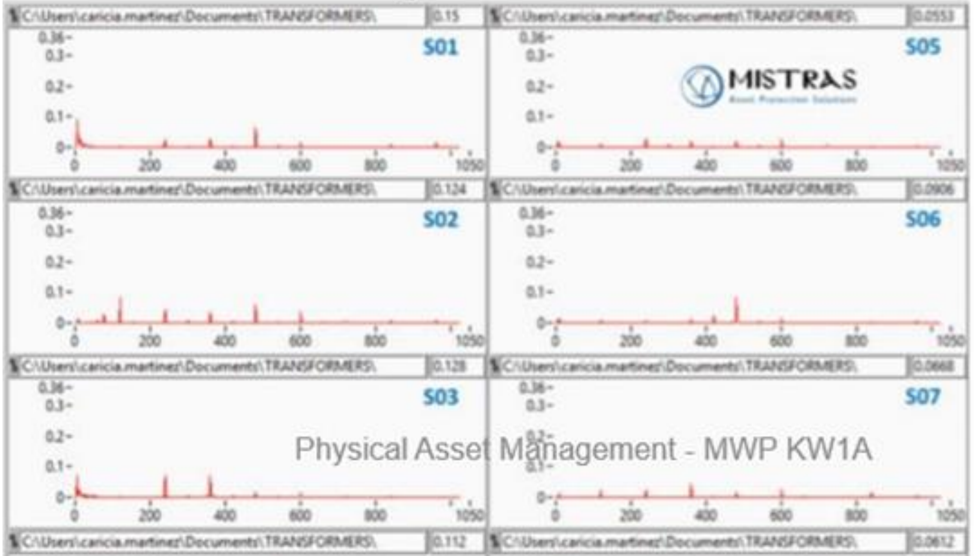
2019 - MWP KW1A Investigation

Acoustical Emission Monitoring

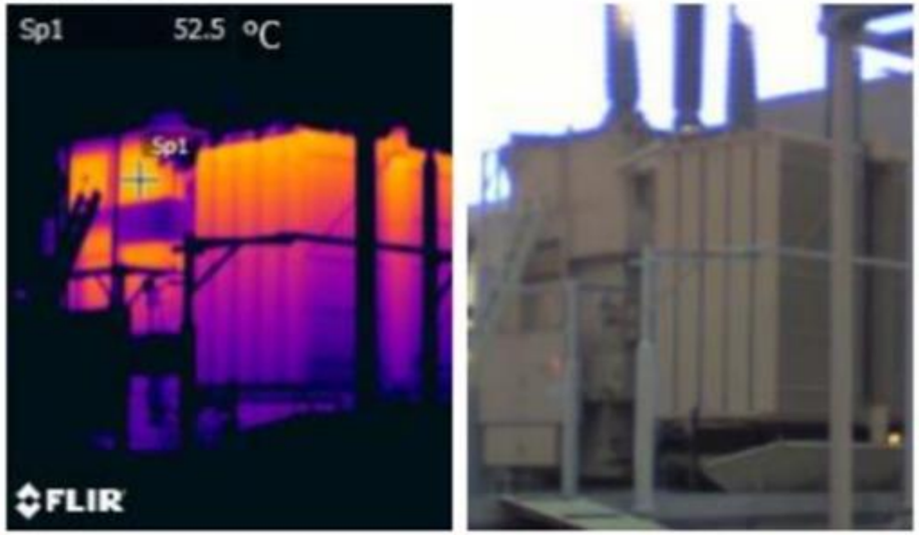


AE Activity for File KW1A_Test01-03_F.DTA

Vibration Monitoring

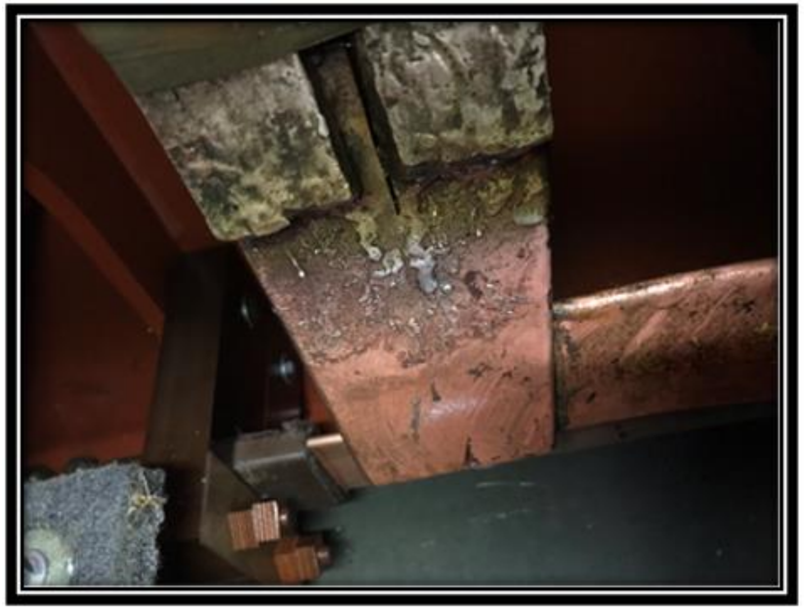


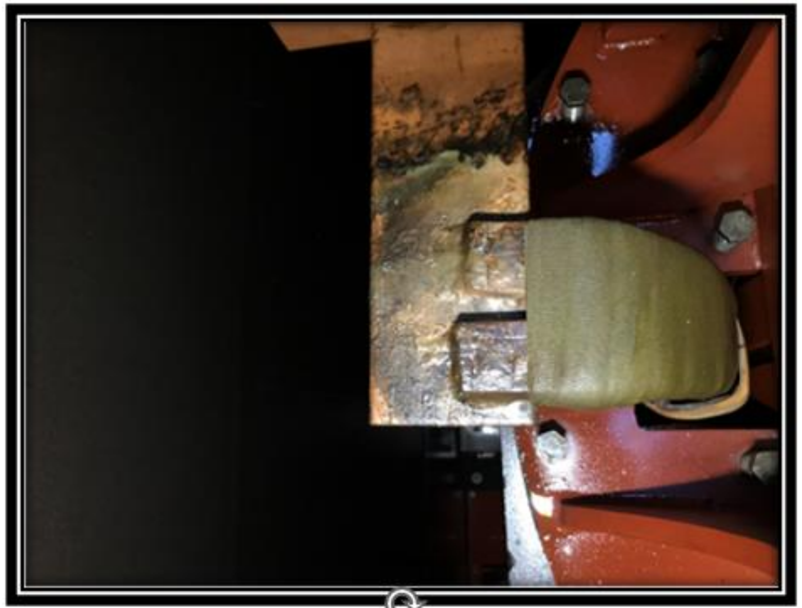
Infrared



View on the left area of the High Voltage side of the transformer

2019 - KW1A Internal Inspection





2019 - KW1A Root Cause and Repairs

- The root cause of the heating was a failure of the “Bank A Cooling Oil - Circulating Bank Pump” which is located internal to the transformer.
- This pump was replaced, the transformer cleaned, and insulating oil was processed to remove gasses, acids, and particulates.
- The transformer was returned to service without incident or significant operational impact.

Activity	*Completed*
Oil processing complete, tank at normal level	4/30/2019
Nitrogen applied to transformer top – 2psig	4/30/2019
Kelman piping re-installed and valves open	5/1/2019
Wiring to circulating pump and flow switches completed	4/28/2019
Electrical Acceptance tests completed	5/1/2019
Release 480VAC auxiliary source	4/29/2019
Check rotation of circulating oil pumps	4/29/2019
Verified fans and pumps control logic	5/2/2019
Verify 86T trip cutout switches are open and lockout relay reset	5/2/2019
Terminate CCB7 terminals 1A3 and 1A5 wiring	5/2/2019
Verified 125VDC breaker 1 on panel CCA3R is closed	5/2/2019
Verified the following 86T1 trips	
Sudden pressure relay 63TF1 (also verify associated alarm)	5/2/2019
Low oil level 71TQLX1 (also verify associated alarm)	5/2/2019
