Thermodynamic Properties of Steam

Purpose of This Session

The purpose of this session is to understand the thermodynamic properties of steam, which affect the design and operation of steam heating systems and process steam systems. An understanding of the basic thermodynamics of steam allows us to properly size equipment and to design piping systems. It also allows us to make informed decisions affecting the energy usage of the system.

Principles of Steam

Water exists in three forms: a) Solid (ice), b) liquid (water) and vapor (steam). For our purposes, the definition of steam is: "the vapor form of water". As steam system designers, we are not really concerned about the solid state, except when water inadvertently freezes in a system. Proper piping design prevents this and we will touch on that later. In our study of the Thermodynamics of Steam, we will concentrate on the liquid and vapor phases of water.

The Key Principle, "Saturation"

To properly select steam products and to design a successful steam system, we must thoroughly understand the principal of saturation temperature and pressure. We define the ***saturation temperature*** as the temperature at which water boils at a given pressure. Refer to the steam tables to discover the first key principle of saturation:

- ***For each pressure, there exists one corresponding temperature and for each temperature, there exists one corresponding pressure.***

Examples 1-3 (Refer to Steam Tables)

1. What is the saturation temperature of 2 PSIG steam?

   The saturation temperature at 2 PSIG is 219° F

2. What is the saturation temperature at 0 PSIG steam? At what temperature would water boil on the stove from an open pan at sea level?

   The saturation temperature at 0 PSIG is 212° F. Because the atmospheric pressure is 0 PSIG at sea level, water would boil from a pan at 212 ° F.[1]

[1] For purposes of this course, we will assume that we are always talking about sea level. Note that Wisconsin in close enough to sea level that any error is insignificant for our purposes.

3. A thermometer measures the steam temperature in a pipe carrying saturated steam. It reads 300° F. What is the steam pressure in the pipe line?

   By interpolation, the saturated pressure at 300 °F is 52 PSIG.

To illustrate the principle of ***saturation***, consider a pan of water on a kitchen stove. The pan is at sea level and contains 60 °F water. At this point we define the water as a ***subcooled liquid,*** which simply means that the water's temperature is below saturation temperature. Since the pan is at sea level the saturation temperature is 212 ° F.

As the burner fires, heat travels through the pan to the water, causing an increase in water temperature. When the water reaches 212 ° F something interesting happens. Instead of getting hotter, the water adjacent to the pan surfaces begins to vaporize rapidly, forming steam bubbles. When the bubbles get large enough, they break away from the metal surface and rise up through the water. As the bubbles reach the top, ***steam*** escapes and floats into the space above the water. As more heat is added, many more bubble form, rise and escape. The surface of the water becomes turbulent and now the water is boiling. Even with continued burner input, the temperature of the water will not to rise past 212 °F. Adding more heat simply results in the water boiling faster. We can make more steam but we cannot make hotter steam with the stove/pan system.

This same phenomena makes possible the old camp fire trick of boiling water over an open fire in a paper cup. While it seems that the cup should catch fire, the water in the cup never rises above 212 ° F. The paper stays close to this temperature, which is below its combustion point.

Let's look at the principal of saturation in a steam boiler. See Figure 1 on the next page.

