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37 Years of Fleet Operating Experience Using Phosphate Ester Fluids for Bearing Lubrication in Gas Turbine/Turbo Compressor Applications

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Source: TransCanada

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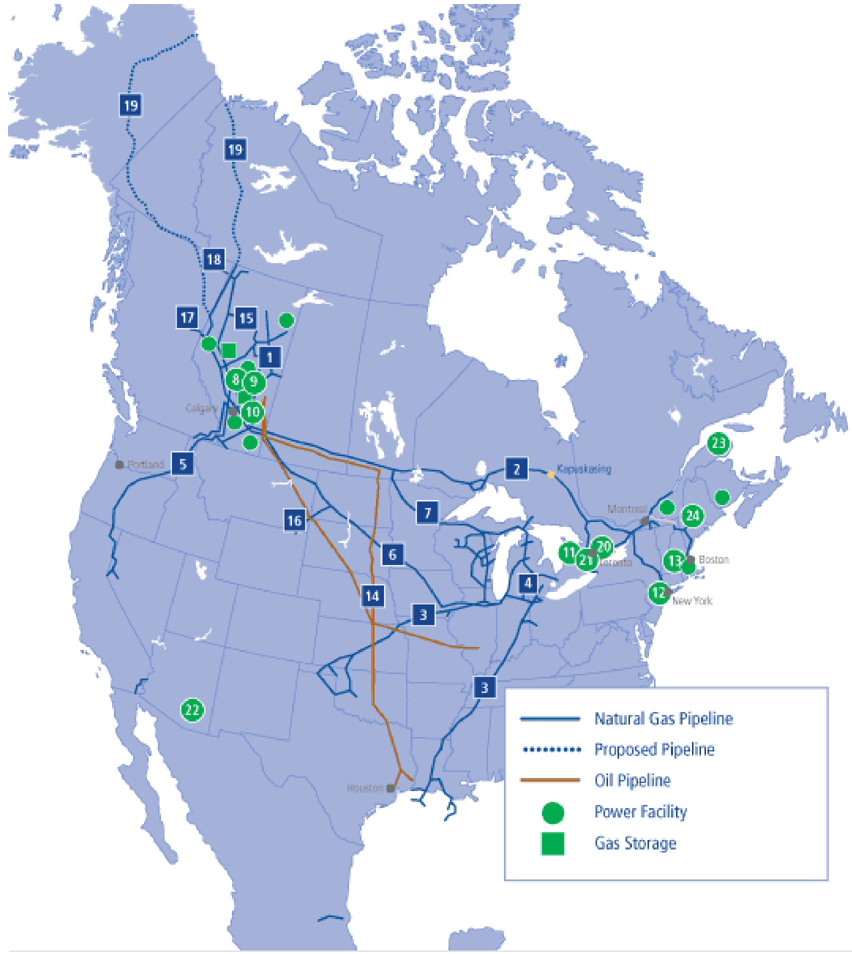
Introduction: TransCanada

- Started operation in 1958
- Grown to become one of the largest and most sophisticated pipeline companies in the world
- 35,500 miles of natural gas pipelines transporting more than 20% of the natural gas consumed in North America
- Moves 15 billion cubic feet (Bcf) of natural gas per day
- 244 gas turbine compressor packages
- Significant gas storage assets >250 Bcf
- Significant power generation expertise



Source: TransCanada

Introduction: TransCanada

1 of >100 Compressor Stations

Main Line

Source: TransCanada

Introduction: TransCanada

- Strong track record of building and operating hydro, simple cycle, combined cycle, and natural gas fired power plants
- Innovative use of natural gas, and waste heat recovery from pipeline compressor stations
- Halton Hills Generating Station is an excellent example of an ultra-modern generating station using state-of-the-art low emissions technology, built in compliance with high environmental standards