High Hot spot temperature 49TA1 & 49TB1	5/2/2019
Verified the following alarms	
Top Oil Temperature 26TQ	5/2/2019
Oil flow 80TQXA & 80TQXB	5/2/2019
Loss of auxiliary power 27TC	5/2/2019
Cooling system selector switch “off” 43TCA 7 43TCB	5/2/2019
Pressure relief 63TRA1 & 63TRB1	5/2/2019
Nitrogen pressure trouble 63TSPL-1, 63TTPH-1 & 63TTPL-1	5/2/2019
Verified 86T1 is reset, close trip cutout switches.	5/2/2019
Verified Kelman is automatically taking oil analysis	5/1/2019
Installed 13.8kV buss-section and links	5/2/2019
Installed 230kV leads	5/2/2019
Transformer has sat for 24hours without oil processing	5/2/2019
Removed grounds and release clearance	5/2/2019
Properly configured 13.8kV bus	5/2/2019
Energized transformer with minimum load for 24 hours	5/3/2019
MWP - Pumps 1 started at 10:00 am	5/4/2019
MWP – Pump 2 started at 11:00 am	5/24/2019

MWP KW1A Take Away's

- 80-90% of failure modes cannot be identified with time, age, or wear based activities.
- When considering risk mitigation, early indication of deteriorating conditions and early intervention are more effective than just limiting the impact of the failure.
- Continuous online dissolved gas monitoring is a best practice for proactive risk mitigation on transformers.
- In this case, the use of online DGA monitoring allowed CAP to identify a hidden failure prior to a functional failure that would have significant repair costs and possible impacts to unit availability and CAP's ability to optimize equipment utilization to minimize power costs.
- Don't just contain the fire – Prevent the fire