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ADVANCES IN POWER PLANT STEAM BLOW CLEANING ANALYSES

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ABSTRACT

Steam blows are used prior to initial turbine powering for steam power plants to clear debris and surface scale that could potentially damage turbine blades during plant operation. Based on experience from steam blows for several dozen plants, enhancements have been made to the techniques in the detailed engineering analysis used by plant startup to perform steam blows. This paper discusses these improvements as applied to combined cycle gas and coal power plants.

The basis for steam blows is that the piping is blown, bypassing the turbine, with sufficient boiler pressure to ensure that the piping will experience a dynamic pressure to assure adequate cleaning. Typically, the boiler pressures during steam blow provide a dynamic pressure throughout the piping, which is at least 20% higher than would be experienced for all plant operating conditions. Therefore, any potentially damaging particles will be blown out of the piping prior to the turbine operation.

The following improvements and enhancements, which are detailed in this paper, have recently been implemented in the analyses used to establish adequate steam blows:

1. Advanced Modeling Techniques
2. Design Coordination with Fast Track Engineering
3. Consideration of Multiple HRSG Plants
4. Analysis Support During Actual Steam Blows (for site engineering and startup)

KEYWORDS:

Steam Blow, Power Plant, Combined Cycle, Cleaning Force Ratio, Startup

NOMENCLATURE

BV - Blow Valve
CFR or CF - Cleaning Force Ratio or Cleaning Factor
CR - Cold Reheat
HP - High Pressure
HRSG - Heat Recovery Steam Generator
HR - Hot Reheat
IP - Intermediate Pressure
LP - Low Pressure
P&ID - Piping and Instrumentation Diagram
RH - Reheater
SH - Superheater
1x1x1 - combined cycle gas turbine power plant where one combustion gas turbine (CGT) supplies heat to 1 HRSG, which supplies steam to 1 steam turbine generator (STG)
2x2x1 - as 1x1x1 but 2 CGTs, 2 HRSGs and 1 STG
3x3x1 - as 1x1x1, but 3 CGTs, 3HRSGs and 1 STG

ADVANCED MODELING TECHNIQUES

Computer programs are used to determine the most efficient conditions for cleaning steam system piping. This is in contrast to the hand calculations based on experience that were performed previously. From the steam system piping and equipment, and maximum service conditions, the programs determine a minimum steam system pressure required to ensure that the necessary cleaning of each section of pipe and piece of equipment is performed. The following provides the method of calculation and the features of the computer programs.

Criteria

The computer programs are used to determine the cleaning forces necessary to remove objects from the pipe and

equipment to be cleaned. When steam flows through the piping system, each object in the system will experience forces due to the steam flow. These forces are called drag forces. For attached objects, the forces tend to shear the objects from the wall and carry them downstream. During normal steam system operation, these forces are present. Therefore, the conditions required during steam blows are those that produce forces on the objects in excess of the maximum forces to be experienced during system operation. Any object that is not removed during the steam blow can be expected to remain in the steam system during normal operation. The Cleaning Force Ratio (CFR) or Cleaning Factor (CF) is the industry-accepted factor that quantifies the ratio of the required dynamic pressure for cleaning to the maximum dynamic pressure existing during the system operation.

It is not possible to calculate the forces on each particle. The only requirement is to exceed the maximum service forces during the steam blow. The drag force is a product of the dynamic pressure and a drag coefficient. If the drag coefficient remains constant, the force is proportional to the dynamic pressure. The shear stress at the walls is the product of dynamic pressure and the friction factor. For a constant friction factor, shear stress is proportional to the dynamic pressure. Friction factor or drag coefficient is a function of the Reynolds number. For any given point, the Reynolds number during the steam blow is of the same order, as at the maximum service condition and the friction factor will change slightly. The change will usually increase the friction factor during the steam blow. The simplifying assumption of constant friction factor will be conservative and produce slightly higher forces during the steam blow than would be expected.

The excess margin used during a blow is determined from past experience to allow for any loosening of attached objects during operation. Temperature cycling may cause this loosening. A customary margin is 20% of the maximum dynamic pressure for the maximum service condition (CFR=1.2). Similarly, the time taken for an object to travel through the system and be ejected cannot be calculated. Instead, a technique of detecting particles in the emerging steam blow is used. This technique checks the emerging steam for particles impinging on a polished metal plate (target).

Flow Types

During the steam blow, the nature of the flow is compressible with friction. The steam is also assumed to behave as a perfect gas. An assumption of the type of flow process is necessary to find the local conditions.

Various flow regimes are possible ranging from all subsonic flow, subsonic flow with sonic condition at the steam blow exit, and complex flow types. The complex flow types may involve more than one sonic point, supersonic regions, and shock waves. The pressures existing will depend on the nature of the flow.

