CHAPTER 13

CLEANING PROCEDURE

List of Contents

1 GENERAL

When the gas turbine performance data indicates a reduction in the performance, or the Gas Compressor discharge temperature indicates a rise of 17°C above the 'clean' condition, a Water Wash procedure should be carried out.

Two methods of Gas Turbine Compressor Cleaning may be carried out:

» **The Crank (Off Line) Wash** procedure is to be carried out whilst the Gas Turbine is shut-down and the Exhaust Temperature indication is below 200°C. A recommended cleaning agent may be used in conjuction with the water to improve the cleaning action.

» **The On-Line Wash** procedure may be carried out whilst the Gas Turbine is operating at its minimum speed. Warm water of acceptable quality is to be used without the addition of a cleaning agent (unless a cleaning agent is approved by the Gas Turbine manufacturer).

NOTE: It is preferential that the Crank Wash procedure be adopted as the normal cleaning method. The On-Line Wash procedure should only be used where the Gas Turbine is on continuous duty and shutting-down is impracticable.

2 CRANK (OFF LINE) WASH PROCEDURE

1. If the Turbine has been operating, allow it to cool so that the outside surfaces are below 90°C, and the indicated Exhaust Gas Temperature is below 200°C. Cooling can be expedited by carrying out a Manual Cranking procedure.

2. Pour the specified quantity, required for a 90 litre solution, of the recommended Cleaning Agent into the recepticle to be used. Place the recepticle alongside the Gas Turbine Enclosure and place the pick-up pipe into the recepticle.

   The Gas Turbine manufacturer's recommended cleaning agents are:

   » Rivenæs Motor Cleaning Agent
   » B & B 3100
   » Ardrox 6322
   » Cleaners meeting the requirements of the USA specification MIL-D-16791

WARNING: Observe all manufacturer's warning with regard to the handling, storage and mixing of their products. For example B & B Cleaner in concentrated form is flammable (Flash Point 68.9°C closed cup) and caustic and the following warning applies:

Use only in a well ventilated area, do not smoke or use near open flame. Avoid inhalation of fumes and direct contact of liquid with eyes or skin. Wear protective rubber gloves, apron and face shield or goggles as exposure to skin or eyes may cause irritation.

3. Where a possibility of low temperatures exist an anti-freeze such as acetone; methyl ethyl ketone or isopropyl alcohol can be added to the wash water.

NOTE: The use of nonisopropyl alcohols, ethylene glycol, or additives containing clorine, sodium or potassium are not permitted since they may attack the titanium and other metals in the Gas Turbine.

WARNING: Acetone, methyl ethyl ketone (MEK) and isopropyl alcohol are extremely flammable. Use only in a well ventilated area, and keep away from sparks or flame. Avoid inhalation of the fumes which are toxic upon prolonged exposure or in high concentrations.

4. At the active control terminal select the CONTROL FUNCTIONS Screen and move the screen cursor to alongside the 'Off Line Water Wash System Enable' option and depress the ENTER Key to instigate the water wash sequence. Observe the colour of the function reference changes to yellow to indicate that the function is activated.

5. Change the display screen to that for AUXILLIARY SEQUENCE and observe the progess of the water wash procedure. The OFF LINE WATER WASH ENABLED indication will be YES.

6. The starter is commenced for three minutes period and at the end of that time provided that the gas generator speed is greater than 5000 rpm the wash cycle will proceed.

NOTE: If the turbine compressor inlet temperator is detected to be less than 3°C then an alarm will be given to indicate that anti-freeze should be added to the wash water. If this has already been done the operator may continue the sequence by selecting 'Acknowledge' on the CONTROL FUNCTION Screen. Otherwise the sequence will be aborted to allow the Operator to add anti-freeze to the water before recommencing the sequence.

7. The Water Wash Tank Vent and Water Supply Valves will be opened and the Wash Tank will be filled to a level of 90 litres. Where a detergent is to be added to the wash water, the action of the water flow through the inlet pipe will create a suction; that will draw the additive from it's recepticle into the wash tank.

8. The water supply valve is closed and the Water Wash Tank Heater is energised. The heater will raise the temperature of the water (solution) to above 50°C and is then de-energised.

9. The Water Wash Tank Vent Valve is closed.

10. The starter is operated to the level one speed. As the starter increases the speed of the Gas Generator above 1200 rpm a three minute start timer is activated.

11. Provided the Power Turbine Inlet Temperature is less that 93°C the Nitrogen Supply and Off Line Shut-off Valves are opened to inject the wash solution into the gas turbine inlet by the drillings in the Gas Turbine Bellhousing.

12. At the end of the timed starter operating segment the operation of the starter motor is discontinued. When the Gas Generator speed falls below 100 rpm the Water Wash Tank Vent Valve is opened and the Water Supply and Off Line Shut-off Valves are closed. If the Water Wash Tank is detected not to be empty then the process is repeated from stage 9 until the solution is used up.

13. A delay timer is commenced for three minutes period and at the end of that time the Water Supply Valve is opened.

NOTE: If the turbine compressor inlet temperator is detected to be less than 3°C then an alarm will be given to indicate that anti-freeze should be added to the wash water. If this has already been done the operator may continue the sequence by selecting 'Acknowledge' on the CONTROL FUNCTION Screen. Otherwise the sequence will be aborted to allow the Operator to add anti-freeze to the water before recommencing the sequence.

14. The Water Wash Tank will be filled to a level of 160 litres.

15. The water supply valve is closed and the Water Wash Tank Heater is energised. The heater will raise the temperature of the water to above 60°C and is then de-energised.

16. The Water Wash Tank Vent Valve is closed.

17. The starter is operated to the level one speed. As the starter increases the speed of the Gas Generator above 1200 rpm a ten minute start timer is activated.

18. The Nitrogen Supply and Off Line Shut-off Valves are opened to inject the water into the gas turbine inlet by the drillings in the Gas Turbine Bellhousing.

19. At the end of the timed starter operating segment the operation of the starter motor is discontinued. When the Gas Generator speed falls below 100 rpm the Water Wash Tank Vent Valve is opened and the Water Supply and Off Line Shut-off Valves are closed. If the Water Wash Tank is detected not to be empty then the process is repeated from stage 16 until the solution is used up.

20. The rinse cycle is repeated for a second time and when the Water Wash Tank is confirmed empty of water the starter will be started to drive the Gas Generator at an idle speed for five minutes to dry the gas turbine.

3 ON-LINE WATER WASH PROCEDURE

1. The Turbine will be operating with the Gas Generator Speed below 8500 rpm.

2. Where a possibility of low temperatures exist an anti-freeze such as acetone; methyl ethyl ketone or isopropyl alcohol can be added to the wash water.

NOTE: The use of nonisopropyl alcohols, ethylene glycol, or additives containing clorine, sodium or potassium are not permitted since they may attack the titanium and other metals in the Gas Turbine.

WARNING: Acetone, methyl ethyl ketone (MEK) and isopropyl alcohol are extremely flammable. Use only in a well ventilated area, and keep away from sparks or flame. Avoid inhalation of the fumes which are toxic upon prolonged exposure or in high concentrations.

3. At the active control terminal select the CONTROL FUNCTIONS Screen and move the screen cursor to alongside the 'On Line Water Wash System Enable' option and depress the ENTER Key to instigate the water wash sequence. Observe the colour of the function reference changes to yellow to indicate that the function is activated.

4. Change the display screen to that for AUXILLIARY SEQUENCE and observe the progess of the water wash procedure. The ON LINE WATER WASH ENABLED indication will be YES.

5. If the turbine compressor inlet temperator is detected to be less than 10°C then an alarm will be given to indicate that anti-freeze should be added to the wash water. If this has already been done the operator may continue the sequence by selecting 'Acknowledge' on the CONTROL FUNCTION Screen. Otherwise the sequence will be aborted to allow the Operator to add anti-freeze to the water before recommencing the sequence.

6. The Water Wash Tank Vent and Water Supply Valves will be opened and the Wash Tank will be filled to a level of 90 litres.

7. The water supply valve is closed and the Water Wash Tank Heater is energised. The heater will raise the temperature of the water to above 50°C and is then de-energised.

8. The Air Supply and On Line Shut-off Valves are opened.

9. A ten minute timer is started and the Water Wash Tank Vent Valve is closed to inject the water into the gas turbine inlet by the nozzles arranged around the Gas Turbine Bellhousing.

10. At the end of the timed starter operating segment the process will continue until the Water Wash Tank is detected to be empty.

11. The Water Wash Tank Vent Valve will open.

12. The On Line Shut-off and Air Supply Valves will be closed.

4 CLEANING AGENT

Water of a distilled or demineralized quality must be used. This water should conform to the following specification:

» Visually clean and free from solid matter

» Total solids (103°C): Maximum 5 parts per million (5 mg/l.)

» Specific conductance: Maximum 20 micro-ohms per centimeter

» pH value: 5.0 - 7.4

» Intake filtration: Not larger than 10 µm nominal

Handling and storage of water requires care to preserve properties, thus storage should be in stainless steel, epoxy coated steel or ideally non-pigmented detergent grade polyethylene plastic. Storage in glass, fiberglass or ferrous containers should be avoided.

A recommended cleaning agent may be added to the water to improve the cleaning action when carrying out a 'Crank Wash'. Gas Turbine manufacturer's recommended cleaning agents are:

» Rivenæs Motor Cleaning Agent
» B & B 3100
» Ardrox 6322
» Cleaners meeting the requirements of the USA specification MIL-D-16791

WARNING: Observe all manufacturer's warning with regard to the handling, storage and mixing of their products. For example B & B Cleaner in concentrated form is flammable (Flash Point 68.9°C closed cup) and caustic and the following warning applies:

Ues only in a well ventilated area, do not smoke or use near open flame. Avoid inhalation of fumes and direct contact of liquid with eyes or skin. Wear protective rubber gloves, apron and face sheild or goggles as exposure to skin or eyes may cause irritation.

Where a possibility of low temperatures exist an anti-freeze such as acetone; methyl ethyl ketone or isopropyl alcohol can be added to the wash water.

NOTE: The use of nonisopropyl alcohols, ethylene glycol, or additives containing clorine, sodium or potassium are not permitted since they may attack the titanium and other metals in the Gas Turbine.

WARNING: Acetone, methyl ethyl ketone (MEK) and isopropyl alcohol are extremely flammable. Use only in a well ventilated area, and keep away from sparks or flame. Avoid inhalation of the fumes which are toxic upon prolonged exposure or in high concentrations.

NOTE: Residual waste following water wash with solvent type cleaning agents should be disposed of in accordance with local environmental regulations.

DSM Limburg Services
Engineering

3 0 SEP. 1991

ag.nr. 92085 Eng./

antw.nr. Eng./

dossier L 72176

30/9 Postel

RECOMMENDED PROCEDURE FOR EVALUATING THE EFFECTIVENESS OF THE ROCHEM GTE CC 'FYREWASH' ON LINE GAS TURBINE COMPRESSOR CLEANING SYSTEM - MARINE LM2500 ENGINE

1) Postel
Seeler Ulrich
ks, 3x
T. Hendriks 2BV

Document Control #TSM1109

6+

ROCHEM GTE CC FYREWASH SYSTEM FOR RUNNING WASH CLEANING OF GAS TURBINE COMPRESSORS

RECOMMENDED PROCEDURE FOR EVALUATING THE EFFECTIVENESS OF GTE CC FYREWASH

ENGINE TYPE: MARINE LM 2500

1.0. PREAMBLE

1.1. Following a number of years of development the Rochem GTE CC FYREWASH system is now in successful commercial use throughout the world for the on-line, full-load cleaning of a wide variety of industrial on-shore and off-shore gas turbines as well as ground-idle washing of helicopter engines and auxiliary power units in commercial airliners.

