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Steps to building an **ANALYZER SYSTEMS MAINTENANCE PLAN**

Can hydrogen be used to **DECARBONIZE FIRED HEATERS?**

Gulf Energy

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Trip your turbine troubles: Optimize the reliability of steam-driven turbines

Steam turbines are essential for successful operations in refining and petrochemical plants, such as at the wet gas compressor and regenerator air blower of a fluidized catalytic cracking unit (FCCU). However, other smaller turbines can also perform critical functions that are important to the overall operation of production units. Much focus is commonly given to the main production process itself; as a result, turbine reliability improvement considerations may be secondary—that is, until severe damage occurs, sometimes causing manufacturing shutdowns for weeks on end.

As one example, severe turbine issues in a medium-size refinery shut down both the FCC and hydrogenation and catalytic cracking (HCC) units for more than 5 wk, resulting in production losses exceeding $65 MM. Such incidents can be mitigated by optimizing the steam quality that drives turbines. This requires designing effective condensate drainage from both the supply lines and respective turbine installations, as well as disentraining wetness from the steam flow to mitigate against erosion, precipitate and slug damage.

Following the delivery of high-quality steam, turbines must also be adequately drained of condensate to help prevent trips during startup, corrosion during idle periods, condensate accumulation during operation, and hydraulic shock to downstream steam lines or equipment. Condensate removal also helps reduce precipitate buildup.

Optimizing the steam system quality begins with proper design of the main utility headers. This requires effective collecting leg design, proper selection, placement and maintenance of condensate discharge locations (CDLs)—including the steam traps and valves—and installing high-efficiency moisture separators upstream of steam turbines. Although most of the steam trapping requirements are relatively simple, load calculations should be done to properly size the traps used to drain condensate from any inlet separator used and from the exhaust side of back pressure or vacuum turbines relative to the potential higher load from steam wetness and condensation. Although not a common consideration, the condensate loads at both the separator and the turbine exhaust side can be substantial.

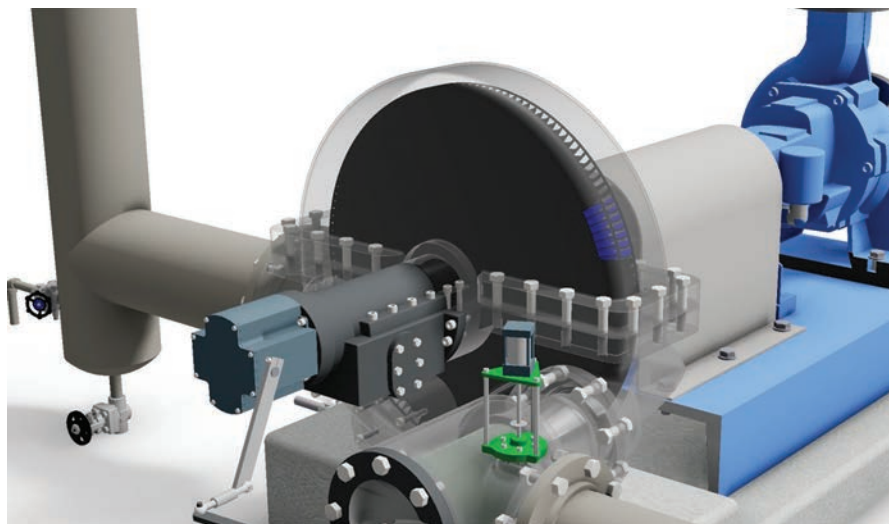

FIG. 1. Even simple, single-stage turbines are sophisticated equipment requiring appropriate care.

When properly designed and installed, a high-quality steam supply helps optimize turbine efficiency and reduce reliability issues associated with blade erosion, plating, turbine trips and severe damage from hydraulic shock.

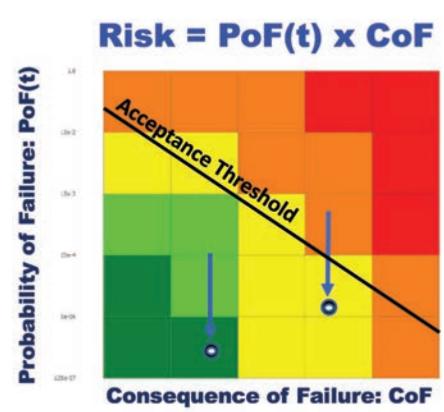

FIG. 2. Lowering risk requires reducing the probability of failure (PoF) for an equipment asset. In the case of turbines, this can correlate to lowering the probability of failure caused by condensate.