Either the system must be arranged to ensure that a known flow type exists or methods must be used that are capable of dealing with the complex flows. The method used is adiabatic flow with friction. This method assumes no heat input or loss during the steam blow. This is a reasonable assumption for the steam blow conditions. In addition, the approach assumes isentropic flow at area changes in the steam system. This assumption is acceptable since losses that occur at these changes are over a short length. The loss factor is added to the friction of the adjacent section.

The method is capable of providing an accurate representation of the conditions existing in the system. If the location of the point in the system where sonic velocity exists occurs internal to the system, the method will correctly locate this point for the lowest pressure conditions. Pressure ratios and flow rates obtained for this condition will be correct. However, at higher pressures, other locations such as the outlet may also reach sonic conditions. If the sonic point as detected is at the exit to atmosphere, the upstream flow is sonic and the method is correct.

This method is modified to exclude the more complex flow types. This is done by ensuring that the flow area at exhaust to the atmosphere is no greater than any of the internal flow areas. This means that the only sonic points must occur at the outlet with the remainder of the flow being subsonic. Since the pressure and flow rates required will be reduced by using the largest exit pipes, it is also worth checking the next largest pipe size. If no internal sonic regions result, the method can be used.

Computer Programs

Two computer programs are used to determine the steam blow conditions. A Bechtel developed computer program BLOWOUT [1] is used for most steam blow analyses. This computer program is based on the imposition of sonic steam flow at the end of the steam system being evaluated. The flow calculation is performed based on a Fanno line (adiabatic flow with friction) expansion. A commercial available program ARROW™ [2] is used in the cases where the steam flow velocity at the end of the piping system is not sonic or there is an internal choke point.

BLOWOUT [1] can be used with a custom EXCEL™ spreadsheet for data entry and execution interface. The spreadsheet entry format provides a rapid and understandable means of providing a complete description of the steam system to be blown. The modeling features of BLOWOUT [1] are:

- Single or parallel steam blow system exits or silencers
- Modeling of piping and all piping system fittings (branch/run-through tees, expansion and contraction fittings, short/long radius elbows, standard/custom valves and fittings)
- Reheaters (RH)
- Superheaters (SH)

- Multiple parallel flow paths
- Multiple steam sources (heat recovery steam generators (HRSG) or boilers)
- Maximum service conditions specified for each length of pipe and piece of equipment to be cleaned
- Once-through boiler modeling
- Continuous or cyclic steam blows
- Steam blow valve (BV) opening and closing times for cyclic steam blows
- Steam drum and evaporator water volume
- Steam drum water level for controlling length of cyclic steam blow
- Maximum temperature drop permitted by boiler vendor during steam blow

BLOWOUT [1] calculates the following:

- Loss coefficients for each section of pipe with fittings and valves
- Loss coefficients for piping reducers
- Mach numbers and pressure ratios throughout the piping system
- Dynamic pressure in each section of piping to be cleaned.
- Boiler pressure, drum water temperature, steam mass flow rate, exit pressure, steam flow velocity, and exit thrust at the initial conditions at the start of the steam blow and final conditions at the end of the steam blow.
- Steam blow duration
- The dynamic and static pressure and flow velocity throughout the system

To validate the computer program, the calculated conditions predicted have been compared with instrumentation data recorded during the steam blows. The parameters monitored are steam drum pressure, superheater outlet pressure, and pressures at downstream locations in the piping system. Good agreement has been found between the computer program and the measured data.

Calculations and Theory

BLOWOUT [1] is used to determine the steam blow conditions required for cleaning the process piping. This code utilizes the Fanno line relationship [3, Page 547] and the pressure ratio relationship at the sonic point based on the line friction, Mach number, and isentropic exponent (see Equation 1).

$$\frac{\bar{f}L^*}{D} = \frac{1-M^2}{kM^2} + \frac{k+1}{2k} \ln \frac{(k+1)M^2}{2+(k+1)M^2} \quad (1)$$

Where:

- \bar{f} = Average friction between 0 and L* (sonic point) for a given diameter D
- M = Mach number
- k = Specific heat ratio = 1.3 for steam [3, Page 22]

The BLOWOUT [1] program treats the flow as adiabatic with friction and imposes a sonic steam flow condition (M = 1) at the end of the steam piping system being evaluated. This is traditional practice since small pressure ratios can cause sonic conditions if the area changes abruptly such as the exit through a steam silencer or valve to the atmosphere. However, the results from the code could be conservative if the required mass flow rate produces M < 1 at the exit, or subsonic flow.