1.2. This system was specifically designed for on-line compressor washing and is not a hybrid of a cold, crank-wash type of syste.. since both procedures are entirely different and require a much different approach.Specifically, any system for on-line cleaning of compressors must be carefully designed in terms of both chemical and method of application to insure complete safety of use and effective result as discussed below.

2.0. WHICH TYPE OF CHEMICAL IS BEST SUITED TO ON-LINE COMPRESSOR CLEANING ?

2.1. The cleaning chemical used must be formulated so that during transition through the compressor it must remain 'stable' regardless of the rapid rise in temperature and pressure i.e. the chemical elements of the formulation should not separate out or form as a deposit on the compressor blading, particularly in the hotter stages or combustion and turbine zone.

2.2. General crank-soak cleaning chemicals are only designed for 'cold' washing and if used for 'fired-washing' can result in severe problems of deposition whereby the fluid itself, or residuals of the fluid, form a sticky mass inside the compressor which attracts and traps airborne contaminents to drastically reduce compressor efficiency thus reducing engine output and increasing specific fuel consumption.

2.3. This problem can occur regardless of whether the cold cleaning chemical is solvent based or so-called 'aqueous'-based.

2.3. Rochem GTE CC FYREWASH cleaning chemical is a solvent-based material which has been carefully formulated to remain in a 'stable' condition during its cleaning process and transit through the operating compressor. Among it's unique characteristics is it's ability to stay in permanent, stable solution with water in which it is mixed in a ratio of 4 to 9 prior to injection into the compressor; the water-mix ratio being dependent on the degree of fouling being dealt with and the frequency of compressor washing.

2.4. Rochem chose to develope a solvent-based material for on-line washing simply because the 'catalyist' to compressor fouling in virtually all gas Turbines is the initial laying down of a oily/greasy film on the compressor blades which then attracts and traps dry particulate matter, including salt, which might otherwise have passed harmlesly through the compressor.

2.5. Unless this oily/greasy film - which results from the injestion of oily vapours ,engine bearing leakages and re-injestion of exhaust emissions and the like - is 'cut', dissolved and removed by the micro-encapsulation process of the cleaning fluid it will continue to build-up in the first 4 or 5 colder stages of the compressor to significantly reduce engine performance.

cont...2/

2.6. The only truly effective material that will remove this oily/greasy base deposit is a solvent-based chemical such as GTE CC FYREWASH and this has been proven in practice against many other cleaners.

2.7 A so-called 'aqueous-based' material - having a water content as high as 98% in some cases - might possibly be quite effective in removing water-soluable deposits. Unfortunately the fouling which can radically affect gas turbine compressor performance is rarely if ever 'water soluable' so such a material can have little cleaning effect because the very small amount of surfactant (perhaps 2 to 5% only) contained in the water is clearly not powerful enough to dissolve oil,grease of carbon deposits.

2.8. On the other hand, FYREWASH chemical is produced as a 100% concentrated material containing virtually no water. It is a complex blend of anionic and non-ionic surfactancts, solvents, glycolethers and other compounds carefully blended to provide a highly stable formulation which is fully compatible with the materials of the engine in which it comes into contact.

2.9. Even when mixed with water, FYREWASH fluid still contains 20 to 10% of active chemicals or up to ten times more active material than aqueous materials - yet its cost of use can be several times less.

2.10. It is also interesting to note that FYREWASH is the only generally approved solvent-based product for fired-washing among the numerous aqueous fluids.

2.11. In the case of turbines operated in the marine environment salt injestion can be an additional major problem although in most modern naval vessels special salt removal systems are fitted in the intakes to prevent ingress of saturated salt droplets (i.e.liquid salt) and/or anti-icing air inlet systems which decreases relative humidity, converts the saturated droplets to dry salt crystals which can be filtered out before reaching the compressor. Salt contamination in marine turbines is therefore not so much a problem of how much salt enters the engine but how much is actually trapped inside the compressor to cause pitting corrosion. If the compressor is kept dry and clean through regular washing the salt crystals have less chance of sticking to the surfaces. However, if there is an oily/greasy surface the salt can be trapped below and within this material. At this point water-washing to bring the salt back into solution and out of the compressor is fruitless since it cannot 'cut' through the oil to make contact with the entrapped salt.

3.0. THE IMPORTANCE OF METHOD OF APPLICATION

3.1. In order to safely and effectively carry out compressor washing with a turbine running at up to full speed and load the physical method of application must be very carefully designed and proven in practice.

3.2. Washing a compressor in the cold, crank-wash mode presents few dangers and large volumes of chemical in a 'deluge' wash process can be injected into the compressor, drained away and flushed out with clean water

3.3. However, cleaning the compressor when the engine is fired presents a number of (a) clearly defined dangers if the method of wash-fluid injection is not carefully thought-out and (b) the guarantee of a negative result in terms of cleaning and performance recovery. These dangers can be briefly summarised as follows:

cont..page 3/

PROCEDURE FOR EVALUATING EFFECTIVENESS
OF GTE CC FYREWASH SYSTEM - MARINE LM2500

3.3.a. AVOIDING THERMAL SHOCK & BLADE EROSION

The flow rate of wash fluid into the operating compressor has to be controlled to a safe level to avoid any possibility of thermal shock, overloading of the compressor or blade erosion over time.The fluid should therefore be injected in a finely-atomised form.

3.3.b. AVOIDING REDEPOSITION IN LATTER STAGES OF COMPRESSOR

Too high a flow-rate can result in a 'wash-out' effect whereby the wet,oily deposit from the first 3 or 4 stages can be washed-off by the high speed deluge effect of the fluid and re-deposited in the hot after-stages without there being time for the chemical dissolving action to take place.

The objective is therefore to merely 'wet' the inlet air with a minimum amount of cleaning fluid so a chemical cleaning action takes place on deposits on the blade suface. Once the deposit is dissolved and its chemical bond is broken it will shed from the blade into the fast flowing air stream and be carried safely into the combustion system where it is harmlessly burned with the fuel. In effect the high-speed air-flow through the compressor performs a similar function as as post-flush with water on the dissolved and loosened deposit.

3.3.c. AVOIDING CENTRIFUGING OF THE CLEANING FLUID

Large droplets or streams of fluid can also result in the fluid being centrifuged out by the action of the first stage rotor such that it merely flows along the inside surface of the comprésor casing without making contact with the compressor blading thus wasting the cleaning fluid and giving a negative cleaning result. Good atomisation, giving small droplets of small mass and weight will not be radically affected by centrifuging.

3.3.d. AVOIDING STRATIFIED AND UNEVEN CLEANING OF THE COMPRESSOR

Comprehensive circumfrential distribution of the cleaning fluid is essential in order to avoid stratified or segmented cleaning of the compressor which could result in rotational imbalance and vibration.

Correct fluid distribution requires the proper placement of a set of fluid atomising nozzles around the bellmouth inlet of the compressor. If there are 'gaps' in the coverage there will be corresponding 'gaps' in the cleaning of the compressor. Once the 'wetted' air enters the bellmouth it flows in an axial/laminar pattern so the blading - particularly the stators - which are in-line with a specific streamline which has not been wetted will not be cleaned.

3.3.c. USING NATURAL AIR-FLOW AND TURBULENCE PATTERNS TO BEST EFFECT

Point of injection of the atomised cleaning fluid is also very important in achieving a positive and comprehensive cleaning result.

cont...page 4/

PROCEDURE FOR EVALUATING EFFECTIVENESS
OF GTE CC FYREWASH SYSTEM - MARINE LM2500

3.4. Over the years Rochem has researched and experimented with the question of the most effective place or point of injection of cleaning fluid into the operating compressor.

3.5. The result of this work is a current patent-pending protection in the U.S. for a method of injection which employs the use of the slower-speed, more turbulent air zone just outside the compressor bellmouth.

3.6. Early experimentation showed that attemps to inject a cleaning fluid from a position anywhere inside the bellmouth resulted in the following:

(i) Severe shearing effect at the tip of the atomising nozzles due to the air speed over the nozzle resulting in the loss of atomisation effect and consequent streaming of the fluid off the nozzle. The resulting 'jets' of fluid being centrifuged out by the action of the first stage rotor giving at best a cleaning of the outer tips of the first few stages.

(ii) Little or no facial coverage of the compressor since the fluid leaves the nozzles in an unbroken stream and there is no further 'spread' of the material due to the axial, laminar air flow at this point resulting in at best stratified cleaning in line with the fluid 'streamlines'

(iii) Potential problems of inducing turbulence into the air flow as the result of nozzles penetrating the air flow

(vi) Potential danger of having nozzles, couplings, manifolds etc inside the plenum area

(v) Inability to inspect or maintain the equipment without having to shut-down the engine.

(vi) Practical difficulties and time required to install nozzle assemblies and impracticality of fitting systems to existing engines.

(vii) Uneccessarily high cost of equipment and installation.

3.7. On the other hand the Rochem philosophy of injecting the cleaning fluid into the slower speed, more turbulent air stream outside the bellmouth results in the following advantages:

(i) The atomisation and spread of fluid from the nozzles is less radically affected since the air speed over the nozzle tip is typically only 15 to 35 ft/sec whereas once its transits into the bellmouth there is a rapid acceleration to the order of circa 250 to 350 ft/sec over a very short distance of not more than a few feet.

(ii) This enables more realistic injection pressures of 100 to 150 psig to be used to inject the fluid.

cont...page 5/

(iii) The convergent air flow around the bellmouth is very turbulent and by injecting the atomised fluid into this zone it is fully dissipated and entrained into the air stream prior to entering the bellmouth. As the air is wetted by the small droplets of fluid during the injection phase - typically 8 to 10 minutes - it is drawn into the bellmouth and compressor in a mist-like form so that it is not radically affected by the initial centrifuging action of the first-stage rotor blades with the result that full root to tip wetting of the blades can be achieved.

(iv) Atomising nozzles can easily be fitted through the fabricated plenum wall in a radial pattern around the bellmouth so that only the nozzle tips are protruding a few inches into the plenum in a zone where any slight turbulence created by them is of no consequence.

(v) The associated fittings and manifold ring of the nozzles are thus on the outside of the plenum wall instead of on the inside and by a special design which makes it impossible for the nozzle to pass completely into the plenum under any circumstances there is no danger of mishap.

In the case of a naval vessel whose machinery has to withstand potentially high shock and vibration forces this is an important consideration.

(vi) By fitting the nozzles and manifold assembly on the outside of the plenum they can easily be inspected and maintained - even while the engine is running if necessary. The design for connecting each nozzle to the manifold ring allows individual nozzles to be removed and replaced without disturbing the rest of the nozzles or manifold.

(vii) The installation of nozzles through the fabricated plenum wall allows for simple retro-fit to existing engines - typically a Rochem nozzle system can be fitted to most types of turbine in 4 to 8 hours by a team of two persons e.g. fitter/welder and helper.

(viii) By its nature this type of installation is much less complex than having to install atomising nozzles and manifolds directly onto the engine bellmouth so the cost of equipment is also considerably less.

4.0. THE ADVANTAGES OF ON-LINE COMPRESSOR WASHING VS OFF-LINE WASHING

4.1. Off-line or crank-soak cleaning of compressors is essentially a short-term cure rather than an attempt to prevent or diminish the problems associated with compressor fouling and attendent loss of output and performance.

4.2 Crank-washing will restore compressor cleanliness and efficiency but between each crank-wash cycle the compressor will continue to foul-up and lose performance with the amount of loss being a function of the time between washes.

4.3 The lost performance and the substantial amount of extra fuel burned in the process can never be recovered. In the past, before on-line, full-load chemical cleaning of compressors was developed and proven to be viable. Industrial gas turbine operators with minimal opportunities for shut-down

cont..page 6

simply accepted the performance loss and extra operating costs as an unavoidable consequence of gas turbine operation. However, many operators are now enjoying the benefits and savings offered by the Rochem FYREWASH system and these can be listed as follows:

5.0. ADVANTAGES OF ON-LINE 'FIRED' WASHING OF COMPRESSORS

5.1 No requirement to shut down for laborious and time-consuming crank washing. Even in the case of naval marine turbines where there may be more opportunity to shut-down the savings in time and labour are an important consideration.