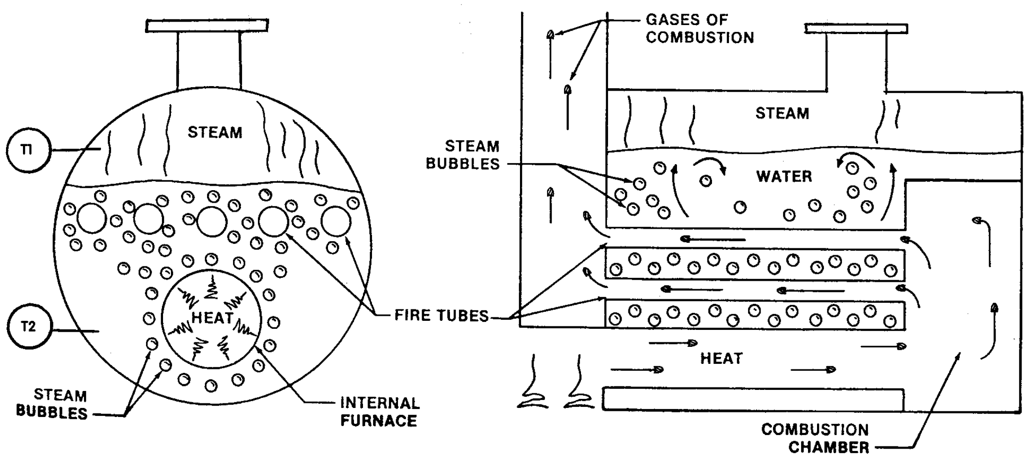

Figure 1, Typical Fire Tube Steam Boiler

Figure 1 shows a ***fire tube*** boiler, meaning the fire from the burner and the resulting hot gasses flows through tubes called ***fire tubes.*** Water is contained in a pressure vessel surrounding the tubes. As the burner fires, hot combustion gasses pass thru the tubes**.** The surrounding water absorbs most of the heat from the hot gasses via heat transfer thru the tubes. The remainder of the heat goes up the stack.

The boiler serves a piping system, which consumes steam the steam produced. The boiler's operating pressure control balances steam production to steam demand by adjusting the burner firing rate to maintain a constant pressure in the boiler. When the boiler reaches the controlled pressure, thermometers T1 (reading steam temperature) and T2 (reading water temperature) read exactly the same--- the saturation temperature corresponding to the controlled pressure.

Assume that the boiler control fails and allows the burner to continue to fire regardless of demand. With nowhere for the excess steam to go, the "extra" burner energy results in higher pressure steam. T1 and T2 still read the same as each other. They now read a higher temperature, one corresponding to the saturation temperature at the higher pressure.

Let's look at saturation from at the other end of the steam system---where the steam is used. Figure 2 shows a shell and tube heat exchanger. Assume that the shell side fluid is saturated steam and that the tube side fluid is a glycol solution. Steam enters the top shell side connection and the glycol enters and leaves the tube side via the threaded connections on the left end of the exchanger. As the glycol absorbs heat from the steam via heat transfer through the tubes, some of the steam in the shell changes state from steam to water. We call the process of changing state ***condensation*** and the resulting water ***condensate*** If you could watch this process (and you will in our lab), you would see droplets of condensate form on the heat transfer tubes, eventually becoming large enough that they fall off and drop to the bottom of the heat exchanger shell. This condensate then exits via the "Condensate Out" connection as a saturated liquid.

Figure 2, Steam to Liquid Heat Exchanger

Instrumentation would show identical temperatures for both the steam and the condensate in the shell. The measured temperature would correspond to the saturation temperature corresponding to the pressure in the shell. *(In actual practice, this might not be quite true. Some manufacturers say that they actually observe a small degree of subcooling in shell and tube heat exchangers. If this happens, it is only because steam systems are dynamic. Possibly some condensate collects at the bottom of the shell and then gives up some additional heat thru the shell wall, and becomes slightly subcooled. In the "ideal" static world, the subcooled liquid immediately absorbs enough heat from the surrounding steam to reheat it back to saturation temperature, thereby condensing a bit more steam. However, since the situation inside the heat exchanger is dynamic, some condensate escapes before being reheated, with the result that the condensate mixture is slightly subcooled. Nevertheless, convention in our industry is to assume that no subcooling occurs in shell and tube exchangers, as the effect is minor if it occurs at all).*[2]

Let's look at our three illustrations (the pan on the stove, the fire tube boiler and the shell/tube heat exchanger) to summarize the key principles of saturation.

Key principles of saturation:

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[2] Note that special power plant heat exchangers called "surface condensers" utilize separate subcooling sections to subcool condensate after it is condensed.

