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Improving Steam System Operation and Management

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Continuing Education for Steam System Operation and Management

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ABSTRACT

Steam is an efficient way to provide heat and energy for high performance buildings. However, new technicians and engineers often have little-to-no technical education for steam system design and operation. Furthermore, steam systems, if not maintained properly, are dangerous and new personnel need hands-on experience to ensure safety and adherence to standard protocols. This paper documents the development of a fully-operational steam training facility at a large Midwestern university that will provide incoming technicians and engineers with knowledge of proper steam distribution, utilization, and condensate return. The steam training facility will contain a smaller scale of all necessary components seen in the field. Not only examples of equipment, but also common mistakes made in typical steam systems, such as poorly pitched pipe, will be demonstrated. The steam training system will prepare students with a comprehensive understanding of a scaled-down steam system and confidence in the field.

1. INTRODUCTION

Steam is used in many different applications. Large manufacturing facilities, skyscrapers and universities use steam for heating buildings, supplying hot water, sterilizing equipment, and providing heat for cooking. Steam is most economical in larger applications that have multiple buildings and multiple uses, which makes it easier to justify the cost of the equipment and personnel to operate the boilers. Universities and hospitals are ideal candidates for steam systems because they have many applications that require heat. Steam systems are also found in district heating applications, like the city of Indianapolis, IN, where a central steam and chilled water plant supplies heating and cooling to many of the large commercial buildings in the relatively dense downtown area (2).

There are many advantages to using steam over other methods of delivering heat. First and foremost, basic thermodynamics shows that steam is an efficient means of delivering large amounts of energy. As liquid water flashes to a vapor, it absorbs the latent heat of vaporization, which is significantly larger than sensible heating that changes only the temperature of liquid water. As a point of comparison, it takes roughly five times more energy to turn liquid water into steam at atmospheric pressure than it does to heat that same quantity of water from its freezing point to its boiling point. The heat of vaporization used to generate the steam in the boiler is also available when the energy is reclaimed from the steam. A steam system operates on an endless loop of phase change, where liquid water becomes a gas in the boiler and is condensed back to a liquid at its point of use.

Steam is capable of travelling miles without having to use a pump or other mechanical device. The relatively simple distribution system for steam reduces equipment, physical space, and energy that would otherwise be used by a pump. Steam easily travels vertically through high-rise buildings without any means of propulsion. Furthermore, steam is completely recyclable. Any steam used for heating will expel its energy, become condensate, and return back to a boiler to be reheated into steam.

Steam is particularly advantageous in larger installations that have multiple uses for steam on a year-round basis. University campuses are one of the best examples for operating large steam systems throughout their facilities. Steam is the ideal solution for heating many lecture halls, laboratory spaces, libraries, dormitory residences, and cafeterias. Steam is not only used for heating, but also for hot water, food preparation, and for sterilizing equipment. Even though they are dedicated to higher learning, few universities have a dedicated steam training facility for engineers and technicians to receive hands-on experience (2).

Despite the clear and distinct advantages for using steam over other methods of heating, many large facilities are growing skeptical of steam systems because of the dangers it imposes to technicians. Steam can be very dangerous. Common horror stories include high-pressure explosions and catastrophic leaks that can cause death by asphyxiation. Despite these well-publicized tragedies, the lack of hands-on experience for engineers and technicians is the most dangerous part of a steam system. With proper training technicians can understand issues such as water hammer and improperly pitched pipe, as well as the signs when something is wrong. Knowledgeable technicians in the field will provide quicker resolution to potentially dangerous issues and reduce maintenance costs for facility managers. Steam systems are reliable and cost effective if installed and maintained properly.

A large Midwestern university is addressing this issue by developing a state-of-the-art steam training facility. A scaled -down model of a steam system will incorporate training stations for technicians to become familiar with all the typical components of a steam system, proper versus improper installation, and typical maintenance. By scaling down the steam training system, improper installation can be demonstrated without creating a safety hazard. However, the design of the steam system had to be carefully monitored to demonstrate improper installations and many teaching stations.