Since BLOWOUT [1] assumes choked flow and a sonic flow condition at the pipe exit, it is possible to perform a Fanno line calculation based on the given system friction from the known Mach number at the exit, provided the fluid behaves as an ideal gas. In addition, the code performs its calculations using a boiler depletion model developed specifically for the steam blow. The program aborts the execution if choking occurs in the piping at a location other than the exit (due to a large area change). This indicates a need to pursue a different approach like using the ARROW™ [2] program.

The object of the calculations is to determine what conditions should exist in the boiler at the start of the steam blow so that the dynamic pressures produced are at least equal to that required. There are three parameters that need to be calculated: the dynamic pressures required, the minimum steam blow conditions, and the initial steam blow conditions.

The minimum source (boiler) pressure is determined based on the service dynamic pressure required at each pipe section location to be cleaned [1]. The required dynamic pressure is calculated for the maximum service conditions. A 20% margin is the basis for the BLOWOUT [1] program and provides the value to be reached during the steam blow. However, the cleaning margin may be modified to meet project requirements. The dynamic pressure from the maximum flow operating condition is defined as [1b, Page D33]:

$$P_{dyn} = \frac{1}{2 \times 144 \times g} \frac{W^2}{A^2} v \quad (2)$$

Where:

- P_{dyn} = Dynamic pressure, lbf in⁻²
- g = Gravitational constant, lbm-ft lbf⁻¹-sec⁻²
- W = Mass flow rate, lbm s⁻¹
- A = Flow area, ft²
- v = Specific volume, ft³ lbm⁻¹

Therefore, the required dynamic pressure for cleaning ($P_{dyn, required}$) is expressed in terms of the maximum dynamic pressure existing during system operation ($P_{dyn, maximum service}$):

$$P_{dyn, required} = 1.2 * P_{dyn, maximum service} \quad (3)$$

The static pressure necessary to produce the required dynamic pressure depends on the local Mach number, which must be known to obtain the static pressure required. The relationship can be re-expressed in terms of flow rate and the

specific volume to eliminate Mach number. When the local static pressure required has been determined, the required boiler drum pressure and associated flow rate can be found.

For some duration of steam blowing to be achieved, the operation must start with the boiler drum at some higher pressure. It is necessary to calculate back from the desired end or minimum required condition calculated above to find the initial drum pressure required. During the steam blow cycle, the local dynamic pressure at the start will be in excess of that required (exceed minimum acceptable CFR) and will be falling to the required value (minimum acceptable CFR) at the end of the steam blow.

Where the flow is highly compressible ($M > 0.2$), the BLOWOUT [1] program utilizes the relationship based on Mach number for P_{dyn} :

$$P_{dyn} = \frac{M^2 k P_{static}}{2} \quad (4)$$

Where:

P_{static} is the local static pressure, psia.

The mass flow rate is defined as [4, Page 84]:

$$W = A \sqrt{144 g P_o k \rho_o} \left(\frac{M}{\left[1 + 0.5(k-1)M^2 \right]^{\frac{k+1}{2(k-1)}}} \right) \quad (5)$$

Where:

P_o = Local stagnation pressure, psia
 ρ_o = Local stagnation density, lbm ft⁻³

The sonic speed, C , when Mach number equals 1, can be estimated as [4, Page 80]:

$$C = \sqrt{\frac{2k}{k+1} RT_o} \quad (6)$$

Where:

C = Sonic speed, ft s⁻¹
 R = Gas constant, ft² s⁻² °R⁻¹
 T_o = Stagnation air temperature, °R

The thrust force of the jet at the pipe exit is estimated as [4, Page 101]:

$$F = \frac{W \times V_e}{g} + A_e \times (P_e - P_a) \times 144 \quad (7)$$

Where:

F = Thrust force, lbf
 V_e = Exit (sonic) velocity, ft s⁻¹
 A_e = Exit flow area, ft²
 P_e = Exit static pressure, psia
 P_a = Atmospheric pressure, psia

Utilizing Equations (5) through (7), the thrust force at the pipe exit can be determined. These relationships are already built into the BLOWOUT [1] program code and the results are provided as part of the output.

DESIGN COORDINATION

New generation power plants are engineered and built in about two years. The engineering for steam blow is initiated early in these fast track project schedules, instead of near the end of the job. Startup, plant design and steam blow analysts are involved in this coordination effort.