Vacuum/condensing turbine installations require additional design considerations relative to the steam quality supplied to the ejectors. Improvements to steam quality can be achieved by incorpo-

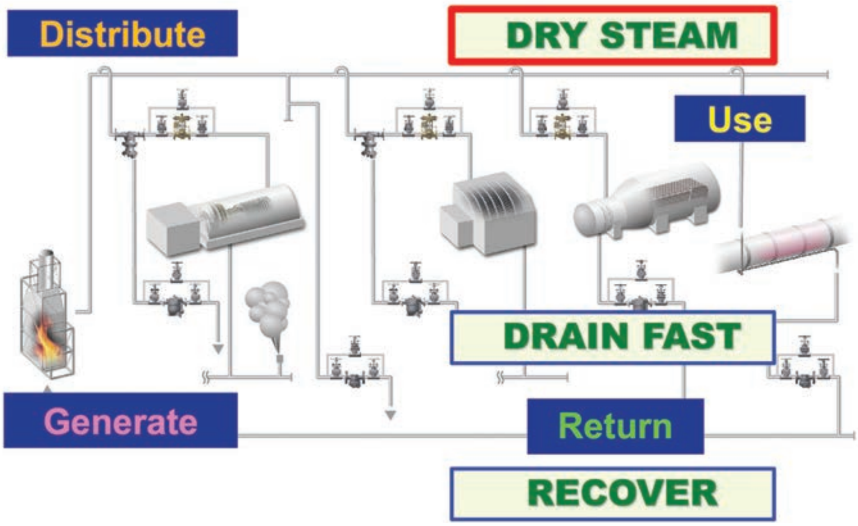

FIG. 3. Dry steam cannot be distributed in a steam system. Steam is either superheated or wet.

FIG. 4. If not superheated, steam contains substantial moisture that should be disentrained and drained.

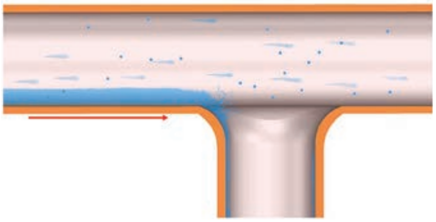

FIG. 5. All steam systems can have condensate flowing along the bottom of the pipe, and moisture is expected in flowing wet steam supply.

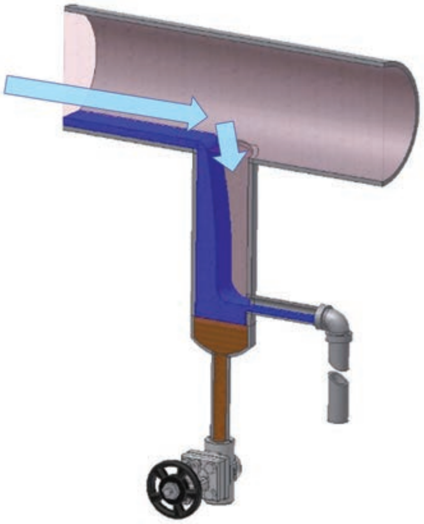

FIG. 6. A collecting leg must be adequately sized for high-velocity condensate to drain into it.

rating best practice design recommendations to help reduce ejector nozzle/throat erosion and precipitate buildup. These actions can help optimize and sustain benchmark vacuum pressures and surface condenser operation for longer periods.

Properly draining pedestal-mounted vacuum steam turbines can be especially challenging, as pumping (rather than trapping) systems may be required to remove condensate from the sub-atmospheric turbine case and exhaust piping. If drainage is inadequate, significant damage to internal turbine components, as well as a reduction in performance of downstream surface condensers, may occur. Each of these elements are reviewed in detail in the following sections.

Reducing risk. Steam turbines, even small ones, are sophisticated pieces of equipment (**FIG. 1**). It is common that turbines are the unnoticed, unsung heroes of the plant, functioning properly for extremely long periods of time—in a sense, forgotten until there is damage that can result in significant maintenance cost and service or production interruptions.

Due to concerns of production interruptions from downtime, many steam turbine areas can look like a fog zone, which is the result of multiple open steam bleeders as an attempt to prevent damage or imbalance. Even in such instances, turbines can experience incidents because the systems are either improperly designed or inadequately maintained.

One professional method to mitigate risk is to follow the principles of API RP 580/581.[1,2] **FIG. 2** shows a typical risk mitigation matrix. Risk is the product of the probability of a failure event multiplied by the consequence of the event (typically in monetary terms). While the consequence of an event usually cannot be lessened without a change in design, multiple actions can be taken to reduce the probability of failure. This article provides focus on some of the possible mitigation designs that can help reduce the probability of failure relative to the steam system, water entrainment in steam, and condensate removal.

Notice the blue arrows in the matrix shown in **FIG. 2** representing the reduction of risk deeper into an acceptance zone for two assets (such as turbines). It is recommended and possible to incorporate risk mitigation practices for all turbines in a plant, as well as other critical pieces of equipment, which lowers the combined risk of unwanted events.

Steam quality. Steam that drives the turbines can be either superheated, near saturation or wet. It is important to have steam without wetness as the drive source, and this is often the reason superheated steam is often selected for the design (**FIG. 3**).

