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GE Power Systems

Experience with Compressed Air Cleaning of Main Steam Piping

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Introduction

This paper presents a summary of long-term and short-term experience that demonstrates compressed air-blow results are "at least as good, and often better than steam-blows." Compressed air-blows have been used effectively on applications for supercritical boilers, drum-type boilers, and heat recovery steam generators for preoperational cleaning of main steam lines at power plants with ratings from 35 to 700 MW.

Cleaning of the main steam piping is required to minimize the possibility of damage to the turbine by removing weld bead deposits, pipe slag, and other foreign material which might otherwise be carried over into the turbine. Any particles that would be dislodged while operating must be dislodged during the cleaning process, and any particles that are or become loose must be removed from the system. Thus, the momentum or cleaning force must exceed the force that occurs during the maximum flow operation. This requirement is satisfied by selecting the initial pressure level so that the momentum or cleaning force ratio is greater than one.

The procedure is similar to a steam blowdown except that compressed air is used as the cleaning medium. The system is pressurized using rented compressors or site equipment and depressurized by rapidly opening the temporary valve. The cycle is repeated until the cleanliness criteria have been satisfied.

The noise level is similar to steam-blows, and mufflers should be used in populated areas. A critical factor in the success of air-blows is the use of a fast-acting temporary ball valve rigged to open very rapidly, on the order of 1 sec. Typical opening times for the temporary gate valves used for saturated steam blows are 15 to 45 sec. The fast-acting valve is necessary to promptly establish the desired flow conditions and momentum ratios because the recharge rate of the air compressors is relatively low compared to the discharge rate.

There is a consistent objection to air-blows because the large temperature change (thermal cycling) associated with steam-blows is not present. Condensation and frost have been observed near the end of the temporary pipe during air-blows, verifying the cooling effect associated with the expansion process. The largest part of the temperature decrease occurs in the temporary pipe and thus has a minimal impact on the pipe being cleaned. The fact that air-blow results for both large and small systems have been consistently rated "as good or better than steam-blows" by experienced personnel indicates that the effectiveness of removing material that could damage the turbine may be independent of thermal cycling and primarily related to obtaining the required flow or momentum ratio.

Another significant effect may be the acceleration forces generated when the temporary ball valve is popped open.

Reference 1 acknowledges that compressed air-blows have been as effective as steam-blows in cleaning steam lines and suggests the cleaning method should be selected based on particular circumstances.

The major benefits of compressed air-blows are scheduling flexibility, extended boiler life by eliminating temperature cycles associated with saturated steam blows, and reduced cost.

Industry Experience with Compressed Air

Allegheny Power

Since 1967, Allegheny Power System has placed 10 supercritical once-thru units in service that range in size from 576 to 668 MW gross. The first of these was the Fort Martin Unit No. 1, which was placed in commercial operation 37 mo after initial groundbreaking. This very ambitious construction and start-up schedule prompted the Allegheny Power System to evaluate and decide in favor of air-blowing in lieu of the customary steam-blowing to remove rust, debris, pipe scale, welding slag, etc. from the boiler and boiler-related piping systems prior to start-up.

Steam blowing requires a longer construction and start-up schedule because the entire boiler and auxiliary systems must be completed and checked out before steam-blowing is possible. Air-blowing of the boiler and boiler-related piping systems, however, may proceed simultaneously with final construction and installation of ash systems, burners, dampers, and controls. The results indicate the schedules of these 10 supercritical units were reduced 6 wk to 3 mo by using air-blowing instead of steam-blowing.

A factor which made the decision to air-blow easier to implement was that the soot-blowing systems for these boilers were compressed air systems. The permanent in-plant Soot-blowing Air Compressors became the air source for the blowing, although adequate rental air compressors are available (in one case, Allegheny Power did rent compressors).

Although the boiler and piping configurations for many of the units were different, the basic air-blow program consisted of pressurizing the boilers, main steam leads, the hot and cold reheat leads, the boiler reheater, and other piping systems in various combinations. Temporary blowout piping was extended from the turbine stop/trip valves to the outside of the plant and was equipped with quick opening blowout valves. The temporary blowout piping was heavily braced, and the blowout valves were 18-in. ball-type valves equipped with an air cylinder operator which fully opened in 1 sec or less. The portion of the boiler and piping system to be cleaned was pressurized up to the rating of the soot-blower air compressor (normally 300–500 psig) and the blowout valve opened, with the escaping air carrying the debris from the boiler. Depending on the section to be cleaned, each system required 1/2 to 1 hr to pressurize, with each blowout lasting 1 to 2 min. The blowout valve would be closed with 75–100 psig remaining in the system because below this pressure, the velocity of the escaping air was too low to effectively remove debris.

The cleanliness of the various boiler and piping systems was determined by periodically placing highly polished metal targets in the air stream near the end of the blowout pipe. To clean a portion of the unit, such as the boiler and main steam leads, would typically require 100 to 150 blows. To air-blow an entire unit, which includes the various sections of the boiler and the boiler-related piping systems, including the rearranging of the temporary blowout piping to accommodate the cleaning of the various related systems, required 3 to 4 weeks.

The piping and boiler cleaning sequence practiced by Allegheny has been to perform the air-blow first, followed by the boiler and high-pressure piping hydrostatic tests, followed by condensate flushing, and completing the sequence with chemical cleaning of just the boiler and primary superheater. Although the secondary super-heater, reheater, and main steam piping were air-blown, they were not included in chemical cleaning.