- ***For each pressure, there exists one corresponding temperature and for each temperature, there exists one corresponding pressure***
- ***When vapor and liquid (steam and condensate) are both present in a vessel, the temperatures of the vapor and liquid are both equal to the saturation temperature corresponding to the pressure in the vessel.***
- ***In an open system, such as a pan, adding more heat to saturated liquid results in more rapid boiling, not in a rise in temperature.***
- ***In a closed system (such as a boiler), adding more heat than required by the process results in a new saturation condition at a higher temperature AND pressure.***
- ***In a heat transfer process, condensing occurs at the saturation temperature corresponding to the pressure of the steam in the heat exchanger vessel. Condensate exits the process at the saturation temperature unless special subcooling heat exchangers are used.***

The Principal of Steam Quality

In the real world, mixtures of steam and very small condensate droplets often exist. The ideal boiler delivers pure steam. In the real world, the velocity of steam leaving the water surface entrains some small water droplets. ***Steam Quality*** refers to the percentage of the total flow that is steam. For example, a specification may call for a boiler that delivers steam quality of 99.7%. This means that of the mass of fluid leaving the boiler, 99.7% consists of steam and 0.3% consists of water droplets.

As soon as the steam enters the piping system, heat loss from the pipe results in condensation of some of the steam. Some of this condensate drops to the bottom of the pipe, but due to pipeline velocity some tiny liquid droplets are carried along in the steam. This reduces steam quality further.

Some industrial equipment, including steam turbines and some high flow, high pressure reducing valves, requires high quality steam at the inlet to avoid erosion from the water droplets. To ensure high steam quality, designers use steam separators mounted near the inlets of such equipment. Steam separators use centrifugal force (the more appropriate “correct” term is centripetal acceleration) to separate the heavier water droplets from the steam. For more on steam separators, see www.watsonmcdaniel.com. Then click on Specialty Products, then WDS Separators. You will see that these separators remove more than 99% of moisture droplets in excess of 10 microns in size.

The Principle of Superheat

Superheated steam is steam that exists at a temperature higher than the saturation temperature. Superheated steam is produced mainly in plants that operate steam turbines for electrical or mechanical power because superheat increases 1) turbine mechanical efficiency and 2) the power available from each pound of steam produced in the boiler.

Example 4

Go back to Figure 1A **(See page 3)**.

4. Is this boiler capable of making superheated steam? Why or why not?
   This boiler is not capable of producing superheated steam. The water and steam are contained in the same vessel, so attempting to superheat the steam with additional firing simply results in higher pressure saturated steam.

Boilers that make superheated steam expose the steam to additional heat ***after it has been physically separated from the liquid.*** We show this schematically in Figure 3.

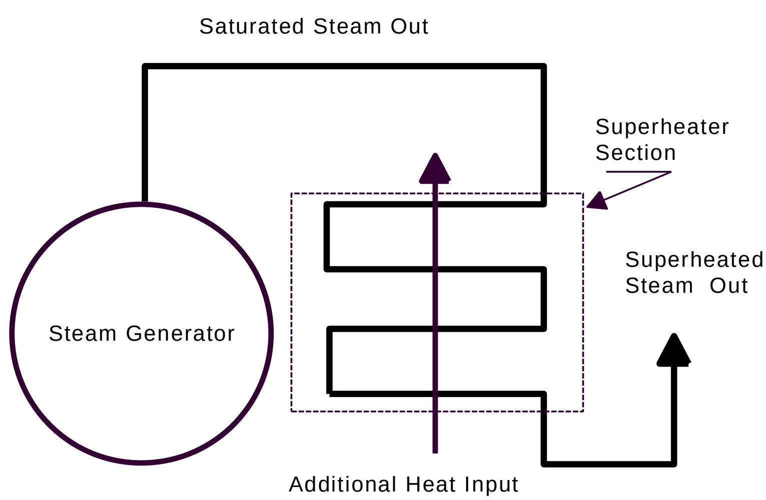

Figure 3, Boiler With Superheater

After the steam is completely removed from the liquid, it is exposed to additional heat, which raises the steam's temperature. Note that this process differs from providing additional heat in the steam generating section, where liquid is present. A discussion of specific boiler designs is beyond the scope of this course. However it should be noted that a boiler designed to make saturated steam cannot make superheated steam. ***If the boiler is to produce superheated steam, the boiler must be equipped with a separate superheater section.*** As a rare alternative, a separately fired superheater can be piped in series with the boiler. This device looks much like a boiler and consists of a bank (or banks) of tubes and a burner.[3]

Enthalpy, Specific Volume and Latent Heat

To understand steam as a heat source, we need to understand the terms ***specific volume*** and ***enthalpy.*** Let's take the easy one first.