5.2. Enables output and efficiency to be maintained at all times since the simple 10-minute cleaning exercise can be carried out on a regular programmed basis or whenever performance loss is evident. For naval ships which demand the availability of full power at all times this is a considerable advantage.

5.3. Compressor washing with engine at up maximum speed and load is a design feature of the FYREWASH system so the procedure does not interfere in any way with the desired operation of the engine. In the case of military vessels this means that a compressor wash which was in process when the vessel was put on action stations could either be allowed to continue or stopped by the turn of a valve.

5.4. Avoids comptletely damaging shut-down/start-up thermal cycles that are associated with crank-washing. Even with naval ships the normal procedure is to carry out a fired drying run after a crank-wash so by adopting a fired-wash routine whenever the vessel is underway using gas turbine power these additional thermal cycles can be completely avoided thus considerably adding to the life of hot section components and reducing longer term maintenance costs.

5.5. Reduces excessive wear and tear on starting motors which during a crank-wash routine are even more overloaded than normal as large volumes of wash fluid and rinse water are drawn through the compressor. Diesel starting systems in particular can be subject to early or unexpected failure due to the demands of additional running cycles for crank-washing whereas fired washing makes no demands whatsover on starters.

5.6. Completely eradicates the problem of dealing with waste wash fluid which is a major concern and possible pollutant hazard in the aftermath of crank-washing. In the case of fired washing virtually all of the compressor foulants and the residual wash fluid are burned and incinerated into an inert gas in the combustion system so there is no waste fluid to store and safely dispose of or any air pollution. In the case of FYREWASH fluid which is hydrocarbon based it will simply act as an additional fuel when it reaches the combustion zone although its relatively low rate of injection of just a few gallons per minute will not upset the normal combustion process.

cont..page 7

6.0. EVALUATION AND UTILISATION OF FYREWASH SYSTEM IN MARINE LM2500

6.1. The FYREWASH system is currently in use in a number of GE LM2500 and LM5000 industrial land-based machines with one LM2500 installation on an offshore-oil production platform.

6.2. The marinised version of the LM25000 is similar in most respects to the commercial industrial unit excepting for a small s.h.p. de-rate in output and the use of an additional inlet screen (FOD guard) over the bellmouth which the commercial unit does not normally have.

6.3. At the present time Rochem is also working with Fiat Aviazione and the Italian Navy for the installation of a trial LM2500 FYREWASH system in a warship. The method of application, equipment and trial procedures have been approved and installation of the system and commencement of the trial is imminent; Fiat having previously evaluated and approved GTE CC FYREWASH fluid and its method of application. Please see letter to this effect which is enclosed.

6.4. The FYREWASH atomising nozzle/manifold installation arrangement for non-naval LM2500 engine utilises the standard Rochem format of a series of nozzles mounted through the fabricated plenum wall - in this instance the aft wall nearest the bellmouth and an installation drawing of this arrangement is enclosed for interest.

6.5. In the case of the marine LM2500 with its specially designed plenum and additional inlet screen it was decided to initially design a simple-yet-safe-to-install and operate retro-fit 'bolt-on' nozzle/manifold ring assembly per the enclosed drawing.

6.6 As noted, the manifold ring is fitted and secured over the inlet screen with atomising nozzles positioned such that they spray through the mesh of the screen and across the face of the bellmouth. A total of 16 atomising nipples are securely welded to the manifold ring and each developes a (static) 80 to 90° spread of fluid. With the engine running there is a 'squeeze' effect on the spray pattern which reduces the spread to an approx 60° fan but with 16 nozzles this is still more than sufficient to provide complete facial coverage of the bellmouth and compressor.

6.7. Since there are no individual component parts of the nozzle/manifold assembly which are smaller in size that the inlet screen mesh openings there is no possibility of passage into the compressor of any part of the noozle/manifold ring even in the highly unlikely event of a complete break-up of the assembly which in the majority is a solidly welded construction.

6.8. The wash fluid is fed to the manifold ring by a single fixed or flexible interface pipe which connects to the existing crank-wash piping system so that the existing pressure injection tank can be utilized for fired-washing.

6.9. The positioning of the nozzle/manifold ring is such that it does not interfere with the air-flow into the bellmouth.

cont..page 8

PROCEDURE FOR EVALUATING EFFECTIVENESS
OF GTE CC FYREWASH SYSTEM - MARINE LM2500

6.10. The nozzle/manifold ring assembly is designed to break-down into four sections for ease of transportation, passage through the small plenum access door and simple installation - estimated time for which should be no more than an hour or two

6.11. Rochem's selling price for the entire assembly, constructed entirely from stainless steel materials,is approx.US$ 7,000 ex-warehouse U.S.A.

6.12. The equipment is manufactured by Rochem and availability is 2 to 3 week from order.

7.0 GENERAL RECOMMENDATIONS FOR TRIALLING GTE CC 'FYREWASH' AGAINST ANOTHER FIRED-WASH CLEANING FLUID AND/OR SYSTEM

7.1. If FYREWASH is to be evaluated against another running wash material it is obviously easier to determine the relative merits of either material by utilising two identical LM2500 engines installed in the same vessel and the trialling/evaluation period would also be halved. If one engine was used it may prove more difficult to assess the superiority of one material over the other.

7.2. As noted, Rochem consider it very important to have the correct method of application in terms of nozzle placement, wash fluid flow rates etc.

7.3. Therefore it is assumed that some form of suitably designed application system would be fitted to the trialling engine or engines or Rochem will be requested to supply the injection apparatus (as earlier described)

7.4. Rochem suggests that the existing inbuilt crank-wash fluid injection system of the LM2500(i.e.holes drilled near the lip of the bellmouth) would not be suitable for an on-line washing trial since the flow rates would be too high and the fluid distribution would be ineffective for the reasons previously discussed.

7.5. However, prior to implementing a running wash trial programme the operator may wish to consider testing the cleaning efficiency of both materials by carrying out a short programme of conventional crank-washing. This would help to at least determine the ability of either chemical to remove the compressor contaminents and provide a reasonable prior indication of which may be more effective when applied to the operating engine.

7.6. In any event Rochem's standard guidlines - whenever one of its systems is installed - calls for the compressor to be crank-washed to a clean condition prior to commencing the normal on-line washing routine.

7.7. The objective is to start with a clean engine and keep it clean by regular line washing rather than attempt to clean-up a heavily fouled compressor. Starting with a clean compressor also provides the essential data points againts which the ongoing performance of the on-line system can be judged.

7.8. It is therefore recommended that the trial engines be post-crank washed with its respective wash fluid before commencing the fired washing trials.

cont..page 9/

PROCEDURE FOR EVALUATING EFFECTIVENESS
OF GTE CC FYREWASH SYSTEM -MARINE LM2500

8.0. PROCEDURES PRIOR TO COMMENCING ON-LINE COMPRESSOR WASHING TRIAL

8.1. Ensure that engine performance readings have been logged prior to shutdown after last operating cycle.

8.2. Prior to crank-washing visually inspect and photograph (as far as possible) the cleanliness of the compressor.

8.3. Crank-wash the compressor of each trial engine per the normal routine using the respective (on-line) cleaning solutions. In the case of Rochem FYREWASH use a dilution ratio of 5 parts water to 1 part concentrate chemical. Total volume of solution as per engine manufacturers recommendation or at volume normally used for routine crank-washing.

8.5. During the crank-wash and post rinse cycles (if possible):

a) Take a sample of waste wash fluid coming from the compressor casing drain just after the wash has commenced and just prior to its completion.

b) Similarly, during the post rinse cycle take a drain sample just at the begining and near the end of the rinse.

The above samples would provide a good visual indication of how much and how quickly the compresor foulants have been removed by the respective wash solutions and if desired could be analysed to determine the levels of salt contamination and rate of removal of same, etc, etc.

8.6. After crank-washing 'fire-up' the engines as normal for the drying cycle and carry out a performance check to determine the level of performance recovery resulting from the crank-wash.

8.7. After engine shut down visually inspect and photograph as far as possible the cleanliness of the respective compressors.

8.8. After installation of the on-line nozzle/manifold assembly carry out a static spray test to ensure all nozzles are spraying correctly.

8.9. In order to obtain a reasonable indication of the distribution and coverage of the on-line washing fluid during running-wash cleaning it is suggested (but not essential) that a chalk line be drawn down the full length of each first-stage rotor and stator blades(i.e. root to tip) about one inch from the leading edge. The chalk will not harm the engine and in Rochem's experience a chalk mark will stay visible on the blading during operation ....but it will be washed off by the cleaning fluid. This is therefore a very simple way of determining whether the wash fluid is wetting the full length of the blades.

cont..page 10

9.0. RECOMMENDATIONS ON EXTENT AND DURATION OF ON-LINE WASHING TRIALS

9.1. As noted elsewhere the objective and philosophy of the Rochem FYREWASH system is to keep a clean compressor clean rather than allow it to become fouled and then attempt to clean it. Any trialling programme should therefore be established on the basis of a series of regular programmed running washes during the trialling period.

9.2. In the case of naval gas turbines whose operating frequency is irregular it is suggested that the washing cycles be based on a specific number of engine operating hours e.g. say every 25 or 50 hours of operation.

9.3. Alternatively, the programme could be based on a compressor wash at every operating cycle of the engine.

9.4. The actual duration of the trial is best decided by the operator but whatever the case it should cover a sufficient number of engine operating hours to establish whether or not the on-line washing routines are capable of maintaining good engine performance levels over long periods without need of crank-washing.

9.5. Previous performance data on the trial engines should help to indicate what the duration of the on-line washing trial should be. e.g. the normally expected reduction and rate of decline in engine performance over a specific number of operating hours or between each crank-wash cycle should first be established. The initial objective is then to establish whether on-line compressor washing will maintain performance over the same period without any significant loss in output.

9.6. An effective on-line washing system will show some degree of performance recovery after every wash if there has been a measurable performance loss since the previous wash.

9.7. Since the naval gas turbine will be operated at varying speeds and loads the simplest way of determining performance recovery after running wash will be to carry out the following procedure;

a) Stabilise the engine at a specific speed and load and take performance readings.
b) Carry out the running wash then re-stabilise the engine back to the same speed and load as before the wash then take the same set of performance readings.

9.8. Apart for the usual data on ambient temperature, barometric pressure etc the most important readings to take before and after each wash will be:

a) Compressor discharge temperature and pressure
b) Exhaust gas temperature
c) Output (shp)
f) Fuel consumption

cont..page 11

11.0. INSTRUCTIONS FOR CARRYING OUT RUNNING WASH WITH GTE CC 'FYREWASH'

The following instructions are those generally given for a Rochem FYREWASH injection system and thus may require to be modified as necessary if the operator uses a system not supplied by Rochem.

11.2. Preparation for on-line cleaning is as follows:

A) OPEN vent valve and CLOSE fluid outlet valve of pressure injection vessel.

B) OPEN chemical inlet valve and fill tank with 5 gallons of concentrate FYREWASH chemical then CLOSE chemical inlet valve.

C) OPEN water inlet valve and fill with 20 gallons of water to make total 25 gallons of wash solution then CLOSE water inlet valve.

N.B. Water quality should be distilled, deionised or demineralised.

D) CLOSE vent valve on tank

E) OBTAIN permission as necessary to commence wash

F) OPEN compressed air supply valve on tank and pressurise to 100 psig (minimum 90 psig) and leave valve OPEN during the wash to maintain steady injection pressure and flow.

G) OPEN wash fluid outlet valve on tank to release fluid to the manifold ring/atomising nozzle assembly.