The first supercritical unit air-blown by Allegheny Power System has been in service for 21 yr. The 10 super critical units air-blown by

Allegheny Power System have a combined service of 160 unit-years of operation with no problems attributed to debris remaining from original construction. Based on this performance, the Allegheny Power System has concluded that air-blowing is an excellent method of cleaning supercritical boilers and their related piping systems in preparation for start-up.

Detroit Edison

The Detroit Edison Company air-blow experience centered on the Belle River Power Plant, which consists of two 660-MW, subbituminous coal-fired, single reheat, steam drum units. Due to the high sodium content of the specified fuel, the Belle River Power Plant furnaces were designed to be extra large in comparison with similar Eastern Coal units. Since this plant was being constructed and placed in service during a time of economic challenge, the overall plant reliability and cost effectiveness were of major importance to Detroit Edison.

Starting with the question of "why steam-blow at all?" Detroit Edison's Belle River Start-up Team researched the steam-line cleaning techniques and criteria of the major electric power companies of the United States. Most companies that were contacted utilized steam- blows as their steam-line cleaning standard. Several major companies, however, were found to be utilizing air as their cleaning standard.

Those that used only steam-blows had no scientifically based rationale for these standards and actually indicated that the standard was based primarily on tradition. Since it was a known factor, they saw no reason to change. The utilities using air as their cleaning medium, did so for a variety of reasons:

1. They did it traditionally.
2. They had found air-blowing to be better than steam-blowing.
3. Air-blowing allowed them construction scheduling flexibility.

Of all the utilities surveyed, there was no real pressure criteria or cleanliness criteria that had a rigorous engineering background. The main finding was that the average pressure range was 300 to 600 psig, with the total number of blows per cleaning path averaging around 10, even though most companies used a target in the blow line with some subjective judgment on number of hits. The bottom line appeared to be that cleaning took place during the initial blows and that subsequent blows built confidence more than anything.

Visits to those companies using air-blows were undertaken, and several very interesting observations and facts were revealed:

1. Air-blows could be conducted prior to unit hydros. (In fact, potential leaks could be identified prior to hydro.)
2. Air-blows could be worked into the critical path without affecting other major critical path activities, except for work on the boiler and steam-line pressure parts, although one company did work within boiler pressure part boundaries.
3. Temperature limitations, especially steam drum metal temperatures were not a consideration for air-blow planning and execution.
4. There were no clear line cleanliness standards based on a rigorous engineering analysis.
5. Prime mover (i.e., air compressor) setups were loosely planned.

After reviewing the steam-line cleaning records of several electric power companies, the Belle River Start-up Team recommended that air be used as the cleaning medium for the two Belle River units and that the **cleanliness criteria** be based on **number of blows per cleaning leg rather than target hit criteria**. The Start-up Team's recommendation was accepted, and both Belle River units were cleaned using air rather than steam. The present indication based on 5-yr plant operation is that air is an effective cleaning medium for major steam generators and steam lines.

Initial studies concluded that, cost-wise, an air-blow and steam-blow would be comparable. The steam-blow would expend fuel as the major expense, while the air-blow would expend equipment rental/installation as the major expense. The air-blow, however, was found to have minimum effect on the construction critical path and only required that the boiler pressure parts and steam lines be completed up to final turbine tie-ins. As a result, air-blowing could be expected to cut up to 90 days off the final completion time of each unit scheduled for commercial operation. After the presentation was made to Detroit Edison's senior management, the decision was made to proceed with the air-blow in lieu of the steam-blow. *Figure 1* shows the compressor layout at the site. Air compressor sizing was based on two factors:

1. The air-blow would be conducted in one week.
2. There would be no temperature build-up in the units due to the large volume of metal and normal conductive cooling. These assumptions were subsequently verified during the first air-blow, and one may confidently predict blowing cycle times based on the unit boundary volumes and air compressor rated flows (i.e., $P_1V_1 = P_2V_2$).

A 24-in. ball valve was selected for this project. The size was primarily chosen to ensure that the ball valve did not become the air-blow system flow choke point. The size and speed at opening presented a concern with the rotational momentum, especially in stopping the ball movement and the potential to shear the ball valve shaft. The valves that were considered were examined closely for the strength of components to handle the rotational momentum forces. A second valve was ordered as a backup due to the potential for incurring large expenses if a ball valve failure did occur. The air-blow valve actuating air supply flow also required close examination to ensure that the air flow could meet the opening time

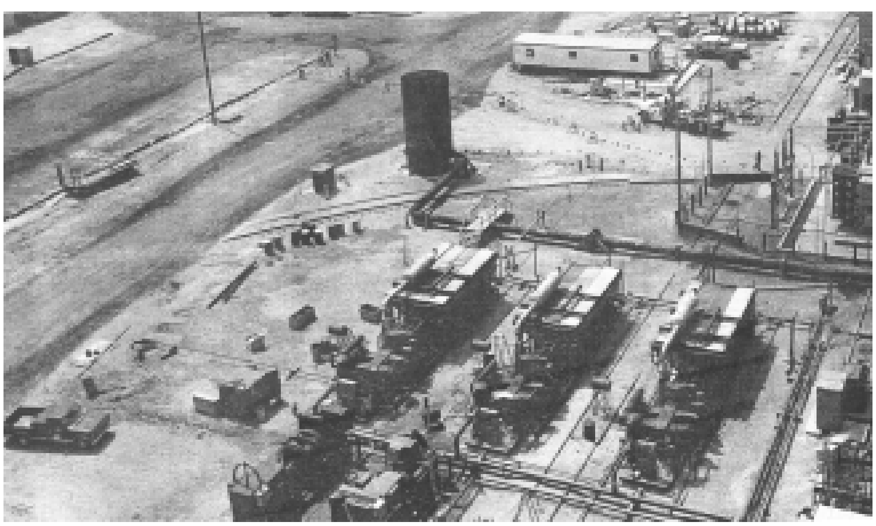

Figure 1. Belle River air-blow compressor layout. Note areas barricaded during blows.