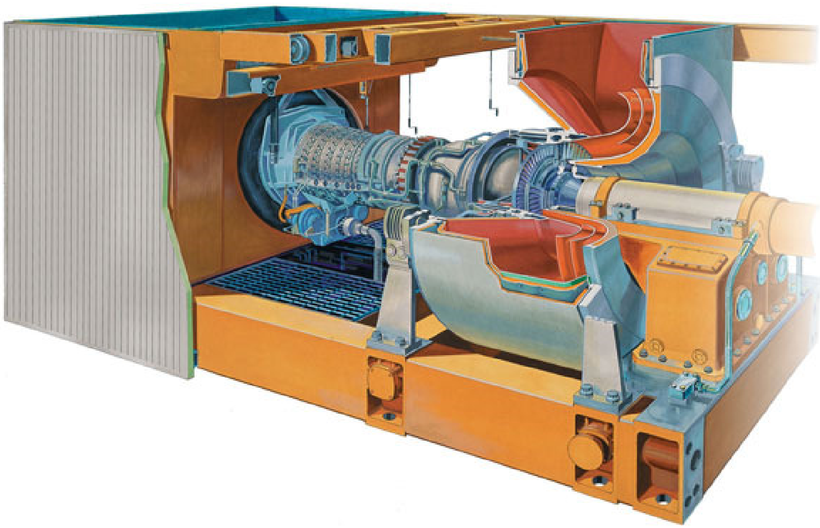
Halton Hills Generating Station
Source: TransCanada

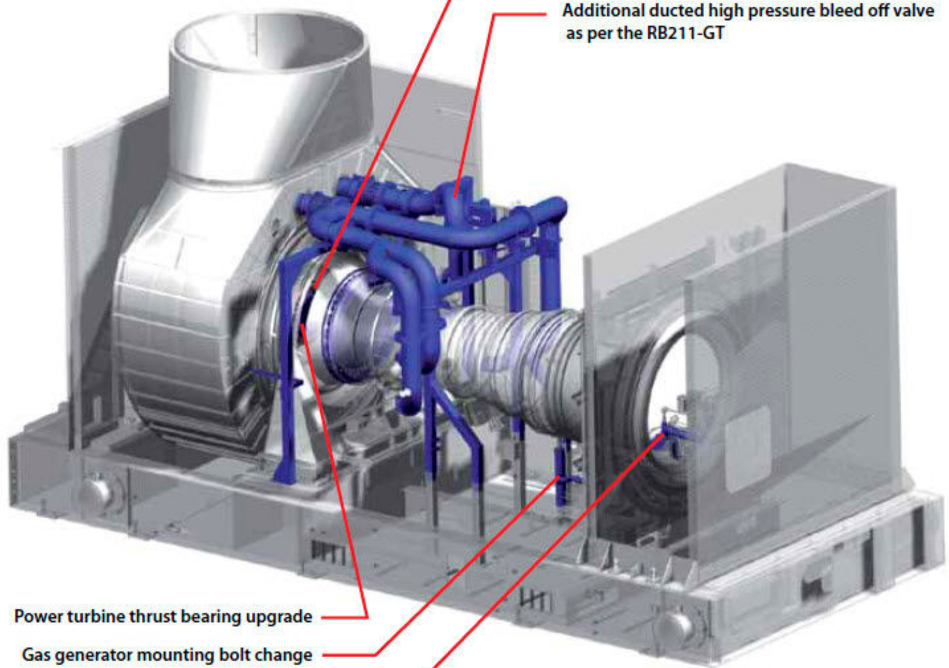
Introduction: TransCanada

- Gas Turbine Compressor Stations designed to operate remotely
- Integrated Health, Safety and Environment (HSE) Management System to minimize risk to the environment, staff, and facilities
- Every year work to reduce emissions and develop technologies to improve environmental performance
- Phosphate ester, fire-resistant fluids used in a majority of the gas turbine compressor packages to minimize the risk of fire