2. STEAM TRAINING ORGANIZATIONS AND INCENTIVES

Steam system manufacturers, such as Armstrong International, in Three Rivers, Michigan, provide nearly all of the training. Numerous online training courses are provided through these manufacturers, but their physical training facility gives technicians hands-on experience that is essential. Other organizations that provide online training include Spirax Sarco, MoreSteam, Hughes Campbell-Sevey, and Steris University. However, even though there are many organizations that provide online training, there are few that provide a steam training facility. Furthermore, while there are many professional institutes and online sessions for steam education, there is no known steam training facilities incorporated through a university (3).

A comprehensive steam system incorporated into a university setting will provide a center for employees, all at different milestones in their careers, to gain a general knowledge of steam, or specialized knowledge on specific components and their characteristics. The steam system training can become an integral part of an employee's professional development plan and lead to promotions and pay raises. This training is intended for both technical staff who operate the steam system and engineering staff who design and specify steam systems. Ultimately, the steam system training will make its way to a variety of undergraduate classes. Engineering, Technology, and Occupational Health & Safety are a few of the undergraduate disciplines that would benefit from exposure to a steam training system (5-7).

Purdue University's steam training system is designed for three types of learners: facilities technicians for promotional benefits, Professional Engineers (PEs) for continuing education (CEs) credits or professional development hours (PDHs), and students for educational credits. Technicians may wish to enroll in the steam institute to gain hands-on experience with steam components and system characteristics. Employers will likely provide promotional incentives for technicians to build their knowledge and experience with steam systems subsequently improving their performance in the field. PEs are expected to earn CEs or PDHs annually or biennially to maintain a working license. States mandate the necessary amount of CEs or PDHs required for professional engineers to continue their practice. Purdue will work with state engineering licensing boards to become an accredited institute to provide PEs with the necessary course hours to maintain licensure. For example, the state of Indiana requires 30 professional development hours every two years for a PE to continue practicing. Undergraduate students will be interested in taking part in the steam training program to get experience and a general understanding of steam systems as well as educational credits towards their degree (4).

3. SYSTEM DESIGN

Purdue University's steam training system was designed with an educational focus to demonstrate the major components of a steam system and their behavior. Furthermore, trainees should leave with knowledge of proper installation technique, common failure modes, troubleshooting, and major safety concerns. The steam training system will give students and new employees a comprehensive hands-on experience with steam system operation.

Figure 1 shows the future location of the steam training system in the basement of the Stewart Center at Purdue University. Its main advantages are that it is relatively unused at this time, is centrally located, and has steam supply/return infrastructure nearby. The red lines in Figure 1 depict equipment to be removed. The room is 1,600 square-feet in size, roughly 40 ft x 40 ft, with poured concrete walls that can be used for mounting steam components. Once the area is cleared, the central space can be used for classroom space. The steam for this system is generated at a local power plant and delivered to the building, therefore no steam generation will be demonstrated.

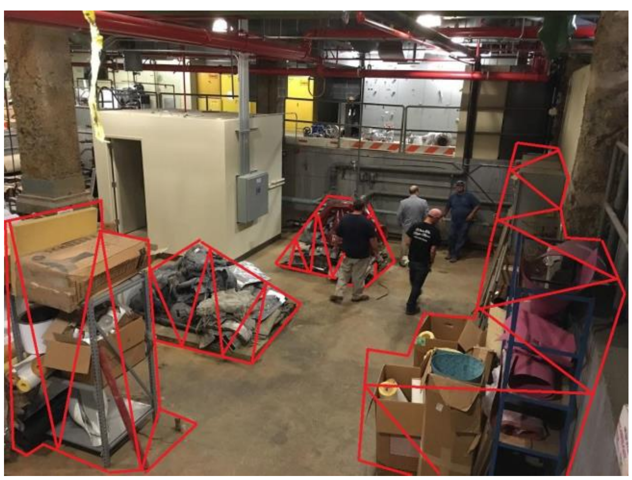

Figure 1: Work area of Purdue's steam training system, south and east Walls

To create a steam system that is not only functional, but also educational, some unique features were emphasized. As compared to a typical compact steam system, Purdue's training system has11 distinct learning stations. At each station, groups of three to four students will participate in a demonstration and complete a lab procedure. The majority of this paper will describe each of these stations and their respective learning objectives.

Figure 2 is a schematic of the steam training system that depicts each of the eleven major training stations in their relative location. The main sections of the steam training system will be divided along the north and east walls. Figure 2 assigns each teaching station a number and location. For example, station 3 "Expansion" will be located on the East Wall to demonstrate the expansion characteristics of piping as it heats up. The objective of each station is to show the operation, maintenance, and safety aspects of each component of a steam system. Considering the educational focus, the system was designed to have more sensors and equipment installed than in a regular steam system, to achieve the teaching objectives.