Specific Volume

Gasses (steam is a gas) occupy less space under higher pressures than under lower pressures. This means that a pound of steam occupies different volumes, depending upon its pressure. The term ***specific volume*** refers to the volume that one pound of steam occupies at a given pressure and temperature.

For our purposes, we concern ourselves with specific volume mostly during sizing steam piping. Steam is more dense at higher pressures, so a given size pipe can carry more high pressure steam than low pressure steam. However, in most cases, we use specific volume only indirectly, as the steam pipe sizing charts already account for specific volume Nevertheless, understanding specific volume helps us in our overall understanding of steam.

Examples 5-6

Refer to The steam tables to answer the following problems:

5. At 5 PSIG, how many cubic feet does 1 pound of saturated steam occupy?

   At 5 PSIG, one pound of saturated steam occupies 20 cubic feet.

6. At 100 PSIG, how many cubic feet does one pound of saturated steam occupy?

   At 100 PSIG, one pound of saturated steam occupies 3.9 cubic feet.

[3] On a per-pound basis, superheated steam contains more BTU's and is less dense than the same pressure saturated steam. Because superheated steam tables are extensive, they entail many pages and are published in books for purchase. If you need specific conditions, give Fluid Handling a call, as we do have superheated steam table books.

Enthalpy

The total heat content of a substance is called ***enthalpy***, and in the English system (the system used in the U.S. but not in England!), enthalpy is expressed in BTU's/pound, where a BTU is called a British Thermal Unit. One BTU is defined as the amount of heat required to raise one pound of water by a temperature of one-degree Fahrenheit from 60^o F. Since heat is a relative term, scientists have arbitrarily assigned a value of 0 BTU to water at the temperature of 32.018 °F. For our purposes, we will assume 0 enthalpy at 32.0 °F. We will leave the 0.018 °F to the research scientists!

Example 7

7. Assume that the boiler in Figure 1 has just been filled with water at 70 F. What is the heat content of each pound of water in the boiler?

   Since water at 32 °F has enthalpy of 0 and it takes 1.0 BTU/pound to raise water by 1 °F:

   Enthalpy at 70 °F = (70 °F -32 °F) X 1.0/BTU/#-°F = 38 BTU/#

The steam tables provide values for the enthalpy of liquid and vapor for various saturation conditions. Note that:

- The "Heat of Liquid" is called ***"Sensible"*** and designated by the symbol h_f.
- The Total Heat of Steam is also sometime called Heat of Vapor and designated by the symbol h_g.
- The ***"Latent Heat of Evaporation"*** represents the amount of heat required to vaporize a pound of liquid, once it has been brought to the saturation temperature. Conversely, it represents the amount of heat that will be released when a pound of steam turns to condensate in the heat transfer phase of the cycle. It is designated by h_{fg}.

Example 8

8. For three different saturation conditions, subtract the sensible heat from the total heat. What relationship do you see? What does this show?

You should find the following relationship: h_g-h_f= h_{fg}. This tells us that the latent heat represents the difference in heat content between saturated liquid and saturated vapor.

Energy Equations

When steam or condensate change state, or when they are heated or cooled, heat is absorbed or released. The general equation for the energy transfer is:

Q = Flow Rate of Fluid X Enthalpy Change During Process ***Equation 1***

Where Q = the heat transfer rate in BTUH

Flow rate is in #/HR (PPH)

Enthalpy is in BTU per pound

Example 9

9. A boiler produces 5,000#/HR of saturated steam at 125 PSIG from feed water at 230°F. Calculate the required boiler output in BTUH.

Q = 5,000 PPH X (hg at 125 PSIG - hf at 230 °F) = 5,000 X (1193 – 198) = 4,975,000 BTUH

When steam is used for heating a space or a process, we use the following general formula to determine the amount of steam required to meet a heat load, Q.