TransCanada Gas Control, Calgary
Source: TransCanada

Typical Equipment Configuration





LM2500 Driven Power Turbine Compressor
4400 gal phosphate ester lubricant reservoir

RB211 Driven Power Turbine Compressor
1050 gal phosphate ester lubricant reservoir

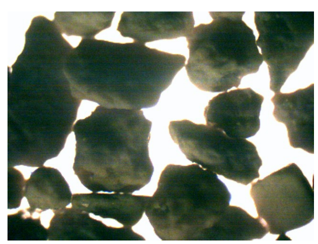
Phosphate Ester Safety

- Based on the design and application, after any turbine shutdown, the high pressure seal oil pump or backup pump must run for 6 minutes to evacuate all natural gas from the system until compressor pressure is reduced from 1000 psi to <50 psi
- Phosphate ester is used to provide <u>sustained fire resistance</u> during this period

Historical Lubricant Maintenance Practices

- From 1958-1981, six 11x19” Fuller’s Earth filters were used to manage acid levels. (approximately 297 lb Fuller’s Earth to 12,500 lb of phosphate ester = 2.4%)
- Filtered when AN >0.50 and shut down when AN <0.30
- Average reservoir life was 5 years
- Fluid maintenance requirements varied directly with which year each reservoir was in the fluid life cycle

Fuller’s Earth Filters
Source: The Hillard Corporation



Fuller’s Earth 4x
Source: EPT

TransCanada Acid Removal System, Source: EPT

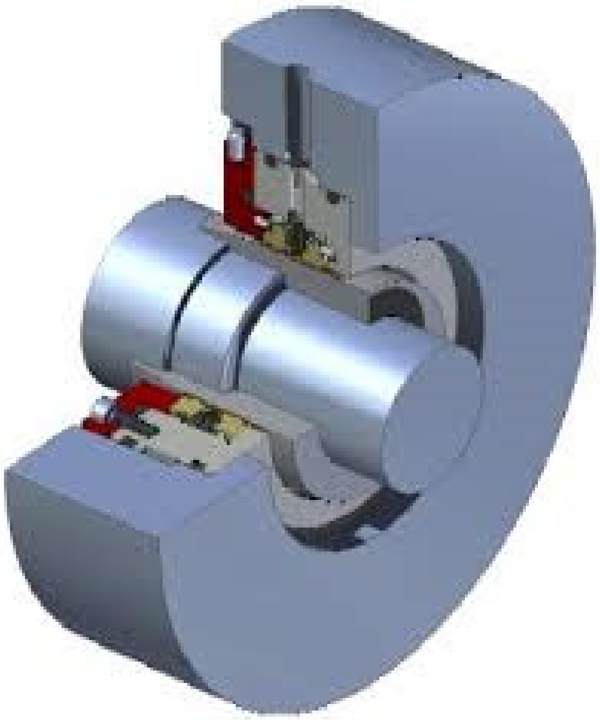
Fluid Maintenance Costs Pre-1984 Using Fuller's Earth

Figure 3: Historical Lubricant Maintenance Costs 1958-1984

Fluid Maintenance Costs by Life Cycle Year	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
# Sets of Acid Filters (6 filters per set)	4	6	8	10	12	40
Filter Costs ($250/filter)	6,000	9,000	12,000	15,000	18,000	1,200,000
Disposal Costs ($100 per filter)	2,400	3,600	4,800	6,000	7,200	480,000
Labor Costs (4 hrs. @ $50/hr. per change)	800	1,200	1,600	2,000	2,400	160,000
Fluid Make-up Costs from filter change ($50/gallon/1 Drum per filter change)	11,000	16,500	22,000	27,500	33,000	2,200,000
Fluid Maintenance Costs	20,200	30,300	40,400	50,500	60,600	4,040,000
# of turbines in each life cycle	20	20	20	20	20	
Total Annual Maintenance	404,000	606,000	808,000	1,010,000	1,212,000	4,040,000
Reservoir Replacement Costs						1,050,000
Total Maintenance and Fluid Replacement Costs						5,090,000