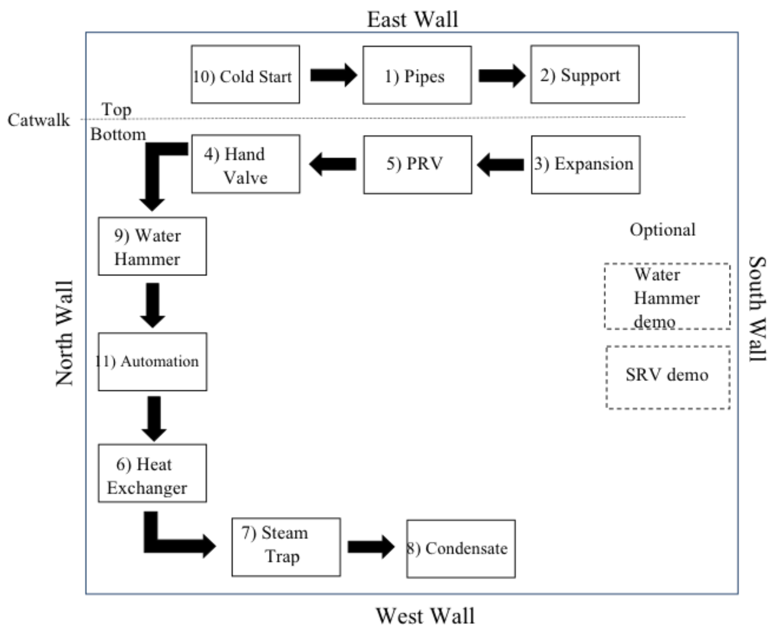

Figure 2: Steam training system learning stations flowchart

Figure 3 is the Process & Instrumentation Diagram (P&ID) for the entire steam training system. It illustrates further details about the components in all 11 stations. Since Figure 3 is relatively small, Figures 4 and 5 on the following page zoom in to show the east and north wall layouts individually. Figure 6 is the legend that includes additional notes and component labels.