N.B. The time required to inject 25 gallons of solution at a nominal nozzle manifold pressure of 90 psig should be approx 9 minutes if a Rochem 16-nozzle manifold assembly is being used.

H) AFTER completion of the running wash CLOSE the compressed air valve and allow pressure to drop to a safe level before slowly OPENING the vent valve to bring tank pressure to ZERO.

11.3. About 10 minutes after the wash it is recommended that the entire injection system be purged with about 5 gallons of clean water. To do this simply fill the tank with the water, pressurise as above and release the purge water through the manifold/nozzle assembly so the system is clean and ready for the next compressor wash.

11.4. After purging remove,clean and replace the water,air,chemical inlet filters and the wash fluid outlet filter.

N.B. If the operator is using a pressure injection system not supplied by Rochem it is vital that a good filter be installed at least on the wash fluid outlet to prevent blockage of the nozzles. In its systems Rochem installs filters of 50 microns.

11.4. Since the chemical cleaning action on compressor blade deposits results in a period of post-wash 'shedding' of the deposits it is recommended that post-wash performance readings be taken 15 to 30 minutes after the wash.

oooooo0000000oooooo

ROCHEM "FYREWASH ON-LINE GAS TURBINE COMPRESSOR CLEANING SYSTEM

IN-SERVICE EXPERIENCE IN THE GENERAL ELECTRIC LM2500 & LM5000

1. The FYREWASH system was specifically developed by Rochem for the on-line or fired-wash chemical cleaning of compressors.

2. The FYREWASH system consists of:

   a) A specially formulated solvent/surfactant-based cleaning fluid.

   b) An engineered injection system designed to deliver the cleaning fluid into the air stream just prior to the bellmouth inlet in an atomised form.

3. Currently there are some 300 industrial gas turbines installed with the FYREWASH system and it is also used extensively for the ground-idle fired-wash cleaning of helicopter engines and power recovery cleaning of aircraft APU's.

4. The aggregate number of running hours since the FYREWASH system was installed/used in the above mentioned turbines is estimated to be as follows:

   a) Industrial gas turbines - 3.5 million hours

   b) Helicopter engines/APU's - 1.2 million hours

5. There has never been a single reported incident of damage occuring to an engine as the result of the installation or use of the FYREWASH system.

6. The majority of the industrial engines installed with the FYREWASH system are base-load machines.

7. To date there have been six LM2500's and two LM5000's installed with a FYREWASH system and a further threeLM2500's scheduled for installation in the near future plus one LM5000.

8. In recent years the FYREWASH system has been fitted as original equipment by the following engine manufacturers/packagers:

   a) John Brown Engineering - GE FS5 & FS6 engines

   b) Ruston Gas Turbines - TB5000 & Tornado engines

   c) U.S. Turbines Inc. - Allison 501 & 570 engines

   d) Sulzer - Type 10 engines

a) During the period March to November 1986 the engine was shut down 16 times for crank-washing for an average of 350 hours between shut downs.

b) The average loss of power output between each of these crank-washes was approx 1.5 mW or just over 7% based on an MCR of 22 mW.

From this comparative data the following can be deduced

a) The total loss in megawatt hours in 1986 over the noted period reslting from performance losses between shut-downs for crank-washing would be in the order of 4,700 mW/hrs i.e. 0.8 mW/hrs x 24 hrs x 7 days x 35 weeks.

To this must be added the losses for downtime required for crank-washing i.e. 1 hr x 22 mW x 16 shutdowns = 352 mW/hrs.

All energy is sold to the grip at approx 7 cents per kWh.

Total loss of revenue would therefore be in the order of 5,052 mWh x 1,000 kW x 7 cents = $ 353,639.

This does not include any costs associated with wear and tear on the starting system.nor any labour costs involved in performing crank-washes.

b) The total loss in megawatt hours in 1987 over the noted period while fired washing was being employed are calculated as follows.

0.17 mWh x 24 hrs x 7 days x 35 weeks = 996 mWh plus losses associated with downtime for crank-wash of 1 hour x 22 mW x 5 = 110 mWh.

Total loss in revenue would therefore be approx 1,106 mWh x 1,000 kW x 7 cents = $ 77,420

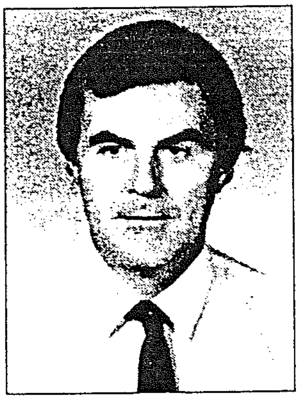
This does not allow for any savings in reduction of wear and tear on the starting system.

This indicates a total net saving for the operator of approx $276,000 over a 35 week period indicating a total potential annual saving in the order of $400,000 based on a 50-week operating year.

The above is supported by the operators calculation that the entire capital cost of the installation was paid for within two weeks of it being operative.

Based on these savings the payback in terms of annual operating cost (chemical usage) over savings is in the order of 100:1

Gas Turbine Compressor Fouling: The Case for On-Line Cleaning



Peter E. McDermott
Managing Director
Rochem Technical Services
London, England

Peter McDermott has been involved in the design and development of on-line gas turbine cleaning systems for some 15 years. He holds the patent on the Rochem Fyrewash on-line cleaning system which is in use with industrial, marine and aviation gas turbines and which has also been adopted by leading gas turbine manufacturers.

Abstract

If done properly, fired-washing can be a very safe and successful method of keeping gas turbines running more efficiently. The process is being constantly improved and perfected and is, without doubt, here to stay as more and more gas turbine manufacturers offer running wash systems as a standard fit or recommended option.

Introduction

Ten years ago performance loss as the result of compressor fouling was generally regarded as a necessary evil inherent in the operation of gas turbines. Little was done about it apart from shutting the machine down from time to time to carry out a time-consuming and laborious crank-soak compressor washing or other cleaning procedures (Figure 1) to restore lost performance.

However, with the popular resurgence of the gas turbine as an industrial prime mover over the past decade, serious interest in the problem of lost performance and increased fuel consumption caused by fouling has led to the development of so-called "on-line" or "fired-wash" compressor cleaning systems. The objective of these systems is to chemically clean the compressor while the engine remains in operation at up to full speed and load in order to extend the output longer and avoid increase in heat rate and subsequent increases in fuel consumption.

In reality, the number of companies and individuals that have been seriously involved in the development of fired-wash systems over the past 10 years or so are few and far between. However, since the process has, of recent, gained the official blessing of some major gas turbine manufacturers, there has been a sudden proliferation of system suppliers and even more running-wash chemical suppliers — who, in many cases, may have scant knowledge or experience of the fired-wash process and the gas turbines to which it is being applied.

If done properly, fired-washing can be a very safe and successful method of keeping gas turbines running more efficiently. The process is being constantly improved and perfected and is, without doubt, here to stay as more and more gas turbine manufacturers offer running wash systems as a standard fit or recommended option.

However, it can also be a dangerous process if injection systems or chemicals are incorrectly designed, fitted or used and operators should be cautious when selecting any on-line cleaning system (see Figures 2 and 3).

Since on-line washing has rather suddenly come into vogue even though deep rooted knowledge and experience of the process is known to rela-

METHODS OF CLEANING FOULED GAS TURBINE COMPRESSOR

OFF-LINE CLEANING METHODS

- Crank-soak chemical washing using in-built chemical injection/water rinsing systems.
- Crank-soak chemical cleaning using hand held hose or lance.
- Partial hand cleaning (e.g. Struts, IGV's, 1st stage rotor & stator blading) using chemicals, rags, brushes and water rinse.
- Full hand cleaning with compressor covers removed using chemicals, various types of abrasives or even light shotblasting techniques.
- Steam cleaning.

ON-LINE CLEANING METHODS

- Injection of abrasives (e.g. crushed nutshells) into the compressor air stream to displace blade deposits by high velocity impingement.
- Injection of plain water to remove water soluble deposits.
- Injection of special chemical solutions (solvent & aqueous based) to chemically dissolve and remove surface deposits from the blades.

Figure 1.

QUESTIONS TO ASK WHEN SELECTING AN ON-LINE CLEANING SYSTEM

ABOUT THE INJECTION SYSTEM

- How long has vendor been in the business.
- An installation reference list.
- Is the system known to engine manufacturers. Do they approve it or have no objection to its installation and use.
- Is the system a recommended option or installed as standard in new gas turbines by any manufacturers/packagers.
- Does the vendor design, manufacture, install, service and guarantee the system himself. (If not, why not).
- Are the materials of the system of good quality
- How long does the vendor say it should take to install the system. Some can take a few hours to install, others can take weeks to install if it involves drilling thick casting etc.
- Is the design safe.
  Could it possibly damage the engine or injure those using it.
- Does the vendor have sufficient liability insurance.

Figure 2.

COST OF FUEL VS ANNUAL OPERATING HOURS SIMPLE CYCLE GAS TURBINES UP TO 25 MW

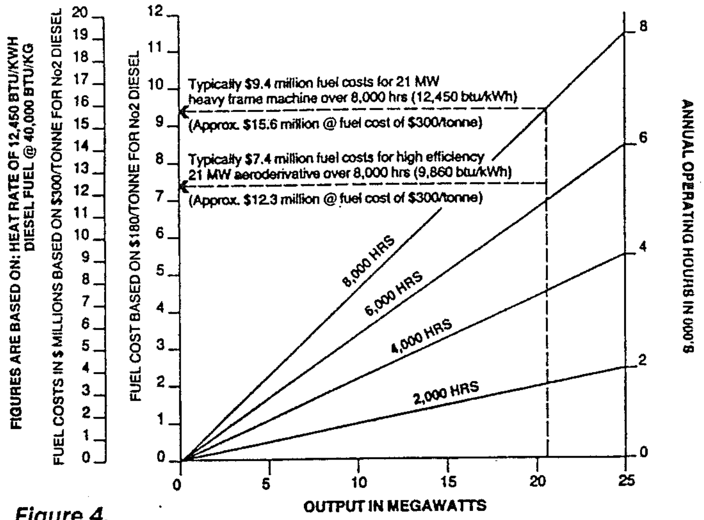


Figure 4.

QUESTIONS TO ASK WHEN SELECTING AN ON-LINE CLEANING SYSTEM

ABOUT THE CLEANING CHEMICAL(S)

- Does the vendor also manufacture special cleaning chemicals for use with the system and are they tried, tested and approved
- Was the chemical on offer solely developed for on-line cleaning or was it originally developed for some other application not connected with gas turbines.
- Does the vendor offer a choice of chemicals (i.e. solvent-based and water based) to suit particular fouling and/or environmental requirements.
- Is the chemical supplied as a concentrate to save storage and transportation costs. Paying for water in ready-to-use chemical solutions can be very expensive and unnecessary.
- Can the chemical offered also be used safely and effectively for off-line compressor washing if need be.
- Does the vendor offer ex-warehouse availability of chemical.
- If the vendor only supplies chemicals are you sure it is safe to use them in your injection system.

Recommendation: Be very wary of using any chemical especially for on-line, fired-washing, unless it has been properly tested and approved and has a good long term safety record behind it.

Figure 3.

ADVANTAGES & DISADVANTAGES OF OFF-LINE CHEMICAL COMPRESSOR WASHING

ADVANTAGES

- When carried out correctly can effectively clean compressor and restore majority of lost performance.

DISADVANTAGES

- Gas turbine must be shut down completely.
- Time consuming process.
- Labour intensive process.
- Costly problems in disposing of waste chemical and rinse water.
- Lost power output cannot be recovered.
- Increased fuel consumption cannot be recovered.
- Shut down/start up thermal cycles for off-line wash are damaging.
- Extra wear and tear on starting system during off-line washing.
- Can wash salt and corrosives into inaccessible parts of engine.
- Only a short term cure & not a prevention for compressor fouling.