requirement, and a backup air bottle supply was included in the setup design. The actual operation proved that the air for the ball valve operation had to be included in the detailed plan since workmen could hook on to the air system to do other work, causing a disruption of the air-blow valve operation. Additionally, the anchoring of the ball valve, due to the rotational and flow forces, must be noted. In actual operation, a distinct "thump" was noted even though anchoring was extremely strong. In many respects, the ball valve is as critical as the air compressors in achieving a successful air-blow operation.

There was concern voiced on the lack of thermal cycling and the ability to break welding slag off of pipe walls. Engineering study, however, indicated that expanding air under the air-blow conditions could theoretically produce a reverse thermal cycle by lowering the temperature of the air. Concern was also expressed that compressed air could carry enough heat to violate the 40°F temperature differential limitation of the main steam drum, and the unit had temperature probes installed to prove / disapprove this concern. The actual air-blow operation demonstrated no unit metal heat build-up during the compression cycles, and it appeared that the unit behaved as an infinite heat sink. On long blows, condensate was observed forming on the temporary piping, which indicated that there was indeed a cooling effect induced by the rapid air expansion. It can be postulated that the surface boundary of the tube metal could be having a very sizeable temperature drop, which should have produced enough reverse temperature shock to pop weld slag off of the pipe internal surfaces. Additionally, one may postulate that target hits could actually be ice-crystal-related rather than metal-debris-related.

Figure 2 shows typical debris collected in the silencer. Since no scientifically based cleanliness standards were found to exist, the air-blow **cleaning criteria was set at 20 blows per cleaning leg** (double what was found as an average for the other utilities). This number was used to size the air compressor requirements based on flow rates needed to achieve the air-blow criteria during

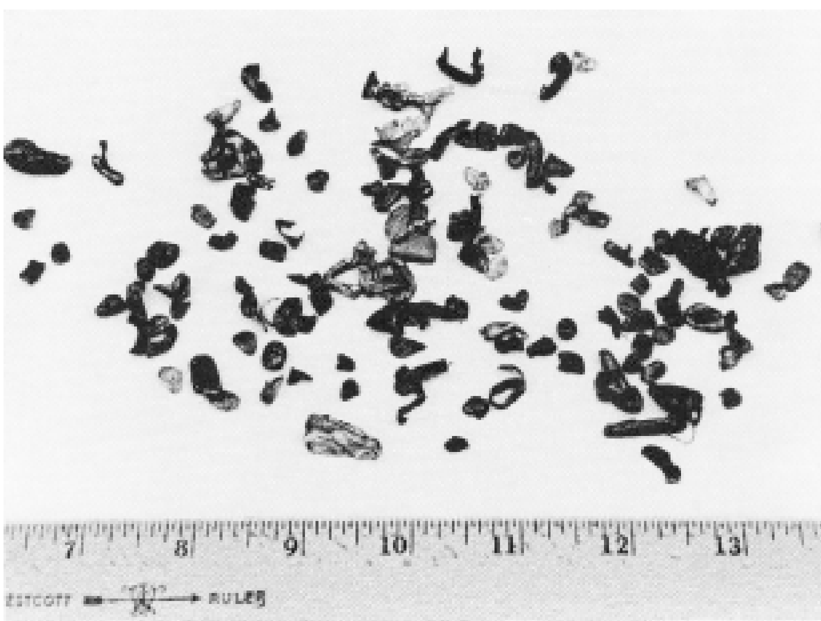

Figure 2. Belle River typical debris collected from silencer.

the scheduled 1-wk period. The only problem was that the silencer (*Figure 3*) muffled the blow noise so that many people believed that there was little cleaning being accomplished. Considering how much horsepower is being consumed in a 30-min pump-up cycle and then expended in less than 20 set, the actual cleaning forces are tremendous. In fact, a well set up and muffled system must maintain a strong safety recognition due to these forces, which could have very serious effects were there to be a major failure in lint or silencer integrity. Although the lines were visually inspected to gray metal criteria, a subsequent turbine-related failure due to a design problem indicated that there was a powder oxide build-up on the turbine blading for the first unit. This was explained as oxide build-up due to unprotected metal during and after the unit hydro; and the second unit had an atmospheric pressure nitrogen cap placed on the boiler pressure parts and steam lines. This capping appears to have prevented any significant powder-type oxides from reaching the turbine in normal operation. The nitrogen cap, however, will require atmosphere testing for worker safety in the locality of the boiler fire side and other confined areas in the proximity of the capped parts.

Figure 3. Belle River typical debris collected from silencer.

An additional benefit of air-blowing is the ability to locate boiler leaks prior to the unit hydro. The Belle River plan allowed for leak detection during the initial system integrity pressurization, and prior to release of all air on the last blow each day. As a result, only two attempts were necessary to achieve successful hydro results in either unit. In fact, one was done on the first hydro, and only one sand hole repair in the other unit's economizer section was required to achieve hydro success. This in itself has a major influence on controlling critical path and resource utilization.