There is a common misconception that plant steam is either superheated or saturated, but this is inaccurate because dry saturated steam cannot be sustained in a plant's steam system.[3] Boiler steam has significant wetness if not passed through a superheater, and usually much more wetness if generated from a waste heat boiler (**FIG. 4**). Steam quality without wetness is so important to turbine reliability that systems that are not supplied with superheated steam are recommended to have a best practice steam trapping design just before the turbine entry point, in addition to a steam separator and drain combination between that trapping location and the turbine entry point.

The need for adequate drainage and separation can be seen by examining FIG. 5. Disentrained condensate flows along the bottom of the steam system piping and some water remains entrained in the steam flow for wet steam systems. A first stage of removal can be accomplished by installing a properly designed collecting leg for condensate capture (FIG. 6).

Capturing and discharging condensate.

Consider that steam's design pipe velocity is commonly at or above 90 mph.[4] A key requirement is to remove the condensate flowing along the bottom of the pipeline that has already been disentrained from the vapor. If not removed, it can form dangerous slugs—many case histories of significant plant shutdowns due to the resulting damage caused are documented (FIG. 7). The velocity of steam under constant load requirement conditions elevates dramatically as the available non-liquid-filled portion of the pipe decreases, escalating the propulsion given to the slug to create turbine destruction (FIG. 8).

Slug buildup can be mitigated by the installation and sustained maintenance of well-designed condensate collecting legs and steam trap stations, also known as CDLs (FIGS. 9 and 10).[4] Turbine reliability begins with well-maintained utility lines.

Another key improvement is to install an engineered separator and drain after an appropriate CDL and before entry into the turbine to disentrain a substantial amount of wetness that may be carried in the steam flow. This not only helps prevent erosion of the turbine blades, but also mitigates precipitate buildup. Examples are shown later in this article.

It is common to see a fog zone around turbines in many plants, the result of open steam bleeders with the intention to mitigate damage from condensate slugs (FIG. 11). Regardless, this practice often does not preclude incidents and proper CDL design and sustained maintenance are recommended.

Superheat.

A misconception persists regarding superheat systems: that because the steam is superheated, adequate

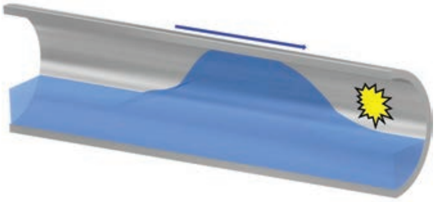

FIG. 7. As a slug's mass builds and closes off the pipe's cross-section, its velocity can rapidly accelerate.

FIG. 8. The potential damaged caused by slug-induced water hammer should not be underestimated.

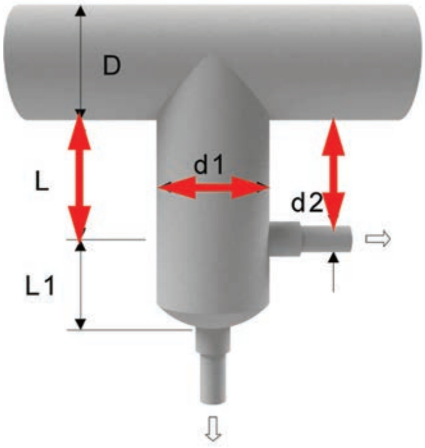

FIG. 9. A properly designed collecting leg requires adequate diameter, depth and distance before the trap take-off.

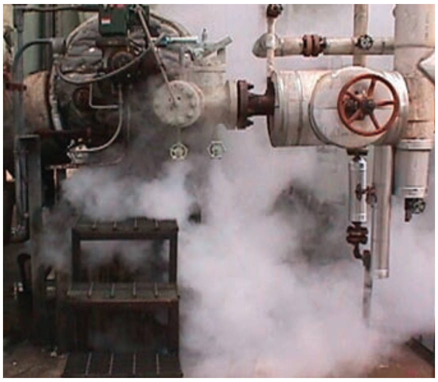

FIG. 11. Fog zones can create visual hazards and still be ineffective to mitigate turbine damage.

FIG. 12. This 24-in., 220-psig superheated steam line had a 400-ft section moved 7 ft by slug hammer.

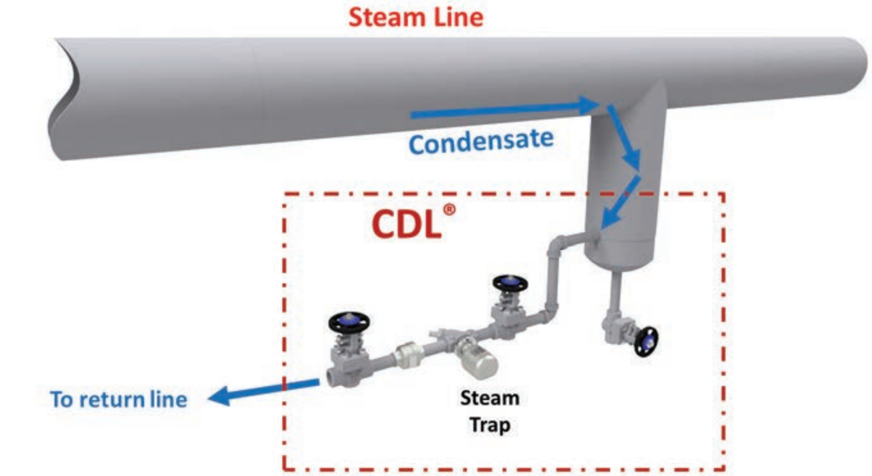

FIG. 10. CDL refers to the entire pipe assembly used to drain condensate, including the steam trap, piping and all valves.