Figure 5.

tively few system suppliers and operators, it is hoped that this paper will be of sound practical help to those operators who would like to adopt on-line chemical washing procedures but who are unfamiliar with the concept.

Can On-Line Washing Really be Cost Effective and Is It Really Necessary — Or Just Another Fad?

Due to the current Middle East crisis the cost of fuel has increased by roughly 70% over the past three months, e.g., No. 2 diesel was, as of October 1, 1990, being quoted on the Rotterdam market at $300/ton whereas three months prior it was priced in the region of $180/ton.

Even if fuel drops back to pre-crisis levels in due time the fuel costs for operating any gas turbine are still substantial (see Figure 4) even when the machine is kept in perfect operating condition and at peak efficiency. A fouled compressor can easily increase fuel consumption by 5% or more. In real terms, a 5% increase for the operator of a typical 25 MW heavy industrial unit running base load for say 8,000 hours/year would add over $0.5 million/year to the fuel bill at pre-Gulf crisis fuel prices and close to $1 million extra at current prices.

This should be more than sufficient incentive for any turbine operator to at least investigate the potential benefits of on-line washing to control compressor fouling when the machine is running because the alternative of off-line crank-soak washing (see Figure 5) can only be a temporary cure and not a prevention of the fouling and performance loss that only takes place when the machine is running. Lost performance is precisely that — lost!

Increased fuel consumption is, of course, only part of the story of compressor fouling (see Figure 6). Loss of power output can be an even greater cost penalty if available power is directly related to production, such as in the case of an offshore oil production facility. In that instance loss of power can equate directly with loss of production and revenue. Similarly, cogeneration facilities which sell excess energy

THE DIRECT EFFECTS OF GAS TURBINE COMPRESSOR FOULING

ON DAY TO DAY OPERATING COSTS
- Higher fuel costs due to increased heat rate.
- Reduction in power output & loss of related production revenue.
- Use of more expensive external power supplies to make up shortfall.
- Higher cost of operating standby plant to make up shortfall.

ON LONGER TERM OPERATING & MAINTENANCE COSTS
- Reduction in life of all hot section components due to higher EGT's.
- Higher maintenance costs in more frequent replacement of components.

ON SAFETY
- Possibility of compressor stall & subsequent engine damage.
- Possibility of rotor imbalance, vibration and catastrophic breakup.

ON CAPITAL EXPENDITURE
- More frequent replacement of expensive hot section components.
- Greater investment in non-productive standby plant and redundancy.
- Shorter amortisation periods for entire gas turbine.

Figure 6.

CASE HISTORY OF OUTPUT LOSSES RESULTING FROM COMPRESSOR FOULING (WHEN USING OFF-LINE COMPRESSOR WASHING)

Graph represents a 35 week operating period in 1986 for a 22 mW aeroderivative gas turbine operating in a city environment

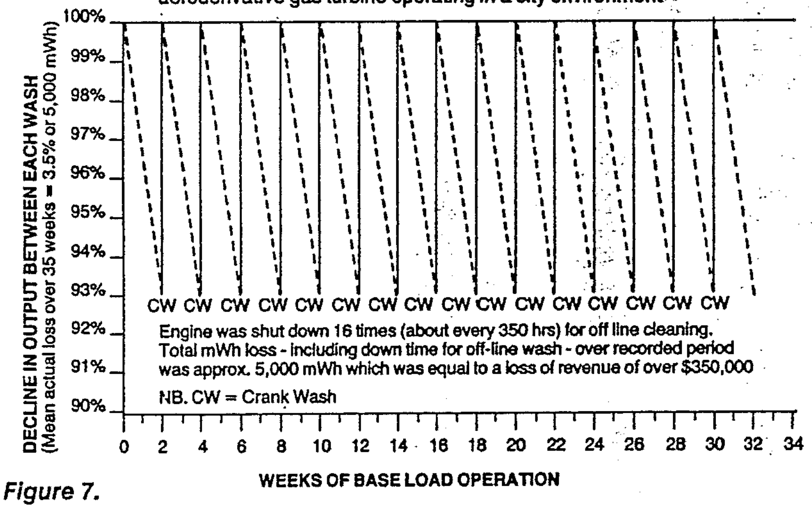


Figure 7.

CASE HISTORY OF OUTPUT LOSSES RESULTING FROM COMPRESSOR FOULING (WHEN USING ON-LINE COMPRESSOR WASHING SYSTEM)

Graph represents a 35 week operating period in 1987 for a 22 mW aeroderivative gas turbine operating in a city environment

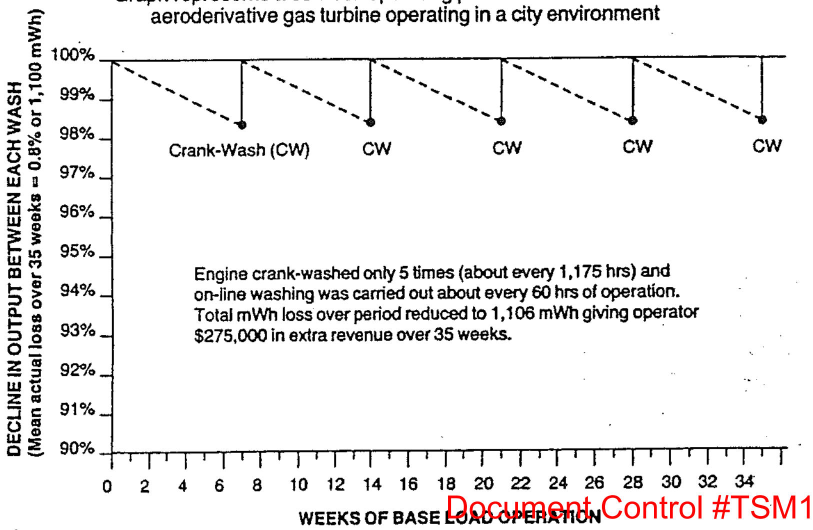


Figure 8.

to guarantee profitable survival can find themselves with major problems if projected amounts of sellable excess power are reduced due to performance loss and/or total shutdown to perform off-line washing to restore lost performance (see Figures 7 and 8).

Based on the above, on-line washing must, in theory, be highly cost effective assuming it works to some reasonable degree and the supplier of the system and chemical is charging on the basis of what it costs to develop, make and service the materials rather than what they think they are saving the customer in fuel or lost output.

In reality a properly designed complete basic running wash injection sytem for a typical industrial gas turbine of around 25 MW — say a GE FS5 — should cost no more than $20,000 and operating cost of cleaning fluid should be around $1,000 to $2,000 per 1,000 running hours depending upon frequency of washing.

The actual cleaning efficiency of the system is wholly dependent on both the method of injection and the cleaning solution, but at the least one should expect to reduce by 50% the rate of degradation that would otherwise be caused by compressor fouling.

If that were extrapolated out in the case of our typical 25 MW/8,000 hour/year baseload machine, the additional extra fuel bill for every 1% increase in fuel burn would be about $110,000 (or $180,000 at present crisis price level). If the on-line washing process prevented even a minimal 50% of this extra fuel burn (a $55,000 or $90,000 saving) then the annual cost of cleaning chemical ($8,000 to $16,000) would be well covered in addition to the capital cost of the system also being recovered from savings within the first six months.

This does not include any cost savings or increased revenue earnings to be realized by maintaining a higher level of output than might normally be expected which can often exceed the potential fuel cost savings (see Figure 8 for actual case history).

Why Not Try To Avoid Fouling Altogether Instead of Spending Time and Money On Compressor Washing Techniques?

The simple answer — at least at this time — is that it is virtually impossible even with the finest multi-stage, high-efficiency, filtration systems to completely avoid compressor fouling.

As indicated in Figure 9, there are many sources of compressor fouling but the worst and the most most common is the ingestion of oil vapors which can readily pass through filtration systems.

Typically, as indicated in Figure 10, these oil vapors are the catalyst to compressor fouling in most cases. After restarting the gas turbine with a clean, dry compressor a film of oily/greasy deposit can build up rapidly on the compressor airfoils (roughly in the first third of the compressor). This forms a perfect "fly-trap" to catch and absorb dry particulate matter which would otherwise have passed harmlessly through the compressor.

In more than 10 years of designing and developing compressor cleaning systems the writer has observed that classic compressor fouling, particularly in polluted industrial environments, is basically a three phase affair.

First, there is the laying down of the oily film and the rapid absorption and entrapment of dry particulates. This can occur within days or even hours after restarting a cleaned engine, and there can be a substantial reduction in output in a relatively short period of time.

Next, there is a slowing down of performance loss as the surface deposit gradually dries and the rate of fouling decreases.

Finally, there is a relatively long phase of slow decline over a period of weeks or even months followed by a further sharp decline as the aerodynamic tolerance of the compressor decreases and/or the surface deposit once more becomes sticky with more oily residues.

A fingernail scratch into the apparent dry, carbonaceous surface deposit on the bellmouth struts of many a compressor is almost sure to reveal the initial oil substrate that was laid down shortly after the cleaned engine was put back into service.

In general, one could say with confidence that compressor fouling would be much diminished if all traces of oil and grease could be prevented from entering the compressor. In this regard close attention to the complete integrity of the air inlet plenum after the filters is strongly recommended since even small breaches can allow inordinately large quantities of unfiltered vapors and particulates to pass freely into the compressor.

Since it is almost impossible to prevent some degree of compressor fouling, the logical approach is to try and find a way of controlling and reducing the rate of fouling and ultimately to control it to a point that it does not affect performance at all.

This means regular compressor cleaning on a sufficiently frequent basis to prevent any meaningful amounts of deposit from building up between each wash and that could mean once per day or once per week depending on operating circumstances.

It would be highly impractical and very costly to do this on a shutdown, crank-wash basis. The only practical solution is on-line or fired washing since this can readily be done without any interference to the normal operation of the engine (Figure 11 and 12).

TYPICAL CAUSES OF GAS TURBINE COMPRESSOR FOULING

- Passage of oily vapours through filtration system.
- Ingestion of oily vapours through breaches in air inlet plenum.
- Leakage of lubrication oil directly into compressor.
- Leakage of oil from oil-bath type filtration systems.
- Passage of very fine particulate matter through filter system.
- Passage of larger particulate matter through breaches in plenum.
- Re-ingestion of exhaust gasses through filtration system & breaches in air inlet plenum casing.
- Ingestion of saturated salt droplets or dry salt crystals through filters and/or breaches in plenum casings.
- Ingestion of seasonal tree and plant gums.
- Ingestion of wide variety of chemicals & other pollutants generated at site of gas turbine operation.

Figure 9.

ASSIMILATION OF RATE OF PERFORMANCE LOSS IN A TYPICAL INDUSTRIAL GAS TURBINE DUE TO COMPRESSOR FOULING

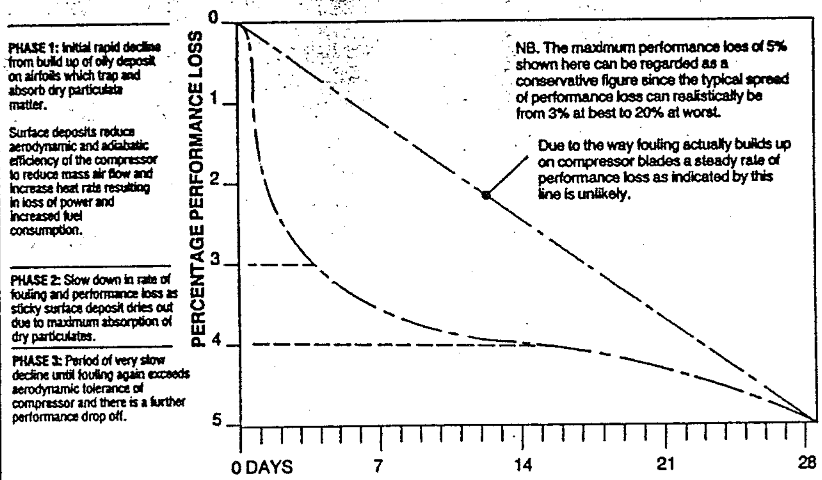


Figure 10.