Chemical cleaning of the Belle River Units 1 and 2 was a one-step operation that included degreasing and mill scale removal of the boiler wetted surface, excluding the superheater and reheater to preclude the possibility of chlorides reaching the stainless steel in the superheater. The feedwater string was alkaline flushed.

The planning sequence is critical for a successful air-blow. The Belle River planning, for example, addressed all boundary valving, either open or closed, and allowed for check-off by valve. Individual job assignments and locations during the air-blow operation were also specified. One individual was placed in charge of the air-blow operation, and all changes/information flow went through him. This alleviated any confusion and did much to smooth out the operation. The advance detailed planning paid dividends during the air-blow operation and allowed equipment failures and operational changes to be made without confusion, which can have critical implications when on a tight critical path schedule.

Some issues that need serious attention in the overall planning/design phase of an air-blow are:

1. Ball Valve Failure: Detroit Edison had an extra valve on site for immediate replacement, although it wasn't needed. One utility had reported a ball-valve failure that set them back several weeks for repairs.
2. Air Compressor Availability: Detroit Edison allowed for the total failure of one air compressor and several quickly repaired failures without going outside the critical path. A "reward" payment to the air compressor rental agency for achieving an availability target may be a factor to ensuring these baseline assumptions.
3. Code Consideration: Detroit Edison reached accord with the state to treat the unit as an unfired pressure vessel for the purpose of the air-blow. This may be a nonissue, but is highly recommended as an issue to address.
4. Planning: Detroit Edison provided for very detailed plans for both operation and safety. These paid dividends during the actual operation phase, and any problems were readily resolved.

The overall experience at the Detroit Edison Company was that an air-blow is an effective method for cleaning the steam piping of a new unit prior to operation. Although the potential for lower cleaning costs (air vs. steam) exists, the keypoint in favor of an air-blow over the more traditional steam-blow is in schedule enhancement, which may significantly reduce project costs. The Detroit Edison Company experience, however, emphasizes the importance of detailed planning for the operation along with contingencies to ensure success.

Basin Electric

Background. The Basin Electric Antelope Valley Station (AVS) consists of two 440-MW units. The lignite-fired Combustion Engineering superheat and reheat boilers supply steam to Westinghouse turbines. Main steam piping on AVS Unit 1 was steam-blown, while compressed air was used on Unit 2. The general feeling is that the air-blow on Unit 2 was more effective than the steam-blow on Unit 1.

The initial concept of using compressed air to clean the steam piping of AVS Unit 2 was suggested by a representative of Ingersoll-Rand (I-R). The main advantage appeared to be the ability to remove the initial steam-line cleaning from the critical path, although in the end, Basin Electric used the air-blow for other reasons, mainly economic. At first, we were skeptical, citing reasons typical of those who have performed the traditional steam-blows. A list of utilities using air-blows as a replacement for steam-blows was supplied by I-R for interview purposes. The utilities contacted were Allegheny Power System and Detroit Edison. No negative comments were encountered, and we received valuable advice on improving the effectiveness of the air-blows.

Fortunately, Detroit Edison was using air-blows at the Belle River plant at the time we were considering air-blows. Clarence Brookins invited Basin Electric to observe the air-blow operation. Based on those observations, the utility interviews, and projected cost savings, Basin decided to proceed with the air-blow rather than steam-blows.

Cost Savings. There was no need for an earlier start-up date on AVS Unit 2 since Basin did not need the additional capacity sooner than originally planned. Thus, there was no advantage in starting the unit early. There were direct savings in the performance of the air-blow as compared with a steam-blow. Since a steam-blow was used on AVS Unit 1, a sister-unit of Unit 2, we had a good basis for a cost comparison. A cost savings of approximately 38% was calculated, mostly due to reduced fuel quantity requirements. Records show that the savings were actually on the order of 17%. There were several items which decreased the savings potential. The original design of the blow-out piping for Unit 2 was the same as for Unit 1. Calculations by Stearns-Roger, the architect-engineer, showed that a piping-size increase was necessary to avoid choking in midcircuit. The additional piping cost plus the purchase of a fast-acting 18-m ball valve would not have been necessary if the system had been designed for air-blows in the beginning. Removing those costs from Unit 2's air-blow totals would have meant a $143,000 savings over the cost of steam-blows. If the air-blow had been the original method for cleaning the steam lines, the actual savings would have been about 26%.

Results. Targets were used to determine the degree of line cleaning achieved. Due to the high volume of debris anticipated during early air-blows, the targets were not inserted into the lines until after the initial blows had been completed. Basin Electric did not have specific acceptance criteria based on target impacts, instead basing an acceptable line cleaning on the acceptance of the targets by station management.

Eighty-three blows were performed on the Main Steam-Cold Reheat circuit, 88 blows on the Hot Reheat circuit, and 23 on the Boiler Feed Pump Low-Pressure piping.

There was one good indication of the forces generated during an air-blow. During an initial blow, the steam lines were observed to move what was considered an excessive amount as the valve was opened. The swing range of the Cold Reheat line required the addition of restraints for the duration of the air-blows. Another action taken to reduce the steam-line swing was decreasing the blow valve's opening rate, which may have led to another problem. In a short time, the valve, an 18-in. ball valve, started to operate slower and slower. Finally, higher pressure air from a portable air compressor was used to actuate the valve. A possible cause of the increasingly difficult actuation may have been that the slower rate exposed the ball sealing surface to the debris-laden flow. Damage to the ball surface would have increased the drag on the seats. While the ball of the valve had a blasted appearance, the damage did not appear to be the absolute cause of the valve actuation problems. The trunions were not removed and examined. Consideration for a high number of cycles and seal surface roughness should be built into the ball valves in the future, if possible.