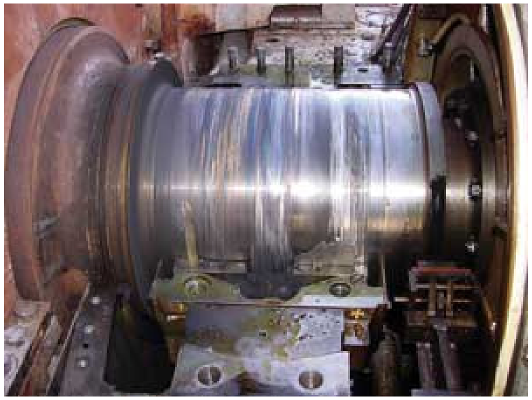
High Pressure Seal Oil Issues

- Until 1997 high pressure seal oil systems were used
- Seal clearance is 0.0015” and is designed this way to minimize oil flow across the seal during full pressure operation (1150 psi).
- Small amount of oil flow is required across the seal to maintain temperature <150°F
- Lubricant deposits on the seal surfaces caused restriction of oil flow/overheating/ melting of babbit surfaces resulting in seal failure
- Repair costs were $120,000 per occurrence and 3.5 days of lost production during repair



Industrial Turbine Journal and Thrust Bearing Damage

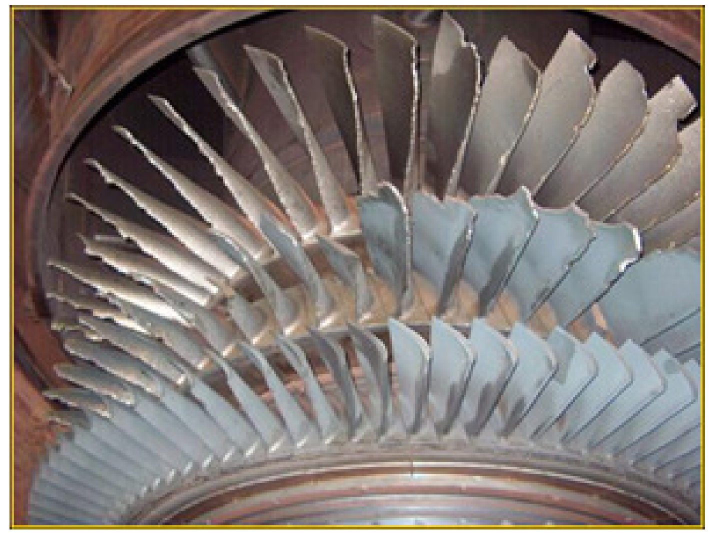
- Three bearing applications
  - Forward tilt-pad journal bearing (axial compressor)
  - Center bearing (combustor assembly)
  - Thrust pad bearing (gas producer turbine rotating assembly)
- Bearing clearances are approx. 0.0065”
- Lubricant deposits on the bearing surfaces lead to bearing failure
- Secondary damage can occur
  - Total failure of all rotating gas path blading
  - Total failure of non-rotating guide vanes or nozzles of the gas producer turbine assembly
- Repair costs were $1.5-2.5 million with 21 days of lost production



Failed Journal and Thrust Bearing photos
Source: Machinery Lubrication

Power Turbine Damage from Thrust Bearing Failure

- Power turbine is the mechanical driver of the gas, but is not connected to the gas turbine
- Most thrust bearing failures caused secondary damage by the excessive bearing clearances, which allowed the high pressure and low pressure turbine rotors to contact the stationary blading of the power turbine
- Repair costs were $1.5-2million with 21 days of lost production