#/HR = Q/(Enthalpy of steam at start of process – Enthalpy of condensate at end of process)[4] ***Equation 2***

Note that for most steam heating applications, which involve saturated steam, the quantity ***"Enthalpy of steam at start of process – Enthalpy of condensate at end of process"*** is simply the latent heat at the pressure in the heat transfer device. Therefore for most heat transfer applications, we can use:

#/HR = Q/Hfg at the steam pressure in the heat exchanger

Equation 3

[4] For the vast majority of heat transfer applications, it may be assumed that the leaving fluid is saturated condensate. Occasionally, special subcooling heat exchangers are supplied, but this is rare.

Example 10

10. A steam unit heater heats an area with a heat load of 250 MBH (250,000 BTUH). Saturated steam is available at 15 PSIG and 150 PSIG. Which pressure results in the lowest steam flow?

    #/Hr at 15 PSIG = 250,000 BTUH/945 BTU/# = 264.6 #/Hr

    #/Hr at 150 PSIG = 250,000/857 BTU/# = 291.7 #/Hr

It may seem counter-intuitive that it takes MORE high pressure steam to provide the same amount of heat as low pressure steam. Read on to see why!

Flash Steam

When high pressure/temperature condensate drains into a lower pressure receiver, a phenomena called ***flash steam*** occurs. Flashing simply means that some liquid quickly turns to the vapor phase. The most common situation is when high temperature condensate is discharged into a standard atmospheric receiver, as shown in Figure 4:

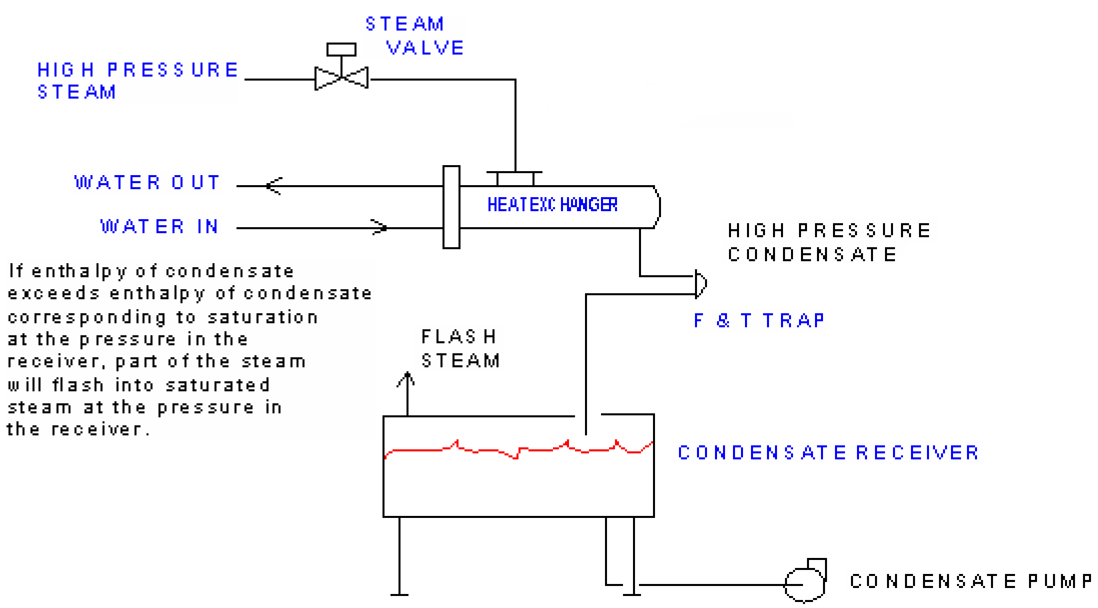

Figure 4, Typical Application Resulting in Flash Steam

The best way to illustrate flash steam is by example. Assume the high pressure condensate in Figure 4 leaves the heat exchanger at 75 PSIG. The enthalpy of the liquid is 290 BTU/# (check it out in the steam tables). Since the condensate receiver is vented to atmosphere, it operates at 0 PSIG. The enthalpy of condensate at 0 PSIG is only 180 BTU/#, meaning that as soon as the high pressure condensate leaves the trap, it contains 110 more BTU/# than it can have at 0 PSIG. So it flashes, with a portion of the flow changing to steam. This happens in the low pressure condensate piping or the receiver, or both, depending upon the length of the piping. Table 1 shows the % of flash steam that occurs when condensate from higher pressure steams discharged from various higher pressures to various lower flash tank pressures.