There are two indications of the air-blow's effectiveness. After a 2-wk operating interval, Unit 2 was shut down to examine the screens ahead of the Main Steam stop valves. Observers indicated the screens looked good with no sign of debris or pluggage. The screens were removed, and the unit returned to service. Sometime later, Unit 2 was again shut down for a routine outage, and the high-pressure shell was removed as scheduled. The turbine blading was found to be in good condition. The general feeling is that the air-blow of Unit 2 had been more effective than the steam-blow of Unit 1.

The preoperational cleaning sequence was:

1. Air-blow of superheater, reheater, and steam lines.
2. Hydro.
3. Boil out of drum and waterwalls with caustic and trisodium phosphate.
4. Operate at full load for 5 weeks.
5. Chemical clean drum and waterwalls with Dowell's vertan.

The air-blow of the Unit 2 piping was performed during early February 1985. The outdoor temperatures during the air-blow were between -20°F and -30°F with winds of 10 to 20 mph. To keep the compressors operating, each compressor was sheathed in plastic sheet and torpedo-style heaters were vented into the space under each compressor. Starting compressors was extremely difficult under these conditions, and operation after starting was not much easier. One compressor self-destructed, and another was badly damaged. One operator had an extreme case of frostbite, and several others were frostbitten to a lesser degree. That the air-blows were completed on schedule is testimony to the perseverance of the compressor contractor's operators. The boiler metal temperature was around 40°F during the air-blow. It did not vary during the test even though the air temperature into the boiler was approximately 100°F.

Table 1 illustrates that the lower specific volume for air combined with the higher mass flow rate resulted in similar momentum (or cleaning force) terms for the air and steam blows on identical units. This data along with the consensus that the air-blow was more effective demonstrates that thermal cycling is not required to effectively clean main steam piping. *Table 2* presents the expected mass flows and blow times for the air blow.

GE Power Plant Engineering

GE's Power Plant Engineering has historically used steam-blows for preoperational cleaning of main steam lines. The recent use of compressed air-blows has confirmed industry experience that this approach is equally effective in cleaning main steam lines.

Momentum Ratio. The momentum or cleaning force ratio compares the mass velocity head during cleaning with that developed during operation at maximum steam flow.

Table 1
Performance Data

AVS Unit 1 Steam-Blow

Circuit	Max. Drum Pressure (psig)	Specific Volume v (ft^3/lb)	Max. Exit Nozzle Pressure (psig)	Max. Mass Flow Q (lb/hr)	Momentum Term (Q^2v)
Main Steam and CRH	700	.6411	40	1,840,000	$2.17*10^{12}$
Hot Reheat	600	.7503	15	1,570,000	$1.85*10^{12}$
BFPT HP Steam	600	.7503	50	70,000	$3.68*10^{12}$
BFPT LP Steam	160	2.6005	25	156,000	$6.3 *10^{12}$

AVS Unit 2 Steam-Blow

Circuit	Max. Drum Pressure (psig)	Specific Volume v (ft^3/lb)	Max. Exit Nozzle Pressure (psig)	Max. Mass Flow Q (lb/hr)	Momentum Term (Q^2v)
Main Steam and CRH	800	.23	40	3,140,000	$2.27*10^{12}$
Hot Reheat	800	.23	20	3,140,000	$2.27*10^{12}$
BFPT HP Steam	800	.23	60	124,000	$3.54*10^{12}$
BFPT LP Steam	150	1.23	20	233,000	$6.68*10^{12}$

Table 2
AVS Unit 2 Effective Air Blowing Times

Circuit	Starting Drum Pressure (psig)	Starting Mass Flow (lb/hr)	Ending Drum Pressure (psig)	Ending Mass Flow (lb/hr)	Blowing Time
Main Steam and CRH	800	3,138,000	625	2,442,000	17.4 sec
Hot Reheat Steam	800	3,140,000	525	2,078,000	29.3 sec
BFPT HP Steam	800	122,000	525	83,000	12.4 sec
BFPT LP Steam	150	237,000	135	212,000	18.6 sec

A momentum ratio greater than one ensures that the mass velocity during cleaning is greater than that developed at the maximum flow condition. Therefore, it will be unlikely that any debris not removed during cleaning will be blown into the turbine during operation.

$$R = Q^2_c\, v_c / Q^2_{max}\, v_{max}$$

where:

R = momentum or cleaning force ratio

Q^2v = momentum term

Q_C = calculated flow during cleaning (lb/hr)

Q_{max} = max steam flow (lb/hr)

V_C = specific volume at pipe segment inlet during cleaning (ft^3/lb)

v_{max} = specific volume at pipe segment inlet at max steam flow (ft^3/lb)

The momentum term in the denominator is defined by the design conditions. The variables in the momentum term in the numerator are selected so that the ratio is greater than one. *Table 1* shows that similar cleaning forces were obtained for steam and air-blows on twin units. A lower specific volume requires more flow to obtain the same value in the numerator. The same cleaning force can be obtained with air, steam, or other cleaning medium.

Initial conditions are selected so that the minimum cleaning ratio at the inlet to various segments of the pipe to be cleaned is greater than one.

In order to obtain a minimum ratio of 1.2 at the critical point in the steam line, the maximum momentum ratio may range from 2 to 5 or higher, depending on the configuration.