ADVANTAGES & DISADVANTAGES OF ON-LINE CHEMICAL CLEANING OF COMPRESSOR

DISADVANTAGES OF ON-LINE CHEMICAL CLEANING OF COMPRESSOR

- Can have limited effect if chemical is not properly formulated.
- Can have limited effect if chemical is not injected correctly.
- Some on-line cleaning chemicals are quite expensive and results may not justify the costs in some cases.
- Some on-line cleaning systems are very expensive and are priced against what the customer may save in operation costs rather than what it actually costs to develop and manufacture the equipment.

Figure 11.

Figure 12.

ADVANTAGES OF ON-LINE CHEMICAL CLEANING OF COMPRESSORS

- No engine shutdown required.
- Can arrest or slow down the rate of compressor fouling while the gas turbine remains in operation thus maintaining heat rate and saving large amounts of money by avoiding additional fuel burn.
- Helps maintain power output to avoid loss of production revenue and unnecessary use of standby machines.
- There is no interruption to production or operation routines as washing can be carried out at full speed and load.
- The cleaning process usually takes only a matter of minutes.
- There is no waste chemical or water to deal with after the wash.
- Assuming the chemical is properly formulated and injected it should not contribute to any additional atmospheric pollution.
- By avoiding shutdowns for off-line washing thermal cycles are also considerably reduced thus extending life of the engine.
- No erosion, thermal shock, bearing damage, cooling system blockage (if properly designed system is used).

ADVANTAGES & DISADVANTAGES OF ABRASIVE COMPRESSOR CLEANING

POSSIBLE ADVANTAGES
- Can be used when gas turbine is operating.
- Simple to use.
- Relatively inexpensive.
- Can remove certain deposits and restore performance.

POSSIBLE DISADVANTAGES
- Blade erosion.
- Bearing damage.
- Blockage of blade cooling systems leading to turbine failure.
- Damage to blade coatings.
- Blockage of instruments and/or control bleed air ports.
- Jamming of variable guide vanes and/or stator vanes.
- Removal of oily/greasy material to rear of compressor and/or into combustion system causing further performance loss.
- Transfer of salt contamination from compressor to hot end and subsequent corrosion.
- Ineffective against lacquered or hard carbonaceous deposits.

Figure 13.

ADVANTAGES & DISADVANTAGES OF CLEANING COMPRESSORS WITH PLAIN WATER

ADVANTAGES
- Can be used when gas turbine is operating (if injected correctly).
- Simple to use.
- Relatively inexpensive.
- Can have some cleaning effects if fouling is purely water soluble.

DISADVANTAGES
- Not effective against oily/greasy contamination.
- Not effective against lacquered or hard carbonaceous deposits.
- May move deposits to hot section of engine to cause corrosion.
- May directly cause corrosion if not inhibited.
- May cause thermal shock/blade stress if not injected correctly.
- Not effective for off-line cleaning (unless deposit water soluble).
- Must be high quality water with very low TDS and suspended solids.

Figure 14.

Other On-Line Compressor Cleaning Methods

The question: "Is on-line chemical washing the only on-line cleaning method?"

The answer is no (see Figure 1), but of the other available choices, it may be the most efficient, safe and practical on-line procedure.

The first alternative — and probably as old as the gas turbine itself — is abrasive cleaning using a variety of crushed nutshells or carbon-based pellets. In general this method is impractical for most modern gas turbines because, among other problems and drawbacks, the abrasive medium can damage coatings and plug turbine cooling holes with possible catastrophic results (see Figure 13).

The second alternative to on-line chemical cleaning is on-line plain water washing (see Figure 14) which has been advocated by some as a cheap solution with the apparent simplistic argument that water must be inexpensive and chemical must be expensive.

This would, of course, be the perfect solution if all compressor fouling was water soluble and the water used was virtually free of all dissolved and suspended solids so as to avoid corroding the engine in the process of trying to clean it.

Unfortunately, compressor fouling is rarely, if ever, of a water soluble nature and good quality pure water is not always easy to come by. Many a gas turbine has been badly corroded by poor attention to water quality particularly when applied to a hot engine.

Water washing should not be confused with the use of so called water-based or aqueous chemicals. Generally, water-based chemicals are formulated from various types of surfactants (surface acting agents) and corrosion inhibitors with water being in the majority (between about 80 and 98% depending on the brand) as the carrying agent.

Some of the new formula water-based materials (some using very pure food-grade surfactants) are quite effective at breaking down stubborn oily/greasy deposits so are proving quite successful even for fired-washing but are particularly attractive for off-line washing because of their high biodegradability factor which makes the disposal of the waste chemical a lot easier.

There are now a number of water-based chemicals on the market for on-line washing but to the author's knowledge there is only one generally recognized and approved solvent-based material available worldwide for on-line compressor cleaning and this material is "Fyrewash SB" which has been produced by his company, Rochem, in its current formulation for almost 10 years. In more recent years a water-based formula "Fyrewash WB" has also been added to the range and either material can be used in the patented Fyrewash injection system. □

This paper was originally presented at the Sixth Turbomachinery Maintenance Congress, sponsored by the Turbomachinery Maintenance Institute, Singapore, October 9-11, 1990.

F P B COGEN, INC.
A SUBSIDIARY OF FEDERAL PAPER BOARD COMPANY, INC.
P.O. BOX 2217, TERMINAL ANNEX, LOS ANGELES, CALIFORNIA 90051
AREA CODE 213 685-5180

January 19, 1988

Mr. David La Monica
Bola Chemicals, Ltd.
1524 Oregon Ave.
Long Beach, Ca. 90813

Dear David:

FPB Cogen Inc. would like to let you know how happy we have been with the installation of your "on-line wash" system on our LM2500. This system has more than paid for itself during the first month of summer peak periods.

During 1986, between March and November and before the "on-line wash" system, we had to shut down 16 times to soak wash the turbine for an average of 350 hours between shut downs, with an average loss of 1.6 MW between shut downs.

During the same time period in 1987, we only shut down 5 times for an average of 1175 hours between soak washes, while losing only an average of .35 MW between shut downs.

We used the "on-line wash" system 3 times a week during summer peak months and twice a week all other times. The solution is 10% Rochem, 90% demin. water.

Enclosed please find a "on-line wash" evaluation sheet for your information. Please feel free to use this or any other information I have supplied as you see fit.

Very truly yours,

FPB COGEN, INC.

James J. Doherty
Cogen Superintendent

JJD:is

Encl.

Document Control #TSM1109

REVIEW OF EXPERIENCE & RESULTS IN THE F P B COGEN INC LM2500

This engine is operated in the co-generation mode at this operators paper recycling plant in Los Ageles and the location is zoned "heavy industrial".

All electricity generated by the engine is sold to the grid with site energy being provided by a steam turbine generator operated from the gas turbine waste heat boiler.

The manager of co-generation is Mr James J. Doherty who is regarded as one of the most experienced LM2500 operators on the West Coast. He is President of the West Coast Users Group and his opinions on the operation and maintenance of this engine type is well respected by his colleagues in the Group.

The FYREWASH system was installed in the FPB LM2500 during an 8-hour shutdown in March 1987 and was commissioned on the same day.

Of interest is that one of the major justifications for fitting the FYREWASH system to this engine was the potential saving in costs related to premature wear and replacement of starter motors due to crank-washing of the compressor.

As noted in Mr Doherty's testamonial letter dated January 19,1988 his experience with the use of the FYREWASH system hase been very satisfactory to date after some 7,000 operating hours. Similar satisfaction with the system has also been expressed by Container Corp of Santa Clara.

Based on the information provided by Mr Doherty the following is noteworthy.

a) During the period March to November 1987 a "FYREWASH" was undertaken approx every 60 hours of operation on average.

b) Total operating hours during the period were 5,875 during which time the engine was only shut down 5 times for an average 1,175 hours between shutdowns. During these shutdowns the opportunity was taken to crank-wash the compressor using FYREWASH chemical. We understand that the shut-downs were not required because of performance degredation but for paper plant operating routines.

c) The average loss of output between each of the 5 shutdowns was approx 0.35 mW or approx 1.6% based on the engine's MCR of 22 mW.

d) For each fired-wash a total of 20 gallons of FYREWASH solution was used this being based on 2 gallons of concentrate and 18 gallons of demin. water.

The above was compared to a similar operating period during 1986 when the FYREWASH system was not in use and the operator relied purely on crank-washing. The data for this operating period shows the following:

NOTE: AS AN ADDITIONAL PRECAUTION ALL ROCHEM SUPPLIED PRESSURE INJECTION SKIDS ARE FITTED WITH 50 MICRON FILTERS (FINER IF REQUIRED) ON ALL INLETS AND THE WASH FLUID OUTLET OF THE PRESSURE VESSEL.

USE OF ANTI-FREEZE MATERIALS ON COLD WEATHER OPERATION

WHILE "FYREWASH" CLEANING SOLUTION IS CHEMICALLY COMPATIBLE WITH MOST TYPES OF COMMERCIALLY AVAILABLE ANTI-FREEZE IN PRACTICE CERTAIN TYPES OF ANTI-FREEZE ARE MORE COMPATIBLE IN TERMS OF STABILITY WHILE OTHERS WILL TEND TO CAUSE SEPARATION OF THE CHEMICAL/WATER PHASE OF THE SOLUTION AFTER A SHORTER PERIOD IF THE MIXTURE IS NOT KEPT AGITATED.

ROCHEM RECOMMENDS THAT THE POINT AT WHICH THE OPERATOR SHOULD CONSIDER USING ANTI-FREEZE IS WHEN THE AMBIENT TEMPERATURE IS +42F 5.5°C IN ORDER TO ALLOW FOR THE 3 TO 4 DEGREE TEMPERATURE DEPRESSION OF THE AIR ENTERING THE COMPRESSOR BELLMOUTH.

EXAMPLES OF THE RELATIVE STABILITY OF "FYREWASH" SOLUTION WHEN MIXED WITH VARIOUS ANTI-FREEZE MATERIALS ARE AS FOLLOWS. ALL PERCENTAGES ARE BY VOLUME AND ARE BASED ON 80 PARTS OF WATER/ANTI-FREEZE MIXTURE AND 20 PARTS "FYREWASH" CONCENTRATE (i.e. 4:1 MIX RATIO) WITH THE WATER/ANTI-FREEZE BEING PRE-MIXED BEFORE ADDING THE CONCENTRATE CHEMICAL.

MATERIAL	RATIO	STABILITY	FREEZING POINT
METHANOL/WATER	30/70 45/55	OVER 2 HOURS OVER 1 HOUR	MINUS 20C/MINUS 4F " 30C/ " 22F
ISOPROPYLALCOL/ WATER	20/80 40/60	10 MINUTES 2 MINUTES	" 5C/PLUS 23F " 15C/ " 5F
ACETONE/WATER	25/75 35/65	OVER 2 HOURS APPROX 30 MIN	" 70C/PLUS 20F " 12.5C/" 10F
METHYLETHLKETONE/ WATER	30/70 45/55	APPROX 10 MIN APPROX 2 MIN*	" 6C/PLUS 21F NO DATA
MONOETHLENGLYCOL/ WATER	30/70 45/55	OVER 2 HOURS OVER 1 HOUR	MINUS 15C/PLUS 23F " 30C/MINUS 22F

*THIS RATIO WILL NOT MIX PROPERLY EVEN WITH AGITATION.