As plants become more complex and fast track, the need for early design coordination of steam blows become more essential and important, especially for multiple HRSG plants. Many different engineering entities are involved as projects proceed toward steam line blowing, to ensure the integrity of the piping system and that the system will function properly and safely. Steam line blowing is a very complex series of startup tests that can have a major impact on the plant startup schedule if delays occur due to problems and/or failures. Even with efforts to standardize plants, constant design changes and unexpected problems can impact the different engineering entities in every phase of the steam blow process. As the pressure and temperature of steam line blows continue to increase, the need to properly design, fabricate, and install steam blow piping systems becomes even more critical, to ensure the overall safety of plant personnel during the actual steam blow. Proper design coordination and advanced modeling techniques will assist in eliminating potentially dangerous situations that could hamper a plant's operation.

Overview of Steam Blow Work Process

The basic steam blow work process is illustrated in Figure 1 and includes the initial steam blow development and engineering design/analysis to actual steam blow execution and beyond. Although many different engineering entities are involved in the steam blow work process, the process can be broken down into three main areas: Engineering, Startup and Construction. The activities of these engineering entities and the information they are required to provide contribute to a properly designed piping system and help to accomplish successful steam line blows.

This paper focuses primarily on the steam blow analyses during the engineering design and analysis phase and how it provides the necessary input and support to Startup. Engineering Design and Analysis activities are outlined below:

- Plant Design group coordinates the design of temporary piping, hangers and restraints; provides isometric drawings showing the physical layout of steam blow piping and details the branch connections being used for the steam line blow "target" holder.
- Staff Analysis group determines the HRSG drum maximum and minimum required steam blow pressures,

flow requirements and exit thrust loads considering the various steam blow design requirements as detailed later. This group also supports startup during the actual steam blow to assess any last minute design changes (see Analysis Support During Steam Blows section) and reviews recorded steam blow data provided by startup to verify analysis codes and methods.

- Central Stress and Pipe Support groups perform the piping stress analysis and pipe support design. They determine the physical location and proper loading of the pipe supports to ensure that the piping system is adequately supported.
- Project Mechanical group verifies the steam blow design conditions and procures steam blow piping & materials in accordance with design requirements. They also incorporate key engineering parameters and requirements into a single engineering document (steam blow P&ID), which must be reviewed by all involved groups.

The steam blow design and analysis is an iterative process (as illustrated in Figure 2), requiring the feedback of preliminary results from various engineering groups as well as Startup, to optimize blow paths and sizing of temporary pipes, blow valves and silencers. The iterative process becomes more important and challenging when the steam blow process is started even before design inputs such as the temporary steam blow isometrics are available.

It is important to note that the initial development of the steam blow scheme/philosophy, which impacts the final steam blow design and analyses, requires the input of all engineering entities. Startup is the party ultimately responsible for the successful cleaning of the steam lines using the steam line blow cleaning method based on the engineering design and analyses. However, prior to Startup's steam line blow cleaning, the above engineering design and analyses ensure that a successful as well as a safe steam line blow cleaning operation occurs.

Steam Blow Paths

Blowing methods for different boiler types use the same basic procedure, with most procedural variations due to the differences in boiler construction. Actual blow flow paths are determined by Startup and depend on plant type, boiler rating, and steam piping configuration. Typical blow paths analyzed for 1x1x1 plants are outlined below and illustrated in Figure 3.

High Pressure (HP) blow path: This is the main blow path for once-through boilers such as small (package) boilers, circulating fluidized bed boilers, simple heat recovery steam generators (HRSGs), and smaller pulverized coal boilers.

High Pressure (HP) Superheater (SH) -> main steam header -> HP stop valve before HP steam turbine inlet -> temporary blowout piping and blow valve (BV) -> silencer to atmosphere

Cold Reheat (CR) blow path: Used in reheat type boilers such as larger oil, gas, and coal-fired boilers and larger HRSGs. This initial blowout path prevents the blowing of any external debris into the boiler reheater tubing.

HP SH -> main steam header -> HP stop valve before HP steam turbine inlet -> temporary blowout piping and BV -> jumpered over to CR line -> Reheater (RH) inlet -> temporary blowout piping -> silencer to atmosphere.

Hot Reheat (HR) blow path:

Same as CR but through RH -> HR line -> RH stop valve before intermediate pressure (IP)/low pressure (LP) steam turbine inlet(s) -> temporary blowout piping -> silencer to atmosphere

After the main steam paths are successfully blown clean, other steam lines such as bypass lines, IP, LP and process lines are blown, as applicable. Targeted blows are generally required for lines discharging to turbine blading or directly to a process such as CR/HR.

For more complex boiler designs that contain HP and LP steam drums and multiple stages of superheat and reheat, the steam blow paths and sequences must be determined on a case-by-case basis, taking into account permissible boiler operating procedures and design limitations. Multiple HRSG plants also face additional challenges as discussed in the Consideration of Multiple HRSG Plants section. Different designs such as supercritical plants have other issues since they have no drum (use condensate storage tank) and have more limited water supply.