Experience with Steam Blows. Several variations of steam-line cleaning have been effectively used by the GE Power Plant Engineering group. The common criterion has been the requirement to select conditions so that the minimum momentum force ratio is greater than one by some margin.

The standard steam-blow was done with saturated steam. Boiler pressure was increased to the selected initial pressure, firing was terminated, and the blowdown valve was opened as quickly as possible. The steam initially would be slightly superheated, but would rapidly become saturated since firing was terminated. Water in the boiler flashed to steam as pressure decayed. The blowdown valve would be closed at a pressure corresponding to the maximum change in saturation temperature allowed by the boiler vendor (usually 75°F). The process would be repeated until targets showed the lines were clean. In this approach, the required cleaning conditions exist only during the initial part of the transient, while the largest part of the transient would be a flushing operation.

Another approach is to continue firing the boiler during the transient. This produces superheated steam, and cleaning can be done at lower pressure with less condensate because the higher specific volume produces the required cleaning ratio at a reduced flow rate.

At Finch Pruyn, a main steam line fed by five boilers had to be cleaned when only two boilers were available for the scheduled cleaning. The main steam line increased in size as the branches from the boilers joined the main line. A saturated steam blow from the two boilers could not develop the momentum ratio required to clean the large segments of the main steam line. The cleaning procedure had to be scheduled so the plant could operate on the available boilers without interruption as the other boilers were brought on line. Instead of renting a boiler, the steam-line cleaning was done with superheated steam at low pressure. The valve was slowly opened to minimize the upset in boiler level, and firing was maintained to obtain the high specific volume of superheated steam. The result was an acceptable cleaning ratio with less flow than would have been required using saturated steam. Firing was terminated, and the pressure decayed as in a saturated steam-blow. This introduced an extended cleaning time at a momentum ratio greater than one compared with the saturated steam-blow, and the largest main steam-line segment was cleaned with the two available boilers. As the remaining boilers became available, they were steam-blown to the connection point.

A similar approach was used at Modesto, the valve was opened in about 5 to 7 min to minimize boiler upsets and temperature swings, remained open for about 2 min, and was closed slowly in 5 to 7 min. In this case, the allowable temperature swing for the boiler was less than the usual 75°F allowed for a saturated steam-blow.

TEPCO, CHUBU, and TALKHA are combined-cycle projects where the steam-blowing time ranged from 3 to 20 min. Cleaning time is limited by the amount of demineralized water available. One extended blow at the desired cleaning condition is equivalent to many standard blows where the cleaning condition exists for several seconds, and therefore, will significantly reduce the total cleaning time.

Experience with Compressed Air. The motivation to use air-blows was a compressed schedule and the need to minimize the risk associated with bonus/penalty construction clauses by removing the steam-blow from the critical path in the start-up cycle. Bob Kelety of Tidewater Compression, the supplier of compressors for the following jobs, circulated a brochure and references advertising compressed-air cleaning of main steam-lines. A reference check indicated that compressed air-blows should be seriously considered because:

1. A theoretical comparison of the potential cleaning ability of steam versus air was made by GE's Steam Turbine Thermal Engineering group in 1984. Using an air temperature of about 120°F, in accordance with information obtained from electric utilities, the group's analysis showed that, for the same initial boiler pressure, the cleaning force (momentum ratio) is about the same.
2. None of the electric utilities contacted observed any indication of abnormal turbine erosion problems over a period of time.
3. Field engineer comments quoted stated that the condition of the temporary strainers was as good as the best observed for steam-blows and better than some. (A good indication of effec-

tive pipe cleaning is the condition of the temporary strainers after an initial operating period.)

A consistent factor for an effective cleaning seemed to be rapidly opening the temporary valve in about 1 sec. This is possible with an appropriately rigged ball valve. The size of the temporary valves used ranged from 8 to 12 in. In all cases, the compressed air-blow followed the hydro test and chemical cleaning of the boiler drum.

When air-blows take place after chemical cleaning, the initial blows should be done at low pressure to ensure that trapped fluids are removed. The procedure called for the first blow at 50 psig, followed by opening drains to remove fluid. This step is repeated until no fluid is removed from the drains, and the pressure is increased in 25 or 50 psi increments until the design pressure level is approached. Start-up engineers have indicated that most of the brown effluent is removed before air-blows start from the design condition.

PERC is a Refuse-to-Energy plant. Two Riley boilers supply steam to a 25-MW GE turbine. Because the com- pressed air-blow at PERC in December 1987 was GE's first air-blow, the procedure selected was to obtain a clean target at a minimum momentum ratio slightly greater than one – then increase the drum pressure and momentum ratio to see if additional debris could be removed.

The initial phase of eliminating trapped fluids took approximately 20 blows and 5 hr on boiler A and 18 blows in about 2.5 hr on boiler B. Thirty-four simultaneous blows on boilers A and B initiated from 165 psig produced a clean target. Twelve additional blows with initial pressures up to 271 psig and higher momentum ratios did not produce additional target impacts. This indicates that higher momentum ratios are not necessary, and is consistent with utility experience of effective air-blows at a momentum ratio of 1.2. After 6 mo of operation, which included 20 to 30 brief excursions to 120% power, 72 hours at 105% power, and many start-ups and shutdowns, the turbine screens were clean. Boroscopic examination of the first-stage buckets by the GE service department (and witnessed by the customer) showed no indication of wear. This result is consistent with industry experience in that the Start-up Manager, Andy White, stated: 'The screens were as clean, if not cleaner, than screens observed in 10 steam-blows." Thus it appears that effective compressed air-blow cleaning can be done at minimum momentum ratios near 1.0.