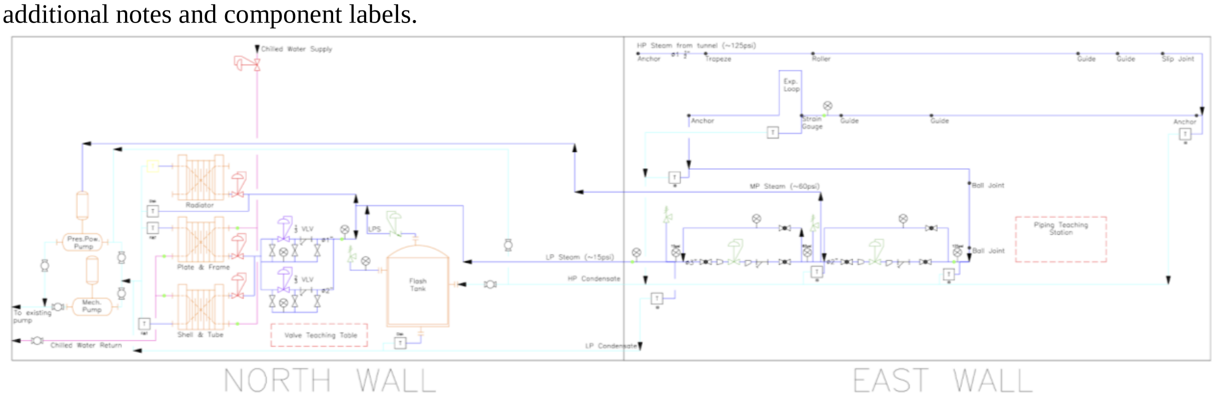

Figure 3: Steam Training System P&ID

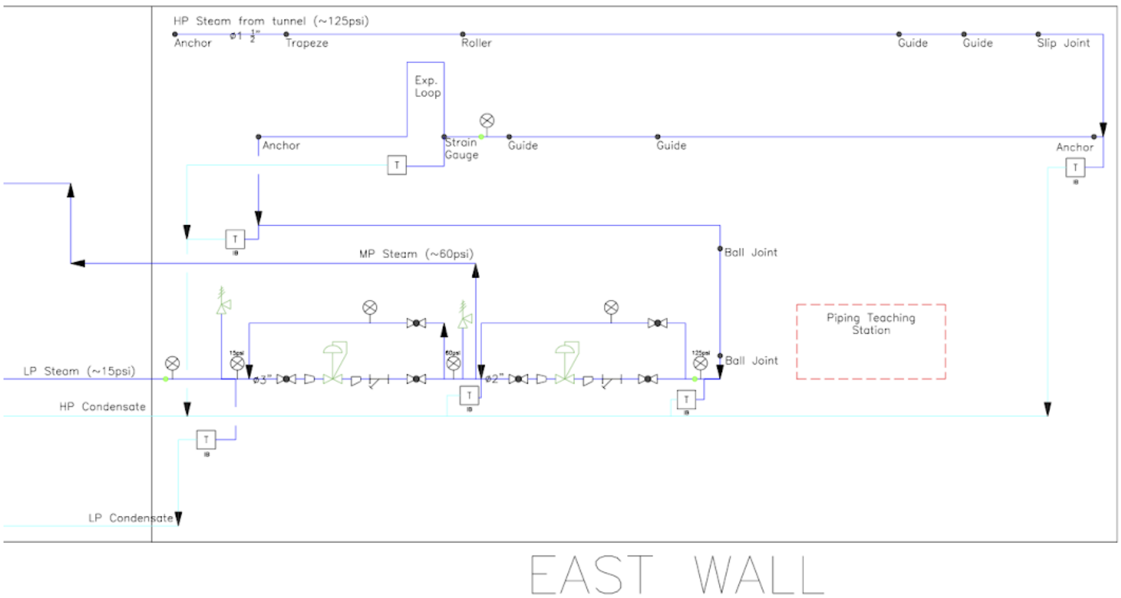

Figure 4: Steam training system east wall P&ID

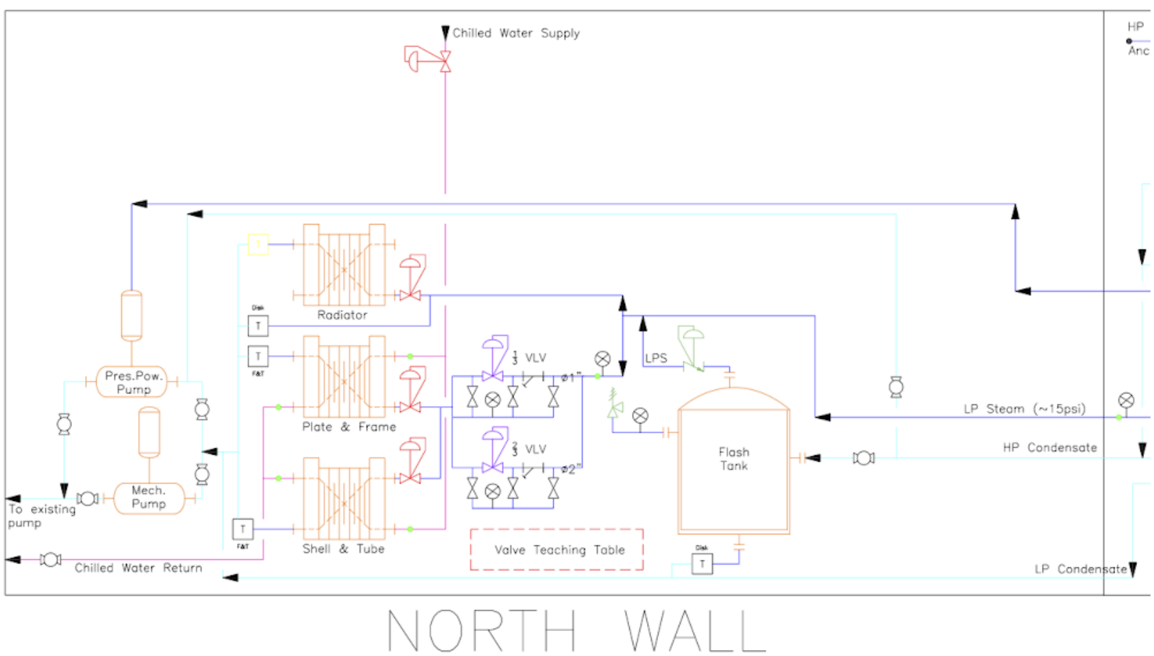

Figure 5: Steam Training System North Wall P&ID

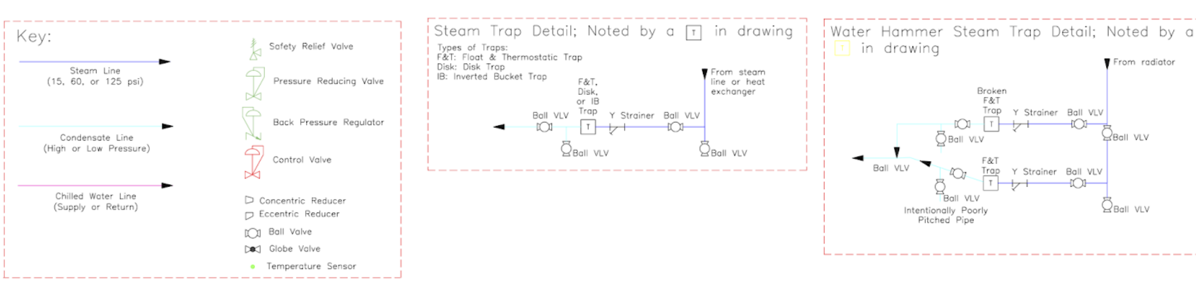

Figure 6: P&ID key and detailed components

4. STATION #1: PIPING

Steam systems can comprise miles of piping networks and therefore the first learning station will supply technicians with the knowledge of different components and properties of piping for a steam distribution system. Piping is the connection between the different components of the steam system and how steam and condensate are transported throughout the cycle. The objective of any fluid distribution system is to supply the fluid at the correct pressure to the point of use. Therefore, trainees will gain ample understanding of piping pressure and sizing charts, will learn about different joining methods, and will study the types of insulation used for steam to be effective and safe.

4.1 Learning Objectives

Having completed this station, trainees will be able to:

- Understand why Sch. 80 pipe is used for condensate and Sch. 40 for live steam.
- Understand why carbon steel is used in a steam system.
- Understand flange ASTM standards and pipe ASME standards.
- Understand the effect of insulation on the steam within the pipe.
- Understand the dangers with failed piping and asbestos insulation.

5. STATION #2: SUPPORTS

The Supports station (#2) will be located after the Pipe station (#1) against the east wall. A pipe support transfers the load from a pipe to the supporting structures. The load includes the weight of the pipe, the contents that the pipe carries, the pipe fittings, and the pipe covering, such as insulation. Additional load comes from the expansion and contraction of the pipe during use. The three main types of pipe supports are anchors, guides, and saddles to control pipe movement (both expected and not) and support the load. Pipe supports are used in high or low temperature applications. The design configuration of a pipe support assembly depends on the loading and operating conditions.