CDLs are unnecessary. FIG. 12 shows a result in systems that are not adequately trapped. Water hammer from a slug of condensate moved a 400-ft. section of this 24-in., 220-psig superheated line a distance of 7 ft. When the drain valves were later opened, condensate drained continuously for 3 d.[5] The moral of this case history is that superheated mains can carry a lot of condensate and require well-maintained CDLs.

Turbine drainage. After utility lines are confirmed to have best-practice trapping and moisture separator installations, it is useful to examine at least seven areas on a turbine installation, starting with the inlet separator and continuing with multiple important stages through the turbine and its exhaust (FIG. 13).[6]

The CDL before the separator is intended to remove condensate that has already been disentrained. Each stage of the turbine installation can pool condensate and appropriate CDLs can mitigate issues.

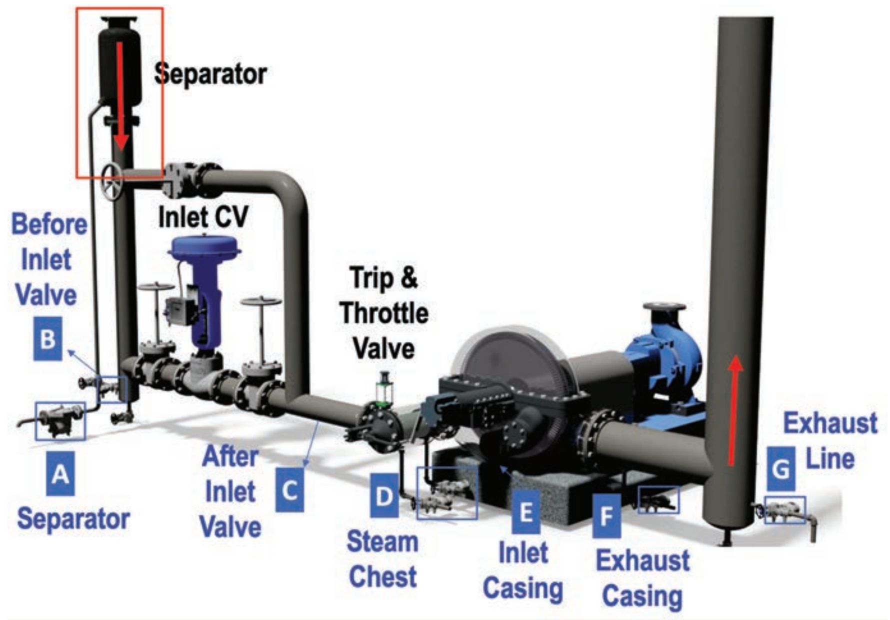

FIG. 13. Installing effective CDL at these seven drainage points can be crucial to improving turbine reliability.

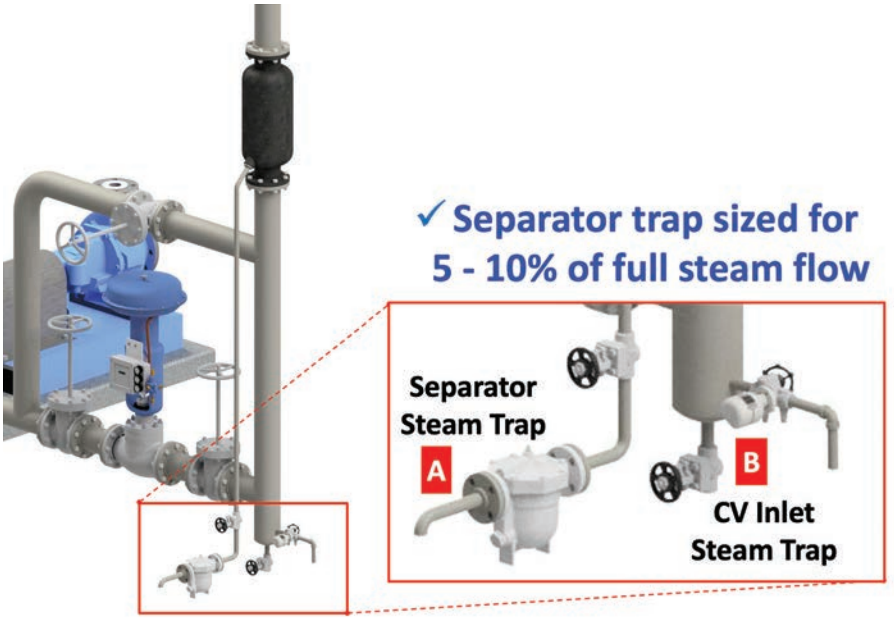

FIG. 14. The turbine inlet piping is the last defense to provide high-quality drive steam to the turbine.