Damaged Power Turbine
Source: Dynamic Power Technologies

Cost of Lubricant Deposit Related Failures

Figure 2: Annual Mechanical Failure Costs from 1980-1992, Fuller's Earth

Mechanical Failure Costs Per Year Associated with Lubricant Deposit Formation.	Mechanical Failure Cost Per Incident	# of Incidents Per Year	# Days to Repair	Cost
Application				
Natural Gas Compressor/ High Pressure Seal Assembly	120,000	20	3.5	2,400,000
Industrial Turbine/ Thrust Bearing	2,000,000	4	21	8,000,000
Power Turbine/ Thrust Bearing	1,500,000	2	21	3,000,000
				13,400,000

The Search for Better Fluid Purification

- The heavy maintenance requirement using Fuller's Earth, high cost, and the excessive equipment failure associated with lubricant deposits led to the search for other types of acid filters
- Alumina based filters demonstrated greater acid reduction, but added a new issue: fluid foaming which was attributed to Na ingression from the filter material
  - Anti-foam additives used to control but eventually provided no relief
- Maintenance costs and fluid life were similar to those associated with Fuller's Earth
- No reduction in seal failures or other mechanical failures was observed

Activated Alumina Pellets
Source: EPT

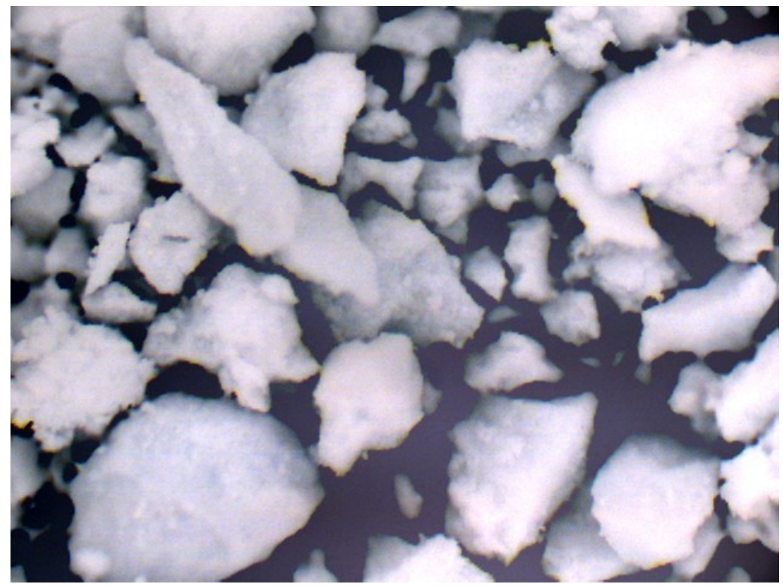
Lubricant Maintenance Costs 1984-1987, Alumina

Figure 4: Historical Lubricant Maintenance Costs 1984-1987, Alumina Filters

Fluid Maintenance Costs by Life Cycle Year	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
# Sets of Acid Filters (6 filters per set)	3	4	5	8	10	30
Filter Costs ($432/filter)	7,776	10,368	12,960	20,726	25,920	1,555,200
Disposal Costs ($100 per filter)	1,800	2,400	3,000	4,800	6,000	360,000
Labor Costs (4hrs@$50/hr.per change)	600	800	1,000	1,600	2,000	120,000
Fluid Make-up Costs from filter change (250Liters per change)	8,250	11,000	13,750	22,000	27,500	1,650,000
Fluid Maintenance Costs	18,426	24,568	30,710	49,136	61,420	3,685,200
# of turbines in each life cycle	20	20	20	20	20	
Total Annual Maintenance	368,520	491,360	614,200	982,720	1,228,400	3,685,200
Reservoir Replacement Costs						1,050,000
Total Maintenance and Fluid Replacement Costs						4,735,200

The Search for Better Fluid Purification

- Since mechanical failures were unresolved using alumina based filters, the search for low sodium alumina based filters began, and led to the usage of Selexsorb® filters (aluminosilicate)
- Fluid foaming issues were resolved and initial results were positive until wide spread reservoir gelling was noted
- Maintenance costs and fluid life were similar to those associated with the other two products
- No reduction in seal failures or other mechanical failures was observed