5.1 Learning Objectives

Having completed this station, trainees will be able to:

- Identify and understand the use of anchor, guide, and saddle supports.
- Understand material and schedule of common steam piping.
- Understand pipe joining methods.
- Understand the relationship between pressure drop, velocity and flow rate.

6. STATION #3: EXPANSION

Pipe materials expand when heated and contract when cooled. One major requirement in piping design is to provide adequate flexibility for absorbing the thermal expansion of the pipe. Two measurements dictate expansion: force and length. Trainees will learn the dangers of expansion by monitoring the force caused by high pressure, hot steam. To demonstrate the force of expansion, a mounted strain gage will be placed on the inside of the elbow of the expansion loop. In order to show the thermal expansion of the piping, a magnetic dial gage indicator will be placed at the location of the slip joint, to show the length of expansion in inches. Actual measurements can then be compared with an interface where users input the parameters of the pipe and steam to find the consequential changes in pipe length.

6.1 Learning Objectives

Having completed this station, trainees will be able to:

- Calculate steam pipe expansion, according to the 2016 ASHRAE Systems & Equipment Handbook, Chapter 46, “Pipes, Tubes, & Fittings” (1)
- Calculate the expansion compensation of a basic expansion elbow.
- Calculate the expansion compensation of a basic expansion “Z” bend.
- Calculate the expansion compensation of a basic expansion loop.
- Understand the application of different expansion joints; including ball joints slip-type joints and bellows.