FIG. 14 provides additional detail on the inlet side of a turbine installation. The trap on the separator is commonly larger than a standard utility main drip trap or the trap at the inlet of the control valve due to anticipated wetness to be removed, while the inlet to the control valve steam trap is typically a smaller size.

It is common to see inadequate drainage at the steam chest, trip and throttle valve, and even the casing drains. Often, these drains are plugged, which can lead to condensate buildup that causes damage. For these reasons, those connections are recommended for steam trap drainage (FIG. 15).

The supply steam quality and work efficiency of the turbine determine the amount of condensate on the exhaust side. Often, the trap for the turbine exhaust is larger than a simple utility main drip trap due to the potential for wet exhaust flow (FIG. 16).

Another misconception about steam trapping on turbines is that any type of trap can be used. However, many types of traps, such as inverted bucket, bimetal or expansion or balanced pressure thermostatics, and thermodynamic, have cyclical discharge characteristics, meaning they can back up condensate into the turbine, which is undesirable. Some traps, such as bimetal or expansion designs, can have large temperature suppression, draining condensate on cold startup but not draining effectively during normal operation. For this reason, it is preferred to use immediate response float trap designs (FIG. 17).[6,7]

Steam trap condition health is sometimes not carefully managed, and this can have a significant effect on turbines and other equipment, such as ejectors on air exhauster systems (reviewed later in this article). A blocked trap causes condensate backup into the separator it needs to drain and can render it useless, which highlights the need for effective, sustainable trap testing and maintenance (FIG. 18).[8]

Condensing turbines. Some turbines are designed to have their steam fully condensed by a surface condenser to create a vacuum or to generate optimum power. One such example is a condens-

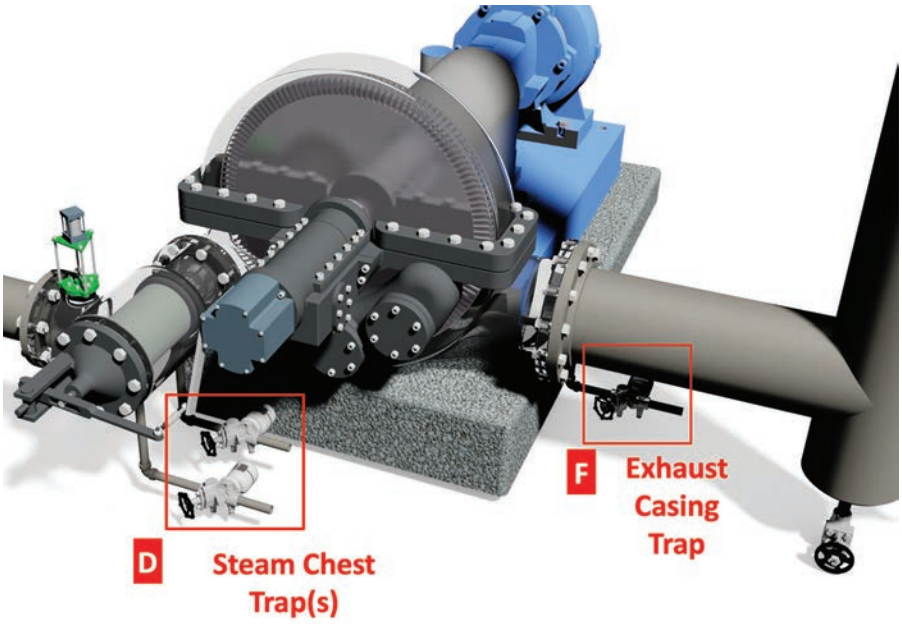

FIG. 15. Once steam enters the turbine, condensate can pool from work and radiation, and must be drained.

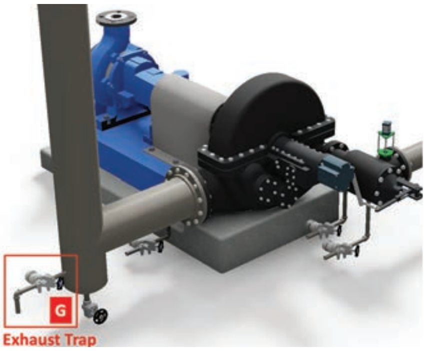

FIG. 16. If an exhaust side trap is not properly installed or maintained, condensate must pool to rise.

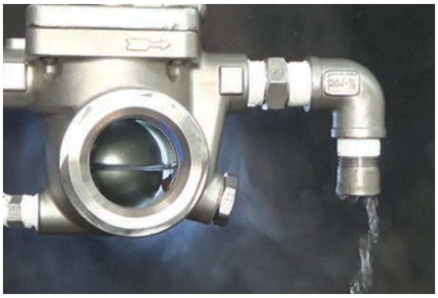

FIG. 17. A correctly selected float trap can discharge condensate immediately, while maintaining a water seal.