AS NOTED THE MOST STABLE ANTI-FREEZE MATERIALS ARE (1) METHANOL, (2) MONOETHYLENGLYCOL AND (3) ACETONE WITH MEK PROVING THE MOST DIFFICULT MATERIAL IN TERMS OF STABILITY AND ABILITY TO MIX.

water/meth

Document Control #TSM1109

MATERIAL SPECIFICTION -- MAXIMUM IMPURITY LEVELS IN CONCENTRATE

"FYREWASH" CHEMICAL IS BLENDED FROM RAW MATERIALS OF THE HIGHEST AVAILABLE QUALITY. THE FINISHED PRODUCT IS DELIVERED TO THE END USER AS A 100% CHEMICAL CONCENTRATE READY FOR MIXING WITH WATER PRIOR TO USE.

WHILE ALL RAW MATERIALS HAVE CERTAIN LEVELS OF IMPURITIES WHICH CANNOT BE COMPLETELY AVOIDED ROCHEM HAS SET ITS OWN LIMITS ON THE VARIOUS ELEMENTS IN ORDER TO INSURE SAFETY AND COMPATIBILITY WITH THE VARIOUS ENGINE MATERIALS IN WHICH IT COMES INTO CONTACT DURING USE.

THE MAXIMUM IMPURITY LEVELS ALLOWABLE IN "FYREWASH" CONCENTRATE ARE THEREFORE AS NOTED BELOW:

A = IN THE CONCENTRATE; B = IN THE SOLUTION AFTER MIXING WITH MINIMUM 4 PARTS WATER TO 1 PART CONCENTRATE --

ELEMENT	A	B
SULPHUR	200PPM	40PPM
SODIUM	40	8
POTASSIUM	5	1
PHOSPORUS	20	4
CALCIUM	5	1
HALOGENS (CL)	50	10
LEAD	1.0	0.2
VANADIUM	1.0	0.2
ALL OTHER METALS	20	4
ASH (% W/W)		
		NIL
FLASH POINT: ABOVE 65C (155F)		7 TO 9

pH: 7 TO 9
PARTICULATE MATTER: NO VISIBLE SOLIDS

NOTE: ACTUAL IMPURITY LEVELS IN THE RAW MATERIALS ARE TYPICALLY LOWER THAN THOSE SHOWN ABOVE SO IN PRACTICE THE IMPURITY LEVELS OF THE 'AS USED' SOLUTION WOULD BE LOWER THAN INDICATED.

RECOMMENDED QUALITY OF DILUTION WATER AT POINT OF USE

THE ON-SITE WATER USED TO DILUTE THE CHEMICAL CONCENTRATE SHOULD BE DISTILLED, DEIONIZED, OR DEMINERALIZED WITH A RECOMMENDED MAXIMUM TDS OF 5PPM AND A pH OF 7 TO 9. IT SHOULD BE FILTERED TO REMOVE ANY SUSPENDED SOLIDS.

As discussed elswhere a certain level of impurity will always exist in a solvent/surfactant-based chemical such as FYREWASH simply because the raw materials from which it is blended contain some impurities. However Rochem takes all possible precautions to ensure that these levels are as small as possible by only purchasing its raw materials from the major and well established suppliers that can provide a guaranteed specification.

The typical level of total impurities that would be found in any batch of FYREWASH can be demonstrated by the analysis shown below. This results from a blind sample taken from Rochem's current stock in Long Beach, California by the Pacific Spectrochemical Laboratory Inc on Tuesday, February 2nd 1988 and is thus representative of the FYREWASH material being used by FYREWASH users in California.

Element	(In concentrate)	Expected level when mixed 4:1 in wat Prior to injection into the engine
Silicon (Si)	1.1 ppm	0.22 ppm + any impurities in water
Iron (Fe)	4.2	0.84
Sodium (Na)	31.0	6.22
Cromium (Cr)	8.7	1.74
Tin (Sn)	3.1	0.62
Manganese (Mn)	0.31	0.06
Antimony (Sb)	0.07 (trace)	0.01
Magnesium (Mg)	0.18	0.03
Potassium (K)	2.0	0.40
Lead (Pb)	1.8	0.36
Nickel (Ni)	0.75	0.15
Aluminum (Al)	2.8	0.56
Calcium (Ca)	1.8	0.36
Copper (Cu)	0.18	0.03
Zinc (Zn)	0.03 (Trace)	0.006
Titanium (Ti)	0.035	0.007

Other elements not detectable
Loss on ignition(sulfur ash) : 99.99%

As the water quality recommended by Rochem is NoX quality with a maximum TDS of 5ppm the "added" impurities from the dilution water would be minimal.

Rochem suggests that the above levels of impurity would cause no harm to an engine under any circumstances particularly as the on-line washing is an intermittent procedure.

WITH REGARD TO THE PERIOD OF STABILITY THIS IS BASED UPON NO FURTHER AGITATION TO THE POINT WERE THE MIXTURE BEGINS TO SHOW SIGNS OF SEPARATION AND STRATIFICATION.

HOWEVER, WHEN A ROCHEM SUPPLIED PRESSURE INJECTION SYSTEM IS USED STABILITY PROBLEMS ARE OVERCOME SINCE ALL SYSTES ARE FITTED WITH A MEANS OF AGITATION WHICH IS OPERATIVE THROUGHOUT THE PERIOD OF THE INJECTION.

ALSO, IN PRACTICE, THE NORMAL PROCEDURE IS TO MIX EACH INDIVIDUAL BATCH OF WASH FLUID IN THE PRESSURE INJECTION SYSTEM FOR EACH ON-LINE WASH AND THE ACTUAL PERIOD OF INJECTION DOES NOT NORMALLY EXCEED 15 MINUTES EVEN FOR THE LARGEST CAPACITY ENGINE. AS SUCH IN MANY CASES THE SOLUTION CONTAINING THE ANTI-FREEZE WOULD NOT HAVE TIME TO SEPARATE EVEN IF NO FURTHER AGITATION WAS EMPLOYED.

WITH REGARD TO COLD WEATHER OPERATION IT IS ALSO INTERESTING TO NOTE THAT ROCHEM DESIGNS AND SUPPLIES INJECTION SYSTEMS WHICH ARE COMPLETE WITH HEATING/ANTI-ICING SYSTEMS WHICH PROVIDE FOR CONTINUOUS WARMING THROUGH THE COMPLETE SYSTEM FROM THE PRESSURE INJECTION SKID THOUGH TO THE ATOMIZING NOZZLES FITTED IN THE ENGINE PLENUM.

THIS SYSTEM IS TYPICALLY BASED ON THE UTILIZATION OF WARM BLEED AIR FROM THE ENGINE COMPRESSOR WHICH IS BLED CONTINUOUSLY THROUGH THE SYSTEM AND CAN ALSO BE USED TO PRE-HEAT THE WASH FLUID BEFORE INJECTION.

RELATIVELY SPEAKING THE VOLUME OF COMPRESSR BLEED AIR USED FOR THIS PURPOSE IS SO SMALL THAT IT DOES NOT AFFECT ENGINE PERFORMANCE -- DETAILS OF THIS SYSTEM ARE NOTED ELSEWHERE.

FINALLY, WITH REGARD TO THE USE OF ANY PARTICULAR ANTI-FREEZE THE OPERATOR MUST CONSULT THE ENGINE MANUFACTURER'S MANUAL TO INSURE THAT THE PARTICULAR MATERIAL WILL NOT HAVE ANY ADVERSE EFFECTS ON ALLOYS SUCH AS TITANIUM OR OTHER METALS EMPLOYED IN THE GAS TURBINE.

INDEPENDENT VERIFICATION OF SAFETY IN USE

INDEPENDENT TESTING AND ANALYSIS HAS BEEN CARRIED OUT ON ENGINE EXHAUST EMISSIONS DURING THE APPLICATION OF "FYREWASH" CLEANING FLUID AND IN THIS REGARDS ATTENTION IS DRAWN TO A REPORT FROM DR. IAN MARR, HEAD OF THE CHEMISTRY DEPARTMENT OF THE UNIVERSITY OF ABERDEEN.

PARTIAL LIST OF USERS AND APPROVALS

CUSTOMER	COUNTRY	ENGINE TYPE(S)	APPLICATION
- CHEVRON	UK	GE FS5	OFFSHORE POWER GEN
- OCCIDENTAL	UK	GE FS5	" " "
- MOBIL	NORWAY	GE LM2500	" " "
- PHILLIPS	NORWAY	GE FS5	" " "
- BRITISH PET	UK	RUSTON TB5000	OFFSHORE & ONSHORE
- TEXACO	UK	RUSTON TB5000	" "
- AGIB	ITALY	GE FS3 GE FS5 KONGSBERG	POWER GENERATION
- DOW CHEMICALS	HOLLAND GERMANY USA	GE FS3 GE FS5 GE FS7 WESTINGHOUSE GE LM5000	SYSTEM USEED IN DOW PLANTS IN USA HOLLAND & GERMANY MAINLY POWER GEN TURBINES
- UNION CARBIDE	USA	GE FS5	POWER GENERATION
- DIAMOND SHAMROCK	USA	GE FS7	
- MISSISSIPPI CHEM CORP	USA	GE LM2500	
- TEXAS EASTERN	USA	GE FS3	
- ALASKA PIPELINE	ALASKA	GE FS3 GE FS5 RUSTON TB5000	PIPELINE & GEN
- SOUTHERN CALIFORNIA EDISON	USA	PRATT & WITNEY	ALL FT4 POWER GEN AT 4 STATIONS (X32 ENGINES)
- TEXACO	USA	ALLISON 501	

CUSTOMER	COUNTRY	ENGINE TYPE	APPLICATION
- BASF	USA	GE FS5	POWER GENERATION
- COASTAL REFINING	USA	GE FS5	" "
- ARCO ALASKA	USA	GE FS3 GE FS5	PUMPING GENRATION
- CROWN ZELLERBACK	USA	DRESSER CLARK	POWER GENERATION
- COLOMBIA GULF	USA	GE FS5	
- TOSCO REFINERY	USA	GE FS5	
- GETTY OIL	USA	GE FS7	
- UNOCAL	UK	SOLAR CENTAUR	PUMPING
- KAISER ALUMINIUM	USA	GE FS5	POWER GENERATION
- NORTHERN TERRITORY ELECTRICITY-COMMISSION/DARWIN/AUST		GE FS6	
- FORMOSA PLASTICS	USA	GE FS5	
- BASF WYANDOTT	USA	GE FS3	
- SHELL OIL	USA	GE FS3	
- S.N.A.M.	ITALY	GE FS3	
- DISTRIGAZ	USA	RR AVON	
- SOLELGAZ/ALGERIA	BELGIUM	GE FS5	
- AMERICAN CO GEN CORP		KONGSBERG	
- BAHRAIN ELECT CORP		KRANFTWERE	POWER GEN
- DUBAI ALUMINIUM	MID EAST	GE FS3	OFFSHORE POWER GEN
- DUBIA PETROLEUM	MID EAST	GE FS9	" " "
- ICI	UK	SULZER 10	POWER GENERATION
- FLORIDA POWER & LIGHT	USA	WEST 501	POWER GENERATION
- EXXON CHEMICALS	USA	GE FS5	
- JACOBS SERVICES	USA	GE LM5000	

CUSTOMER	COUNTRY	ENGINE TYPE	APPLICATION
- INLAND CONTAINER CORP	USA	GE FS6	POWER GENERATION
- BROWN BOVERI	W.GERMANY	TYPE 9 TYPE 11 TYPE 13	
- CENTRAL JERSEY POWER & LIGHT	USA	GE FS5	
- DUBAI PETROLEUM	UAE	RR AVON	
- SULZER	SWITZ	TYPE 10	
- AMOCO	USA	GE FS6	
- REYNOLDS METALS	USA	WEST.101	
- Q.G.P.C.	QATAR	GE FS3 GE FS5	
- SOHIO	ALASKA	GE FS5	
- FEDERAL PAPER	USA	GE FS7	
- TEXAS GULF	USA	GE FS7	
- BORDEN CHEMICALS	USA	WEST 101 WEST 171	
- UNIVERSITY CO-GEN	USA	GE LM2500	
- CONTAINER CORP	USA	GE LM2500	
- E.I.DUPONT	USA	GE FS7	
- DOW CHEM	USA	GE FS5	
- UNITED AIRLINES	USA	GE LM2500 (AIRPORT POWER GEN.)	
- W.E.D. ABU DHABI	UAE	BBC TYPE 11	
- EXXON	USA	GE FS3	
- CHEVRON EL SEGUNDA	USA	GE FS6	
- FOSTER-WHEELER	USA	GE FS6	
- NUOVA PIGNONE	ITALY	GE FS1	
- SHELL	USA	GE FS3	
- KW BERLIN	W.GERMANY	BBC 13	