7. STATION #4: HAND VALVES

The hand valve station will have an activity and a presentation table. The activity will be four parallel runs of pipe with different hand valves (check, globe, ball, and gate valve) on each run. The station will include pressure gauges on the discharge sides of each valve and one pressure valve on the inlet side for all four valves to show how pressure behaves as valves are opened or closed. Trainees will understand the characteristics and proper use of hand valves, as well as common issues and typical maintenance. The main components at the hand valve learning table will be a globe valve, check valve, ball valve, gate valve, and butterfly valve. A detailed journal with descriptions of where to use each valve (and why not to use a butterfly valve) as well as their respective advantages and disadvantages will be included with the presentation.

7.1 Learning Objectives

Having completed this station, trainees will be able to:

- Identify valve types and their operations.
- Understand proper placement of valves.
- Understand safety concerns with opening and closing valves.
- Understand installation and maintenance of hand valves.

8. STATION #5: PRESSURE REDUCING VALVE AND SAFETY RELIEF VALVE

The PRV and SRV station is designed to teach the different processes that can occur in the PRV, as well as the operation and sizing of an SRV. It will consist of a two-stage pressure regulator system with the objective to reduce the high-pressure steam to a low-pressure steam that will be used in the other stations. Trainees will leave the station with a greater understanding of the different processes that can occur in the PRV. By opening and closing valves, trainees will gain hands-on experience and understanding of how pressure, temperature, and flow velocity behave for different configurations.

8.1 Learning Objectives

Having completed this station, trainees will be able to:

- Describe the PRV functions and identify its components.
- Identify the pressure reduction from high-pressure to medium-pressure and low-pressure.
- Understand the relationship between temperature and pressure.
- Recognize the PRV malfunctions.
- Understand the operation and sizing of an SRV.

9. STATION #6: HEAT EXCHANGERS

A heat exchanger transfers heat between a solid object and a fluid, or between two or more fluids. The heat exchanger station will give trainees background on the technical characteristics and installation of heat exchangers in a steam system. The primary purpose of the heat exchanger is to extract the heat from the steam and transfer it to the water until it is at a desired temperature. Three heat exchanger types will be demonstrated at this station: a shell and tube, plate and frame, and radiator heat exchanger. Each of the three heat exchangers has their own applications and characteristics. Trainees will leave the station with an understanding of where to find these heat exchangers, common issues with each type of heat exchanger, as well as advantages and disadvantages for each type.

9.1 Learning Objectives

Having completed this station, trainees will be able to:

- Understand how heat exchangers work.
- Understand a plate and frame, shell and tube, and radiator.
- Understand how to perform maintenance on a heat exchanger.
- Learn the dangers of a heat exchanger as well as its operation.

10. STATION #7: STEAM TRAPS

This training station will demonstrate steam traps in their proper and improper function. The station will include four pairs of steam traps. The four pairs will be comprised of inverted bucket, float & thermostatic, disc, and thermodynamic traps. Each pair will include a functioning trap and malfunctioning trap. This training station will include elements to show the equipment's function like valves to atmosphere and temperature and pressure sensors.

10.1 Learning Objectives

Having completed this station, trainees will be able to:

- Differentiate a properly working steam trap from a malfunctioning one by:
  - Using an ultrasonic listening device.
  - Opening a valve to atmosphere.
  - Using a thermal measuring gun.
- Understand that steam blowing through a trap can:
  - Create a false reading on a condensate meter.
  - Cause a mechanical pump to malfunction.
- Understand and identify a trap that has failed open versus failed closed.

11. STATION #8: CONDENSATE PUMPS

The condensate return of the steam training system is designed to take the condensation from the heat exchangers and return it back to the power plant. This is then re-used in a boiler to reheat the condensate and start the process over. Main components demonstrated in this station include a flash tank and different types of condensate pumps.

11.1 Learning Objectives

Having completed this station, trainees will be able to:

- Identify what kind of pump is used for a specific task.
- Describe the functions of each pump.
- Differentiate a properly working condensate pump from a malfunctioning one.
- Understand the different pressure drops as a result of condensate pumps
- Recognize and describe the difference between a mechanical, vacuum, and pressure-powered pump.