ANR is a gas/oil-fired STAG plant which consists of a Frame 6 GE gas turbine, a supplementary fired ZURN heat recovery steam generator (HRSG), and a 28-MW GE steam turbine. The main steam line and gas turbine injection steam-line cleaning at ANR was done with nitrogen instead of air with the same result, an exceptionally clean screen. A Union Carbide Industrial Services Company (UCISCO) liquid-nitrogen truck and pumper were rented instead of air compressors. The economic trade-off compares the high transportation charges of the air compressors with the cost per hundred cubic feet for nitrogen.

Nitrogen blowing has an economic advantage for small volume systems. The capacity of the pumper allowed a continuous blow on the gas turbine steam injection line.

Brian Palmer, the Start-up Manager at ANR, said, "The nitrogen-blow of the main steam line and the gas turbine injection steam line resulted in substantial cost savings due to reducing the impact of steam line cleaning on the ANR commissioning schedule. Steam turbine inlet screens were inspected after a 30-day operational test at plant full load with no evidence of particle impingement or accumulated debris."

COGEN TECH is a gas/oil-fired STAG plant, with three Frame 6 gas turbines, three VOGT HRSGs, and a 65-MW GE steam turbine. The main steam lines and gas turbine steam injection lines were cleaned with compressed air. The main steam line cleaning took approximately 21 to 30 blows from each HRSG to obtain clean targets. Ted Duncan, Senior Construction Manager, participated in the inspection for cleanliness. He said, 'We found no residue in the strainers and less than 5% (visual) closure of the mesh openings from fine deposit after approximately 90 hr at base load." The conclusion was that air-blow vs steam-blow of the piping systems was very acceptable. Charles Johnson, the Start-up Manager, stated, "Air blow certainly takes pipe cleaning out of the critical path and is easier to do. It is schedule-enhancing."

REDDING, a wood burning plant where two Riley boilers supply steam to a 23-MW GE steam turbine, had the fewest blows of any project. Boilers A and B both had acceptable targets within 12 individual blows, including low-pressure blows to eliminate trapped fluids. Three simultaneous blows produced the final acceptable target.

Ron Flanagan, the mechanical engineer at both PERC and REDDING had the following comments about the advantages of air-blows versus steam-blows.

1. Schedule Effects: Because firing the boilers is not required for air-blow, this work operation can be scheduled immediately after boiler hydro and chemical cleaning, allowing other work items to be started.
2. Manhours: The different conditions between air-blow and steam-blow reduce the amount of time required to install temporary piping and supports. It also reduces the personnel and time required to perform the operation.
3. Effectiveness: Inspection of the fine mesh screen and stop valve revealed one minor impact on the screen. The air-blow was very effective in both cost of operation and cleaning at REDDING and PERC.

BURNEY FOREST is a duplicate of Redding. The steam line cleaning procedure was identical, but more blows were required. Temporary screens were removed January 1990. Warren Behrens, the Project Manager, reports that the compressed air-blow was quicker and less expensive, with results equal to or better than steam blows, with the added benefit of being completed earlier in the construction schedule.

TBG COGEN is a gas/oil STAG plant with two GE LM2500 gas turbines, two supplementary fired HCG boilers, and a 13-MW GE steam turbine. After approximately 200 hr of operation, with slightly more than 100 hr at full load, Andy White, the Site Manager, stated the screens were "beautiful" and consistent with experience at PERC. *Figure 4* shows the turbine strainer. *Figure 5* focuses on the only trapped particle. *Figure 6* displays a larger segment of the clean strainer.

Figure 4. TBG COGEN strainer.

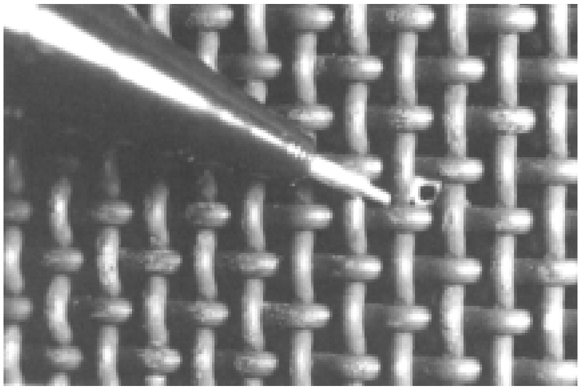

Figure 5. Particle trapped in TBG COGEN strainer.

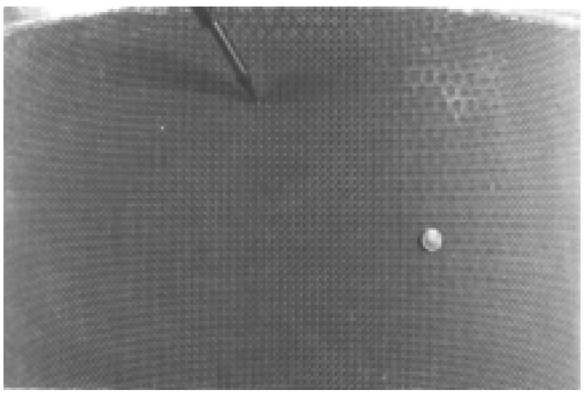

Figure 6. Larger segment of clean TBG COEN strainer.