Selexsorb® at 4x
Source :EPT

Selexsorb is a registered trademark of BASF

Historical Lubricant Maintenance Practices

Figure 5: Historical Lubricant Maintenance Costs 1987-1992, aluminosilicate

Fluid Maintenance Costs by Life Cycle Year	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
# Sets of Acid Filters (6 filters per set)	3	4	5	8	10	30
Filter Costs ($600/filter)	10,800	14,400	18,000	28,800	36,000	2,160,000
Disposal Costs ($100 per filter)	1,800	2,400	3,000	4,800	6,000	360,000
Labor Costs (4hrs@$50/hr.per change)	600	800	1,000	1,600	2,000	160,000
Fluid Make-up Costs from filter change (250Liters per change)	8,250	11,000	13,750	22,000	27,500	1,650,000
Fluid Maintenance Costs	21,450	28,600	35,750	57,200	71,500	4,290,000
# of turbines in each life cycle	20	20	20	20	20	
Total Annual Maintenance	429,000	572,000	715,000	1,144,000	1,430,000	4,290,000
Reservoir Replacement Costs						1,050,000
Total Maintenance and Fluid Replacement Costs						5,340,000

The Need for Better Fluid Purification

- By 1989, the high costs of fluid maintenance (5 million dollars per year) and excessive mechanical failures (13.4 million dollars per year) was making the continued use of phosphate ester fluids economically unviable
- The downtime and lost production ($869,000/day) was pushing management towards conventional lubricants and installation of fire suppression systems at a cost of $200,000 per unit
- Time to resolve the ongoing fluid maintenance issues was limited

The Search for Better Fluid Purification

- In 1989, based on some earlier experiences from Europe where ion exchange resins were tested for acid removal in phosphate ester, investigation began
- Since ion exchange filters were not available, a local manufacturer was used
- Different types of ion exchange resins were field trialed
- Several issues and technical challenges were experienced but eventually overcome
- By 1992, ion exchange elements were installed on a fleet wide basis

ICB™ ion exchange resin at 10x and Filter Canister, Source: EPT

Fluid Purification Solution Achieved

- Ion Exchange Findings
  - 90% of all reservoirs regardless of Acid Number could be returned to <0.10 mg/KOH/g
  - Metals ingression from acid filters (Fuller's Earth, alumina, and aluminosilicate) was eliminated
  - Existing metals reduced to <10 ppm over time
  - Foaming eliminated
  - Gelling eliminated
  - Maintenance costs reduced by 88%
  - Mechanical failures reduced by >95%
  - Lost production virtually eliminated
  - Axial flow format filters were preferred
  - Stainless steel construction

Lubricant Maintenance Costs – Ion Exchange

Figure 7: Historical Lubricant Maintenance Costs 1992-2013

Fluid Maintenance Costs by Life Cycle Year	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
# Sets of Acid Filters (6 filters per set)	0.7	0.7	0.7	0.7	0.7	3.3
Filter Costs	3,492	3,492	3,492	3,492	3,492	349,200
Disposal Costs	0	0	0	0	0	0
Labor Costs	133	133	133	133	133	13,333
Fluid Make-up Costs from filter change	1,833	1,833	1,833	1,833	1,833	183,333
Fluid Maintenance Costs	5,459	5,549	5,459	5,459	5,459	545,867
# of turbines in each life cycle	20	20	20	20	20	
Total Annual Maintenance	109,173	109,173	109,173	109,173	109,173	545,867
Reservoir Replacement Costs						131,250
Total Maintenance and Fluid Replacement Costs						677,117