12. STATION #9: WATER HAMMER AND FLASH TANKS

Water hammer occurs when the steam system is not installed or functioning properly. Water hammer in this steam training system will be incorporated with condensate management. The improper control of condensate and steam mixing will cause the water hammer in a poorly pitched glass pipe, a flash tank, and a steam trap that has failed open. A potential additional area of the water hammer station could involve compressed air and the use of a gate valve to give a non-hazardous demonstration of water hammer due to opening or closing a valve.

12.1 Learning Objectives

Having completed this station, trainees will be able to:

- Identify and troubleshoot water hammer.
- Understand proper sizing/types of flash tanks.
- Understand flashing high-pressure steam.
- Understand water hammer occurring in a flash tank, in a trap stuck open, and in a poorly pitched pipe.
- Understand safety hazards due to water hammer.

13. STATION #10: COLD START

A cold start is a procedure done when a steam system is shut down and needs to be reactivated. Cold starts are dangerous and can cause a host of problems to the system including thermal shock and water hammer. A cold start procedure will affect piping, expansion, steam traps, and condensate stations.

13.1 Learning Objectives

Having completed this station, trainees will be able to:

- Understand why a cold start takes so long.
- Understand the beginning stages of turning on a steam system.
- Understand that it will take approximately 60 minutes to bring the steam training system online.
- Understand the real-time monitoring of temperature and pressure across the system.

14. STATION #11: AUTOMATION, METERING, AND CONTROL

The automation, metering, and control of the steam training system comprises a set of metering and control systems that are installed throughout the teaching stations. It provides metering of flow, pressure, and temperature for all teaching stations. It also provides automation control for demonstration purpose. The automation, metering, and control of the steam teaching stations will be connected to a Building Automation System (BAS).

14.1 Learning Objectives

Having completed this station, trainees will be able to:

- Identify and read common sensors and gauges used in steam systems.
- Understand readings for sensors and actuators.
- Read and analyze data trends.
- Understand the operation of control valves at heat exchangers.
- Compare the operation of a control valve on the steam inlet compared to a control valve on the condensate discharge of a heat exchanger.

15. SAFETY

Given that a majority of the people interacting with the steam system will be untrained, having a safe environment for them to work in will be critical. There are two aspects to safety with this system. One issue is making sure the steam training system always operates safely, even when demonstrating malfunctioning steam system components. The second issue is instilling a culture of safety among the personnel who are being trained.

The system labeling will consist of floor and equipment markings, safety zones, and proper tool identification. Per OSHA, the floor markings must be at least 2" wide and painted using the proper color identification as dictated by the color chart (i.e. red=flammable, yellow with black= physical hazards, yellow= traffic or pedestrian areas, etc.). These markings should use a minimal amount of tape and be efficient in nature to maintain a simple, easy-to-follow layout. Once the final layout has been confirmed, a work area near the piping and equipment will be designated and marked to clearly identify a safe viewing distance for the trainees who are not directly operating the equipment. This open area can be considered a "safety zone" where trainees can watch the operations if not directly part of the activity.

All piping will be labeled with proper colors, flow direction, and pressure. This should follow the same standard as used in many university buildings. In the case of this system, extra marking indicating the state of the fluid may be used. Each piece of equipment will be individually labeled and tied back to a specific control manual for referral. Furthermore, equipment will be locked-out and tagged-out to maintain proper access control during times when the system is not in use. All tools for the training area will have a specific, marked location to be returned to. At the discretion of the facilities staff, some of the tools may be kept in a lockable cabinet to maintain proper access control of the steam system when no classes are taking place.

Per OSHA, both verbal and written training are recommended for the best knowledge retention, so “quick-reference” cards will be hung on individual pieces of equipment identifying specific health or safety hazards as well as proper usage instructions. Doing so will help each trainee remember the unique characteristics and safe practice of everything component they use. Before any trainee will use the system, they will go through a safety course to gain familiarity with unique steam terms and safety topics such as water hammer, skin scalding, and pipe leakage.

16. CONCLUSIONS

Steam is an important means of providing district heating at universities and other large campus-type situations. Due to a perceived lack of training, a steam training system has been planned for educating practicing engineers, working technicians, and inexperienced undergraduate students. The steam training system will consist of eleven different stations that illustrate proper processes and practices for safely working with steam. Proper steam training will improve efficiency, extend equipment life, and enhance safety for university personnel.

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