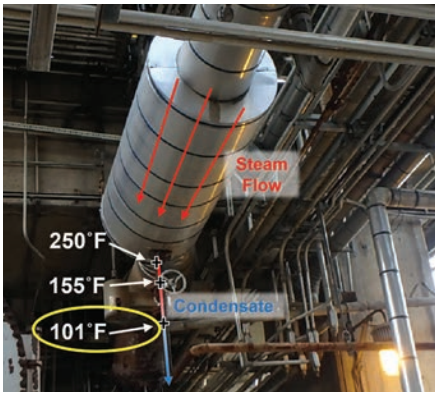

FIG. 18. The low temperature indicates a trap or other blockage failure, reducing separator effectiveness.

ing turbine driving a gas compressor. Those turbines mounted directly on top of a condenser typically do not experience issues with condensate removal from the turbine casing. However, turbines mounted on a pedestal that exhaust steam upward to the condenser can experience significant difficulties in getting proper condensate drainage from the turbine casing.

Consider the desired discharge of condensate from a turbine casing through a steam trap to atmosphere. Depending on the elevation of the turbine over the trap and because the turbine drain/trap inlet is at vacuum, approximately 35 ft of head is needed to discharge to atmosphere. Typically, this is not available and, therefore, the system cannot drain (**FIG. 19**).[6]

An alternative might be to discharge the casing drain condensate to the hotwell, but unless the condensate can drain down by gravity, this system cannot work. Condensate will try to flood the turbine casing by manometer effect up until the horizontal entry level into the hotwell. However, it is likely that the water is spun by the turbine blade itself before this higher condensate level is reached. This can cause damage, loss of power, erosion and precipitate buildup issues (**FIG. 20**).

Since the turbine casing is in vacuum, a pumping method is needed where condensate gravity drains down into the pump's reservoir to be pumped into the hotwell (**FIG. 21**).

Air removal and steam ejectors. Condenser systems condense steam, but not non-condensable vapors such as air. As a result, an air exhauster/removal system is needed. **FIG. 22** shows basic details of such a system, incorporating first- and second-stage ejectors as well as a hogger jet system for large volume air removal on startup.

Steam ejectors are critical to create the necessary suction to pull air from the condenser, but the resulting mixture contains both some of the motive steam and air in the entrained flow. The multiple stages of the exhauster system are designed to condense that motive steam as it passes through, and eventually enable the air to be vented to atmosphere at the end of the second stage in the example shown in **FIG. 22.**

A condenser system can be expected to have significant amounts of air present on startup, so an additional "hogger" jet is often used initially to pull substantial amounts of air out of the condenser and exhaust it. Hogger systems do not have additional condensers, so a lot of steam can also be exhausted. For this reason, hogger systems should only be used on startup, but many are commonly used during normal operation to supplement the rest of a deficient suction system.

A hogger used in normal operation typically indicates that the main air exhauster system is not pulling enough air out of the condenser and the hogger is used to compensate. In many cases of proper ejector sizing, it indicates that the ejector nozzles and/or throats may have become enlarged due to erosion, and this can be an indication of poor steam supply to the ejectors. There may also be a precipitate buildup on the diffuser that further weakens the suction produced.

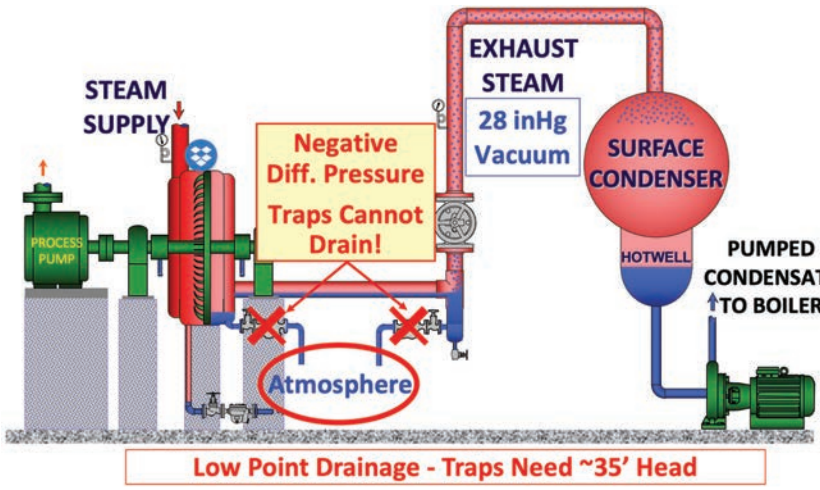

FIG. 19. A trap with supply side connected to vacuum cannot easily discharge to atmosphere.