Design Requirements

During the course of the steam blow analyses and temporary piping design, technical, cost and safety considerations need to be addressed.

Technical Considerations:

In the past, steam blows were performed based on experience or rules of thumb instead of detailed analyses to determine the required drum pressures. For example, one rule of thumb method states "the pressure head of the entire boiler and piping system must be the same or exceed that for full load operation." This method uses a blow pressure based on experience that is greater than "50% of the nominal pressure of the section of the pipe to be blown." Also by experience, the steam is heated with 50 to 100°C of superheat at the blow pressure. This approach does not calculate the required pressure and flow rate based on the dynamic pressure for the maximum service condition. Therefore, the required blow pressure and mass flow rate can be either over or under estimated. The maximum service condition for the piping system is a function of the mass flow rate and the specific volume. Full load operation is not necessarily the maximum service condition for each section of pipe.

As detailed in the Advanced Modeling Techniques section, the Bechtel computer program BLOWOUT [1] is used by the analysis group to determine the initial and final pressures in the boiler drum required to achieve the necessary dynamic pressure during a given duration of the blowing cycle.

Engineering parameters and design requirements, which affect the detailed steam blow analysis, are:

- Steam blow paths, methodology and philosophy & sequencing (see above for typical blow paths)
- Targeted and non-targeted (or service) steam blow paths
- Lines to clean; clean reheater or HRSG (will increase required drum pressure)
- Cyclic versus continuous blows
- Steam versus air or gas blows (only steam blows are addressed in this paper; air blows have the highest cost and safety risk)
- Required cleaning force ratio (CFR) or cleaning factor (CF) – typically use 1.2 versus 1.0.
- Temporary pipe configuration, design conditions, size, material classes: Temporary blowout piping and restraints are now designed and treated like permanent piping, based on the required drum pressure results.
- Pressure and temperature limits for permanent and temporary piping, reheater, and valves; may need to adjust maximum drum pressure accordingly.
- Number of HRSGs to use (if 2x2x1 or 3x3x1 plant) based on scheduled availability
- Stop valve parameters – blow through valve or not, blow kits and inserts drawings if applicable
- Steam blow valve size, location, rating, number
- Bypass line blows – blow thru bypass or non-return valve (NRV) or not, blow kit drawings if applicable
- Silencer – size, number, foundation issues, no silencer option, design flow/pressure/temperature
- Vendor requirements/input – acceptance criteria (target, CF, steam quality) may affect blow paths
- Differences in standards and practices for different projects and plants in different countries.

Due to the iterative nature of the steam blow analysis and design process as shown in Figure 2, any subsequent changes to any of the above design parameters require reassessment of not only the steam line blow analysis but also the stress and supports analyses and the material selection and piping wall thickness requirements. Any subsequent changes must be properly documented and processed through an engineering review to ensure the integrity of the piping system and that the system will function properly and safely.

Cost considerations:

It is desirable to reduce the required minimum blowout pressure and flow rate to facilitate plant startup. By reducing the required minimum blowout pressure and flow rate, permanent plant equipment and temporary steam blow wear

can be reduced and time between steam blows can be reduced (avoid starting second gas turbine). Pressure to reduce steam blow duration schedule to reduce cost is driven by the following factors: steam produced from the boiler for steam blows is costly, steam line cleaning is typically critical path, money issues at the end of a job.

Cost reduction efforts are considered in the engineering design/analyses and during startup phase but are interrelated. The following aspects of the steam blow analysis can help reduce the steam blow schedule and cost:

- Establish temporary steam blow piping requirements early in the project.
- Optimize steam blow scheme by performing service blows of nontargeted lines as part of the targeted line blow paths.
- Hydrolaze short sections of piping that only require service blows, in lieu of blowing to reduce the number of blows (and less blows requiring analysis).
- Use more than 1 HRSG if available to reduce pressures and schedule.
- Maximize use of available materials from other projects. Existing blow valves and silencers can be used to save money and can be modeled in the steam blow analysis.
- Cyclic versus continuous blows: Properly executed cyclic blows are the least cost and shortest duration option; have similar duration, engineering and material cost, and use much less water than continuous blowing.
- Use of concurrent blows: Blowing more paths concurrently helps shorten the net steam blow duration.

Safety considerations:

During all phases of the steam blow work process, safety is a primary concern and should not be compromised even while trying to reduce schedule and cost.

Steam line cleaning involves the release of high-energy material since it imposes abnormal and severe conditions upon the boiler and steam piping. The steam blowing is the first time that the unit is fired at any significant rate. Consequently, boiler startup as well as the steam line blowing must be performed with great care. Properly performed, steam line cleaning safety can be enhanced and considering the following in the steam blow analyses can mitigate the risks.