Lubricant Maintenance Cost Savings using Ion Exchange Purification

Figure 8: Lubricant Maintenance Program Cost Savings 1992-2013

Fluid Maintenance Costs by Life Cycle Year	1987-1991	1992-2013	Cost Savings Per Year	# of Years	Total Cost Reduction
Filter Costs	2,160,000	349,200	1,810,800		
Disposal Costs ($100 per filter)	360,000	0	360,000		
Labor Costs (4hrs@$50/hr.per change)	160,000	13,333	106,667		
Fluid Make-up Costs from filter change (250Liters per change)	1,650,000	183,333	1,466,667		
Fluid Maintenance Costs	4,290,000	545,867	3,744,133		
Reservoir Replacement Costs	1,050,000	131,250	918,750		
Total Maintenance and Fluid Replacement Costs	5,340,000	677,117	4,662,883	21	97,920,550

Reduced Equipment Failure using Ion Exchange Purification

Figure 9: Mechanical Cost Reductions Achieved 1992-2013

Mechanical Cost Reductions Achieved with TransCanada Lubricant Maintenance Program.	Mechanical Failure Cost Per Incident	Reduction in # of Incidents Per Year	Annual Total	# Years	Total
Application					
Natural Gas Compressor/ High Pressure Seal Assembly	120,000	20	2,400,000	5	12,000,000
Industrial Turbine/ Thrust Bearing	2,000,000	4	8,000,000	21	168,000,000
Power Turbine/ Thrust Bearing	1,500,000	2	3,000,000	21	63,000,000
Total Mechanical Cost Reduction			13,400,000		243,000,000

Environmental Waste Reduction

Figure 10: Filter and Phosphate ester Waste Reduction Calculations 1992-2013

# of Fuller's Earth Filters used per year that would be landfilled	**4,800**
Ion exchange filters per year that are used	400
Reduced number of filters used per unit per year	4,400
Total reductions between 1992-2013	92,400
Total filter waste reduction (Lbs.)	5,082,000
Annual Phosphate Ester Fluid Consumption pre 1992 (Gal)	65,000
Annual Phosphate Ester Fluid Consumption post (Gal)	8,800
Total reductions between 1992-2013 (Gal)	1,108,200
Lubricant waste reduction (Lbs.)	13,926,000
Total filter and lubricant waste reduction (Lbs.)	19,008,360

Lessons Learned

- The rate of acid production is not linear and increases as acid number increases
- If AN values can be maintained at very low levels, less fluid maintenance is required
  - Since 1995, TransCanada Operating Procedure has set AN upper limit at 0.07
- The presence of dissolved metals in a phosphate ester lubricants makes them less stable and prone to more rapid acid production and fluid foaming
- Solid deposit formation in phosphate ester applications occurs predominantly when dissolved metals are present.
  - When the metals can be removed and maintained at very low levels, this primary pathway to solid deposit formation can be avoided
- Fluid gelling was observed when the use of aluminosilicate filters were applied to in-service, degraded, phosphate ester lubricants

Summary

- The use of ion exchange resin purification has been used successfully for the past 21 years on over 100 gas turbines demonstrating that ion exchange provides safe, reliable, and cost effective acid removal
- Ion exchange filtration has a very high capacity to remove acids and also removes the harmful metals contributed by the other types of acid removal filters
- The removal of these metals reduces the lubricant's propensity to form deposits, therefore the associated mechanical failures can largely be avoided

Summary

- TransCanada's use of ion exchange purification has reduced environmental waste by 19 million pounds. (9,047 lb per turbine per year)
- The use of ion exchange resin purification has significantly reduced lubricant maintenance costs, saving TransCanada $97 million dollars since 1992 or approximately $1 million dollars per turbine ($46,306 per turbine per year)
  - Return on investment (ROI) on the fluid maintenance program at TransCanada is 689% excluding mechanical failure reductions
- The use of ion exchange resin purification has reduced equipment failure to nil saving $13.4 million per year ($134,000 per turbine per year)
- Based on the excessive failure costs before 1992, the continued usage of phosphate ester may have been considered economically unviable, unless ion exchange resin purification was adopted

Acknowledgements

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