FAYETTEVILLE is a gas/oil STAG plant with eight Frame 5 GE gas turbines, three VOGT HRSGs, and a 55-MW GE steam turbine. Six Frame 5 gas turbines feed into three HRSGs (2 GTs per HRSG) and the steam generated is delivered to the steam turbine. Two gas turbines operate simple cycle. Main steam lines were blown individually and flushed simultaneously. Individual blows were 18 on HRSG 2, 35 on HRSG 1, and 94 on HRSG 3. There were 32 simultaneous blows of HRSGs 1, 2, and 3. It appears likely that debris from HRSG 3 was pushed back into the other legs. The target following the simultaneous blows was accepted by the GE turbine erector and the Black and Veatch representative. Dave Buchyn, the mechanical engineer, observed the strainer during an early shutdown for valve repair said, "The general consensus of those observing the valve and strainer after 8 hr at full load operation was that the air-blow was a success. Five small indentations were made on the solid face of the strainer basket where the steam enters the valve. A small amount of scale was found at the bottom of the valve on either side of the flow splitter plate, which is a low velocity area." *Figure 7* is a closeup of the strainer, with no evidence of particle impingement. *Figure 8* shows the full strainer, and *Figure 9* is a view of the top of the main steam stop/control valve. The strainer was kept in service because of the limited operating time at full load, and is scheduled to be removed after the publication date.

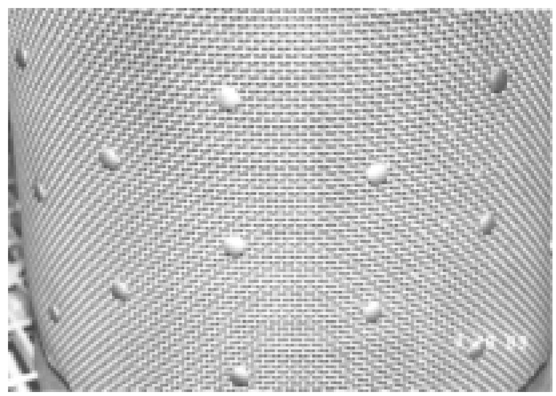

Figure 7. Fayetteville strainer closeup.

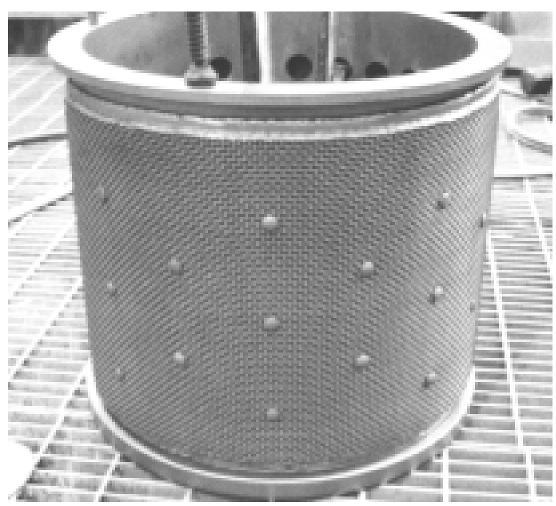

Figure 8. Fayetteville strainer.

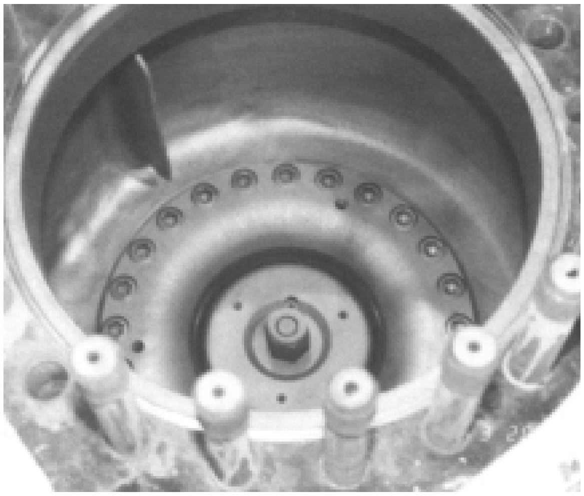

Figure 9. Fayetteville main stream stop/control valve.

Conclusion

Experience over the last 20 yr on power plants ranging from 35 to 700 MW, with supercritical boilers, drum-type boilers, and heat recovery steam generators has shown that compressed air-blows may be the most effective and economical approach to cleaning main steam lines.

Benefits of compressed air-blows are:

1. Flexible scheduling because air-blows can be worked into the start-up schedule without affecting other major critical path activities, except for work on the boiler and steam-line pressure parts. Balance of plant equipment associated with the boiler and boiler auxiliary systems must be completed and checked before steam-blowing is possible.
2. Reduce manpower, time, fuel, condensate requirements, and cost.
3. Extends boiler life by eliminating temperature cycles in the boiler associated with steam blows.
4. Eliminates construction risk due to delays that can occur when steam-blow is a critical path item.

The GE Power Plant Engineering approach has been to do the compressed air-blow after hydro and chemical cleaning of the boiler. Allegheny Power, Detroit Edison, and Basin Electric performed the air-blow prior to chemical cleaning of the boiler. In all cases the superheater, reheater, and main steam piping were cleaned with compressed air.

Although the approaches varied, experienced start-up personnel have consistently rated compressed air-blow results "as good as the best and better than some"steam blows.

Reference

GEI-69688E, Cleaning of Main Steam Piping and Provisions for Hydrostatic Testing of Reheater, 1989, General Electric Company.

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