- Pipe location and layout considerations – vicinity of debris, direction of jet
- Temperature considerations – superheat, thermal stresses. Usually a saturation temperature drop not to exceed a suggested 75°F limits the boiler pressure drop. The 75°F change in temperature during the blowing period (and used in the steam blow analysis) has been established to prevent excessive stresses to the steam drum.
- Pressure considerations – for personnel and equipment protection, the pressure ratios and the maximum exit pressure are used to calculate the pressure in the permanent piping and the temporary piping used for steam blows to

ensure that the piping will not be over pressurized or overstressed at any point in the steam blow system.

- Silencer considerations – exit thrust loads, noise issues, direction of jet. Relocate as needed so discharge angle avoids equipment such as transformers. The maximum exit thrust and steam mass flow rates are calculated to properly design the steam blow silencers.
- Reducing the number of steam blows to the minimum required to clean the system, thus reducing the number of opportunities for failures and injuries. Pre-blow cleaning such as steam line hydrolazing, chemical cleaning of boiler superheater/reheater piping, etc., may substantially reduce the actual number of blows required.
- Standardize steam blow methodology to better identify areas of risk and appropriate mitigation actions.

CONSIDERATION OF MULTIPLE HRSG PLANTS

Because of boiler and piping pressure limits, common headers in multiple HRSG plants may need mechanical and chemical cleaning in addition to steam blows. Plant configuration has significant influence on steam blow duration. The 2x2x1 configuration is more complex to steam blow (due to the “common” piping requiring more blow paths) than a 1x1x1, and the 3x3x1 significantly more so. The reheat cycle, versus the nonreheat cycle, is also more involved due to the additional blow paths. Bypass line blows and export/process lines can further complicate the steam blow schemes.

Other multiple HRSG challenges include:

- Complicated blow sequencing and blow paths, which can keep changing right up to the start of the actual blows.
- Use of non-conventional blow schemes such as back blows instead of the typical blow paths previously outlined based on Figure 3.
- Use of more than 1 HRSG to reduce pressures.
- Not cleaning the reheater or common lines via steam blow if the pressures are too high even with 2 HRSGs, requiring the common headers to be mechanically or chemically cleaned (must ensure this requirement is reflected in Startup’s steam blow procedure).
- Blowing into previously cleaned lines.
- More piping to clean, higher pressures.
- More schedule difficulties.
- HRSGs arrival/timing factor into schedule and blow paths sequencing.

Therefore, it is more important with multiple HRSG plants to have a complete model and early steam blow coordination to avoid overlooking any aspect of the blows since the work process will be more complex and iterative.

Bechtel has designed, analyzed and performed the steam blows for over 30 plants since the mid-1990s. Based on recent experiences, some lessons learned and improvements to the

steam blow analyses and startup support are discussed in the next section.

ANALYSIS SUPPORT DURING STEAM BLOWS

Just prior and during the steam blow, the detailed steam blow model is used to support both refinements to the steam blow configurations and to address turbine vendor comments on the acceptability of the steam blow procedures. Also, a recent innovation has been adopted to reduce the initial pressure for targeted blows based on the detailed steam blow model analyses while considering the actual measured steam blow valve opening times, flow and pressure histories. This reduction in the initial steam blow pressure for targeted blows significantly reduces the number of targeted steam blows necessary to assure adequate cleaning.

Changes are often made to steam blow configuration up to and during the actual steam blows. An immediate assessment is needed to demonstrate that the required steam blow-cleaning factor will still be achieved. Often this assessment requires the use of the detailed computer models to ensure the cleaning factors reported in the steam blow procedures (based on the steam blow analysis) are achieved. Reanalyzing the blow configuration provides definitive proof of the acceptability of the change in configuration.

Without a reanalysis there is the potential that a seemingly insignificant change may compromise the effectiveness of the steam blows. For example, a change in pipe size, pipe length or valve size may result in a previously unanalyzed condition such as an internal choke point in the piping. This internal choke point limits the steam blow velocities in the piping resulting in an associated reduction in the cleaning achieved.

Possible changes to the planned steam blow configuration are numerous. A change may be needed because the original steam blow valve is unavailable or needs to be retooled. Similarly, the as-designed silencers may not be available. Sometimes the blow configuration is changed from one large silencer to two smaller silencers piped in parallel. Additionally, the forces associated with the blow may need to be re-evaluated and the direction of steam blow changed to reduce the potential for rainout of hard parts on personnel and equipment from the steam blow discharge.