CUSTOMER	COUNTRY	ENGINE TYPE	APPLICATION
- BAYOU CO-GEN	USA	GE FS7	POWER GEN.
- P.D.O.DUBAI	UAE	GE FS5 GE FS6	
- NUOVA PIGONE	UAE	GE FS3 GE FS5	
- SIGNAL ENERGY	USA	GE LM2500	
- POWER OPERATING CO	USA	GE LM2500	
- U.S.TURBINES	USA	ALLISON 501 ALLISON 570	(STANDRD FIT - ALL NEW ENGINES)
- JOHN BROWN ENG	UK	GE FS6 X 2	(NEW ENGINES/CHINA)
- SUNLAW	USA	GE LM2500	
- JOHN BROWN ENG	UK	GE FS6 X 2	(NEW ENGINES/CHINA)
- PURFLEET BOARDMILLS	UK	RUSTON TORNADO	
- BOLA	USA	SOLAR SATURN	
- ARCO	ALASKA	TB5000	
- RAAF	AUST	HELICOPTERS	
- NUOVA PIGNONE	ITALY	GE FS1	
- RIFFA POWER STATION	BAHRAIN	KRAFTWERKE	
- UNION CARBIDE	USA	GE FS6	
- GILROY	USA	GE FS7	
- PHILLIPS PETROLEUM	NORWAY	GE FS5	
- ESSO FAWLEY	UK	GE FS6	
- LOT POLISH AIRLINES	POLAND	AIRCRAFT ENGINES	
- AIR PRODUCTS	USA	GE LM2500	
- GE SCHENECTADY	USA	LM 2500	
- HARBOR CO-GEN	USA	GE FS7	
- BAYOU CO-GEN	USA	GE FS7	
- STEWART & STEVENSON	USA	ALLISON 570	(NEW ENGINES)

CUSTOMER	COUNTRY	ENGINE TYPE	APPLICATION
- EXXON CHEMICALS	USA	GE FS5	POWER GEN
- BASF	USA	GE FS6	
- CALIFORNIA CO-GEN	USA	GE LM2500	
- ARCO	ALASKA	GE FS5	
- POWER OPERATING SYSTEMS	USA	GE LM2500 X 6	
- PPP LAKE CHARLES	USA	GE FS7	
- NAVAIR	USA	AIRCRAFT	

temperatures lower than this, an antifreeze/water solution will be required. See Table I for antifreeze/water mixtures.

TABLE I - WATER WASH ANTIFREEZE MIXTURES

Water Antifreeze Mixtures for Cleaning Compressor

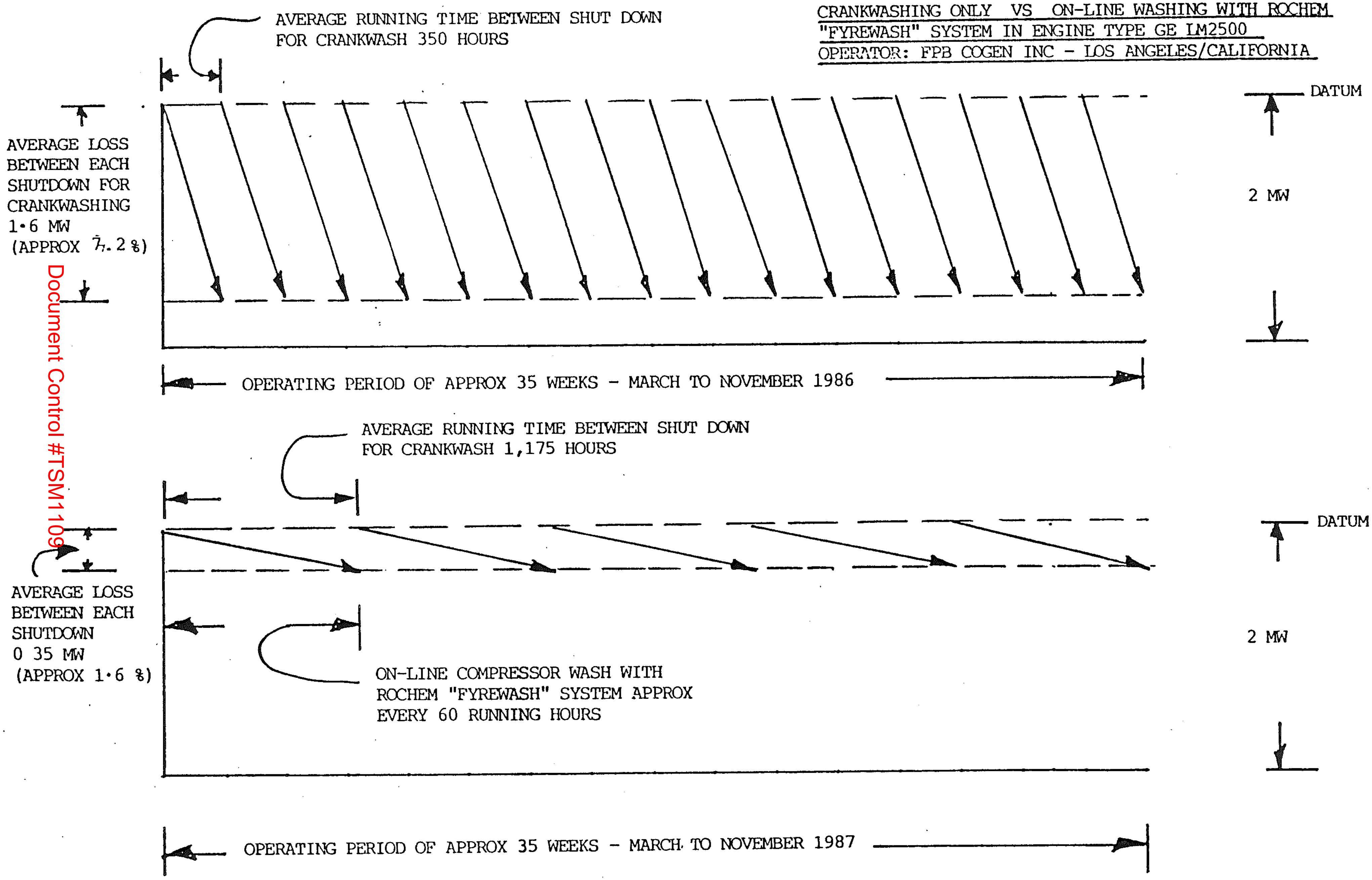
Outside Air Temp °F (°C)	MEK % Vol	H_2O % Vol	Acetone % Vol	H_2O % Vol	Isopropyl Alcohol % Vol	H_2O % Vol
+20 to +32 (-7 to 0)	28	72	25	75	22	78
+10 to +20 (-12 to-00)	47	53	40	60	34	66
0 to +10 (-18 to -12)	59	41	53	47	47	53
-10 to 0 (-23 to -18)	69	31	63	37	72	28
-20 to -10 (-29 to -23)	75	25	69	31	88	12
-30 to -20 (-34 to -29)	78	22	75	25	97	3

Water Antifreeze Mixtures for Rinsing Compressor

Outside Air Temp °F (°C)	MEK % Vol	H_2O % Vol	Acetone % Vol	H_2O % Vol	Isopropyl Alcohol % Vol	H_2O % Vol
+20 to +32 (-7 to 0)	23	77	20	80	18	82
+10 to +20 (-12 to 00)	38	62	33	67	27	73
0 to +10 (-18 to -12)	48	52	43	57	39	61
-10 to 0 (-23 to -18)	55	45	50	50	58	42
-20 to -10 (-29 to -23)	60	40	55	45	70	30
-30 to -20 (-34 to -29)	63	37	60	40	77	23

SIMPLIFIED GRAPHICAL ANALYSIS OF PERFORMANCE LOSSES ATTRIBUTED TO COMPRESSOR FOULING.

CRANKWASHING ONLY VS ON-LINE WASHING WITH ROCHEM "FYREWASH" SYSTEM IN ENGINE TYPE GE LM2500
OPERATOR: FPB COGEN INC - LOS ANGELES/CALIFORNIA



POLICY FOR MATERIAL SPECIFICATION, MANUFACTURING QUALITY CONTROL AND PREPARATION PROCEDURES AT POINT OF USE

PREAMBLE

"FYREWASH" CHEMICAL IS SPECIALLY FORMULATED FOR RUNNING-WASH CLEANING OF GAS TURBINE COMPRESSORS USING A PATENT METHOD OF INJECTION ALSO DEVELOPED BY ROCHEM.

THE PRESENT CHEMICALL FORMULATION HAS BEEN ESTABLISHED FOR SOME THREE (3) YEARS FOLLOWING AN EARLIER DEVELOPMENT PROGRAME LASTING SOME SIX YEARS DURING WHICH TIME THE BASIC FORMULATION WAS MODIFIED AND IMPROVED ON THE BASIS OF IN-SERVICE EXPERIENCE WITH THE MATERIAL.

ALTHOUGH SPECIFICALLY DEVELOPED FOR 'FIRED-WASHING' THIS MATERIAL IS ALSO A VERY EFFECTIVE PRODUCT FOR OFF-LINE COMPRESSOR CLEANING IN THE CONVENTIONAL CRANK-SOAK MODE.

THE "FYREWASH" SYSTEM AND CHEMICAL IS NOW IN EXTENSIVE USE IN A WIDE VARIETY OF INDUSTRIAL GAS TURBINES -- BOTH HEAVY AND AERODERIVITIVE -- AS WELL AS IN THE AVIATION FIELD PARTICULARLY FOR GROUND IDLE FIRED WASHING OF HELICOPTER TURBOSHAFT ENGINES AND COMMERCIAL AIRCRAFT APU's.

A DERIVITIVE OF THE "FYREWASH" FORMULATION IS ALSO TESTED AND APPROVED TO THE LATEST U.S.MIL SPECS FOR COMPRESSOR WASHING FLUIDS AND IS SOLD UNDER THE TRADE NAME "KRANKWASH".

COMPOSITION OF "FYREWASH" CHEMICAL

"FYREWASH" CONCENTRATE CHEMICAL IS HYDROCARBON BASED AND IS A COMPPLEX BLEND OF ANIONIC AND NON-IONIC SURAFACTANTS, GLYCOETHERS AND AROMATIC SOLVENTS.

BIODEGRADABILILTY OF THE SURFACTANTS IS OVER 90% (PER EEC DIRECTIVE 82/243 ANND 82/242) AND SOLVENT MOLEWEIGHT IS 156.

THE FORMULATION DOES NOT CONTAIN BENZENE, XYLENE, TOLUENE OR ETHYLBENZINE.

TOXICITY LEVELS ARE MINIMUM, VIS:

- ORAL: LD50 - RATS -- OVER 1,000 MG/KG
- DERMAL: LD50 - RABBITS -- OVER 100 MG/KG

THERE ARE NO KNOWN RESTRICTIONS IN TERMS OF HEALTH AND SAFETY ON THE USE OF "FYREWASH" CHEMICAL, THE ESSENTIAL ELEMENTS OF WHICH HAVE NOW BEEN IN USE FOR SOME TEN (10) YEARS WITHOUT A SINGLE CASE OF INJURY OR DAMAGE BEING RECORDED.