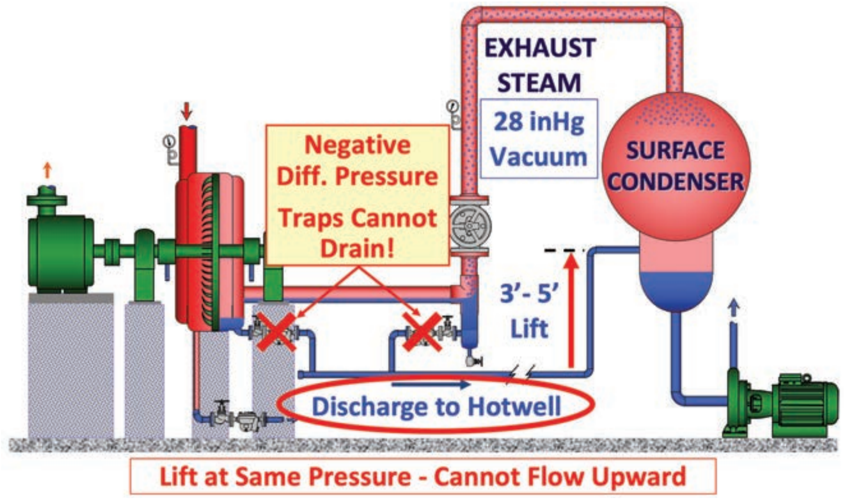

FIG. 20. A trap can only drain into the hotwell if there is sufficient hydraulic head or downward flow by gravity.

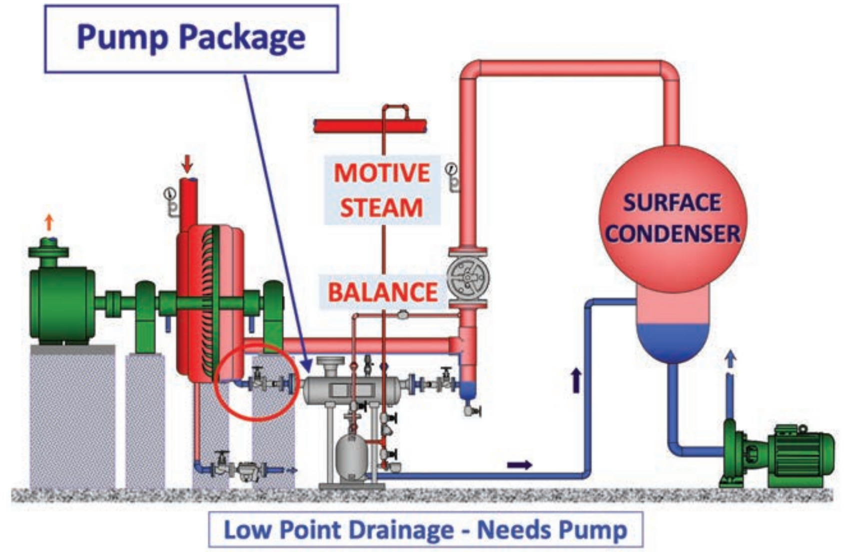

FIG. 21. Getting condensate to flow up to the hotwell requires a pump system when hydraulic head is insufficient.

Virtually every article published by Graham Manufacturing Corporation or such industry experts as J. R. Lines, R. T. Smith, Elliot Spence, Loren E. Wetzel, Norman P. Lieberman, Scott W. Golden and Andrew Sloley—to name a few—recommends the necessity of a well-insulated steam supply line, near saturated steam as the motive source, and comments on the importance of having a steam trap and separator/drain installed before the steam ejector. Even so, it is common to see neither insulation, a steam trap, nor separator/drain before an operating system.

The necessity for insulation and the separation and drainage equipment is to minimize and remove the wetness present in typical steam supply to the ejector. What may not be considered is that the steam velocity exiting the ejector's motive nozzle is in the range of 3,000 ft/sec–4,000 ft/sec.[9] The presence of wetness in the steam has multiple debilitating effects, from reducing the suction to eroding the orifice. Once the orifice diameter is enlarged by 7%, it must be replaced—until that is done, the vacuum is reduced and the steam demand increased. The reduced vacuum strength requires other ejectors to be put into service if additional suction is needed, which can significantly increase the steam used above the flow through the enlarged nozzle (**FIG. 23**).

An additional common error found on the inter- and after- condensers in an air exhauster system is the balancing of the drain trap (**FIG. 24**). Improper or non-existent balancing is frequently experienced, and this practice can severely impact the condenser performance due to insufficient drainage from and subsequent reduction of heat transfer duty of a flooded/partially flooded condenser. Close attention should be given to the correct installation and drain trap balancing, as well as maintaining the trap to correct operating condition, to help optimize condenser performance.

Takeaways. Consider these case history-based experiences to help improve steam turbine performance and vacuum system reliability. Begin by improving the quality of steam supplied from the utility headers, supported by proper CDL placement and maintenance (**FIGS. 4–10**). This is crucial to turbine efficiency and reliability, without which optimization becomes impossible. Then, drain and separate moisture from the steam supply immediately before each turbine. Drive steam can travel a long distance through piping systems that may have insufficient insulation, along lines where there may be insufficient or blocked CDL and, in some cases, where steam is improperly pulled from the bottom of the utility header rather than the top. Plants are complex and it is common that the lines supplying steam to the turbines may have some improper piping practices, so optimizing the steam quality at the turbine's entrance is a best practice recommendation. Properly select and size float traps to provide effective drainage through the turbine itself, as shown in FIG. 13.