Other changes in configuration that need to be immediately evaluated are associated with the reality of system unavailability during plant startup of multiple HRSG units. For example, the planned sequence and configuration for pipe cleaning may change because of HRSG availability.

Having a detailed steam blow model is of value provided the turbine vendor agrees with the methodology. Different turbine vendors have different criterion for accepting steam blow conditions. Immediate justifications for the

appropriateness of the detailed steam blow model are often provided to the turbine vendor during the steam blows. These justifications may include comparisons with the vendor blow pressure or cleaning factor criteria, or further details on the inherent conservatism of the use of a detailed model.

A recent valuable improvement in the steam blow process has been the availability and use of a Digital Control System (DCS). This web-based system provides a remote real time read out of plant conditions and can be used by the steam blow analyst to remotely assess the performance of the steam blows. Use of the DCS is of particular value when the steam blow analyst is evaluating steam blows at various sites in the world.

Other analysis support during the steam blows involves troubleshooting. The steam blow is an off normal condition involving temporary configurations and transient effects. These may involve excessive valve cycling and unanticipated large loose material in the piping system. In troubleshooting, comparisons are often made of the detailed model predicted pressures and flows with the actual measurements.

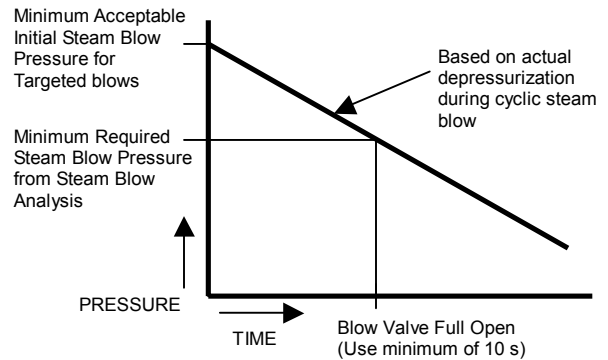
Recent Innovations in Limiting the Number of Targeted Steam Blows

There are inherent conservatism in the use of the detailed steam blow model. The first is that the blow pressures are determined so that every portion of the piping sees at least the design-cleaning factor. As a result, most of the piping sees cleaning factors well in excess of the design-cleaning factor. A further conservatism is that, to account for the valve opening times, the initial steam source pressure determined by the steam blow analysis is greater than needed to ensure adequate cleaning. Therefore, all sections of the pipe will experience steam cleaning in excess of the design-cleaning factor. Consideration of these inherent conservatism and the actual steam blow transient pressures are used to limit pressures for targeted steam blows. Reducing the initial steam pressure reduces the number of targeted blows. This has eliminated unnecessary over cleaning of piping and has also reduced the number of targeted blows needed to demonstrate cleaning.

The initial steam blow pressures are determined in the steam blow analysis to provide the greatest steam cleaning. The steam pressure is limited by system design pressure and by thermal cycling limits on the boiler or HRSG. In the steam blow analysis, a conservatively short duration is predicted because make-up flow and heat addition is intentionally not modeled. Also, the calculated steam blow duration considers a conservatively long blow valve opening and closure times. In reality, the actual duration of the blows is much longer than are predicted in the steam blow analysis. Therefore, the actual boiler or HRSG pressure response can be used to limit the initial pressure for targeted steam blows.

The steam blows for a steam blow path are first made using the maximum pressure determined by the steam blow

analysis. After a sufficient number of steam blows, all sections of the piping will have been subjected to conditions in excess of the required cleaning factor and all loose material will have had sufficient time to be swept out of the piping. The recorded actual steam source pressure history is then used to determine an actual, but reduced initial pressure, for which all portions of the piping will see a higher than required cleaning factor (see figure below). This pressure becomes the initial pressure for targeted blows for that steam blow path.



Use of this method has reduced the pressure for targeted blows and has been of particular benefit in greatly limiting the number of targeted steam blows. In some cases the pressure of targeted blow has been reduced by 200 psi, while reducing the number of targeted blows from hundreds to tens.

CONCLUSIONS

Advances in steam blow analyses, as detailed in this paper, have greatly increased the effectiveness of the steam blow process while helping to reduce the overall plant cost and schedule, without compromising safety.

REFERENCES

[1] a. Bechtel Standard Computer Program (SCP) TE620 (BLOWOUT). "Steam Blowout Analysis," Release 3, Oct. 1991. (Bechtel Proprietary)
 b. TE620 (BLOWOUT) Users/Theoretical/Validation Manual, Revision 3, Oct. 1991. (Bechtel Proprietary)
 [2] AFT Arrow™ Version 2.0, Compressible Pipe Flow Modeling, Applied Flow Technology, 2000.
 [3] White, F., Fluid Mechanics, Second Edition, McGraw-Hill Inc., 1986.
 [4] Shapiro, A. H., The Dynamics and Thermodynamics of Compressible Fluid Flow, Volume I, 1953 Edition, The Ronald Press Co., N.Y.

Figure 1: Basic Steam Blow Work Process Map

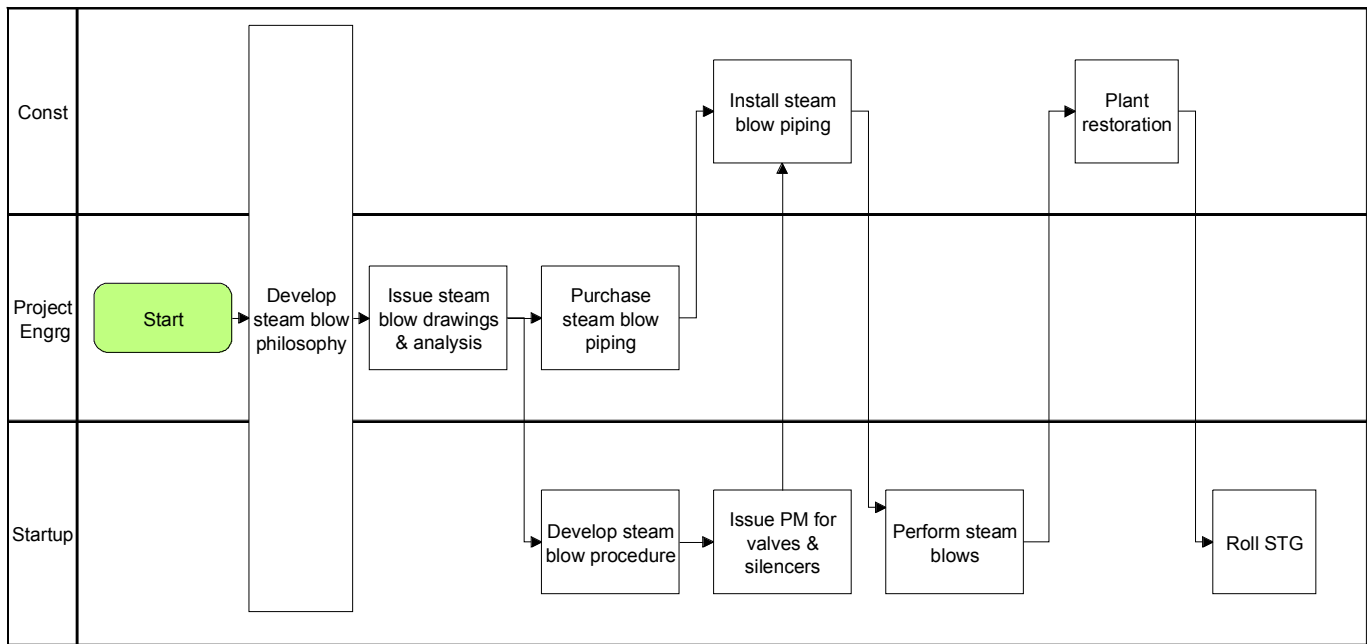


Figure 2: Engineering Design and Analysis

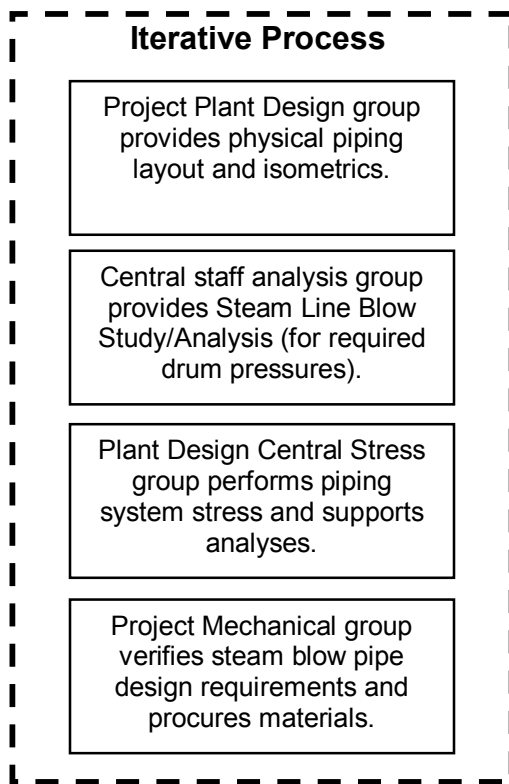


Figure 3: Typical 1x1x1 Plant Layout