Condensing turbines require special considerations when draining from vacuum to atmosphere or into the condenser hotwell, such as pumping condensate or using extremely high hydraulic head to fill a trap with condensate (FIGS. 19–21).

Air exhauster systems are critical to condenser operation, and similar steam-quality and condensate-removal principles are recommended for the steam supplied to ejector systems to optimize nozzle reliability and benchmark performance (FIGS. 22 and 23). Finally, drain traps on inter/after condensers must be properly balanced for proper condenser performance (FIG. 24). HP

ACKNOWLEDGEMENT

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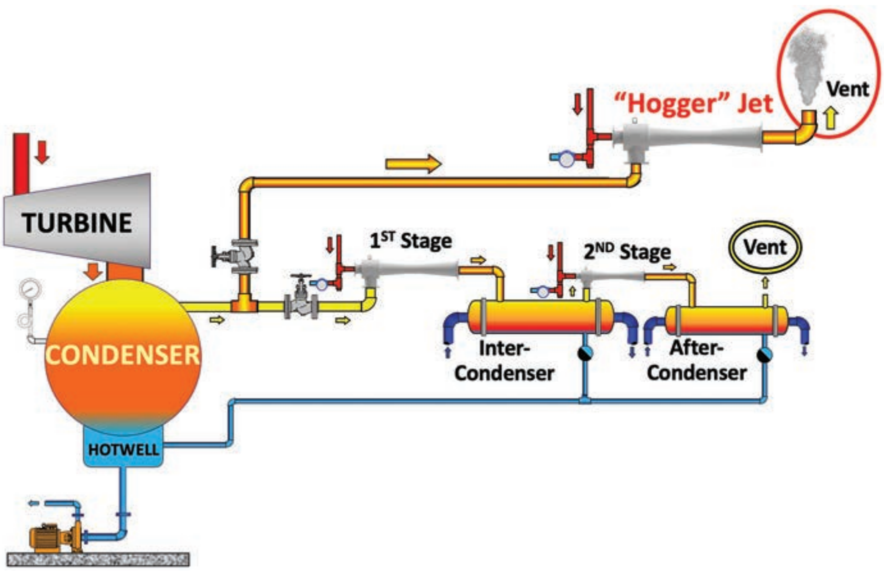

FIG. 22. Optimal ejector entrainment is crucial to effective air removal and system performance.

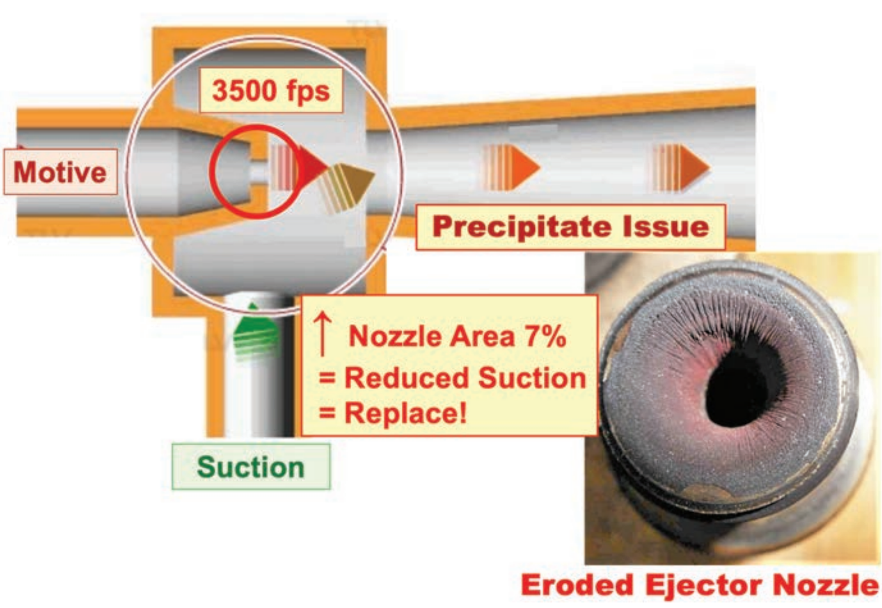

FIG. 23. Poor quality motive steam can cause accelerated wear and costly but weakened performance.

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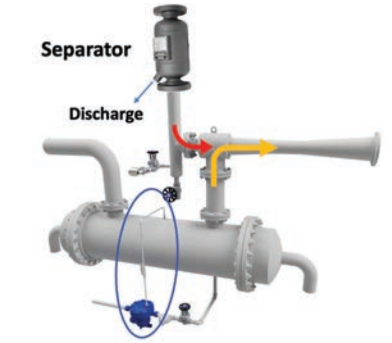

FIG. 24. An improper ⅜-in. to ¾-in. balance connection can severely hinder system operation.