Table 1

Steam Pressure psig	Atmosphere 0	Flash Tank Pressure-psig 2	5	10	15	20	30	40	60	80	100
5	1.7	1.0	0								
10	2.9	2.2	1.4	0							
15	4.0	3.2	2.4	1.1	0						
20	4.9	4.2	3.4	2.1	1.1	0					
30	6.5	5.8	5.0	3.8	2.6	1.7	0				
40	7.8	7.1	6.4	5.1	4.0	3.1	1.3	0			
60	10.0	9.3	8.6	7.3	6.3	5.4	3.6	2.2	0		
80	11.7	11.1	10.3	9.0	8.1	7.1	5.5	4.0	1.9	0	
100	13.3	12.6	11.8	10.6	9.7	8.8	7.0	5.7	3.5	1.7	0
125	14.8	14.2	13.4	12.2	11.3	10.3	8.6	7.4	5.2	3.4	1.8
160	16.8	16.2	15.4	14.1	13.2	12.4	10.6	9.5	7.4	5.6	4.0
200	18.6	18.0	17.3	16.1	15.2	14.3	12.8	11.5	9.3	7.5	5.9
250	20.6	20.0	19.3	18.1	17.2	16.3	14.7	13.6	11.2	9.8	8.2
300	22.7	21.8	21.1	19.9	19.0	18.2	16.7	15.4	13.4	11.8	10.1
350	24.0	23.3	22.6	21.6	20.5	19.8	18.3	17.2	15.1	13.5	11.9
400	25.3	24.7	24.0	22.9	22.0	21.1	19.7	18.5	16.5	15.0	13.4

Percent flash steam produced when high temperature condensate is discharged to atmosphere or into a flash tank controlled at various pressures.

In cases where more accuracy is required or for conditions outside the table, the following formula can be used to determine flash quantity:

$$\textbf{\% Flash} = \frac{(h_f \text{ at higher pressure} - h_f \text{ at lower pressure}) \times 100}{h_{fg} \text{ at lower pressure}}$$

Examples 11,12

11. 2,000 #/HR of condensate forms at 60 PSIG. How much flash steam occurs when the condensate discharges from the trap to the atmospherically-vented condensate return system?

Enter the table at the left column at 60 PSIG. Follow to the right to the column for "Atmospheric Pressure (0 PSIG) and you will find that 10.0% of the condensate flashes to 0 PSIG steam, or 200 #/Hr.

12. Where does this flash steam go?

    It goes out the vent of the receiver. If the vent is piped to the outside, it will be seen as a plume coming out the vent pipe. If the receiver vent is open to the room, it results in a very humid room!

Look at Example 10 again. It now becomes apparent why it takes more steam at a higher pressure to perform specific heat transfer process in a typical heat exchanger, coil, etc. It is because much of the heat in the higher pressure steam leaves in hot condensate. In Section 3 of this course, we will learn some tricks to utilize this heat so that we don't lose it as flash steam from the receiver.

Superheated Steam from Throttling

Figure 5 depicts a common throttling process, where steam is throttled from a high pressure to a lower pressure in a ***pressure reducing valve (PRV)***. Confusion exists regarding the temperature of the steam leaving the PRV. Throttling steam drops its pressure *at constant enthalpy*, because no energy is removed from the steam. You might say, "What about the friction in the valve as the steam is throttled to the lower pressure?" Significant friction DOES occur, but friction results in heat and the heat ends up, guess where? Back in the steam! (There is a small heat loss from the valve to the atmosphere but this is a very minor portion). The result is that the low pressure steam at the valve outlet has the same enthalpy as the high pressure steam entering the valve. Therefore, the resulting throttled steam contains superheat---that is, its temperature exceeds the saturation temperature. Failure to recognize this superheat has caused many problems, as one of the first "Mind Teasers" in the quiz at the end of the chapter illustrates.

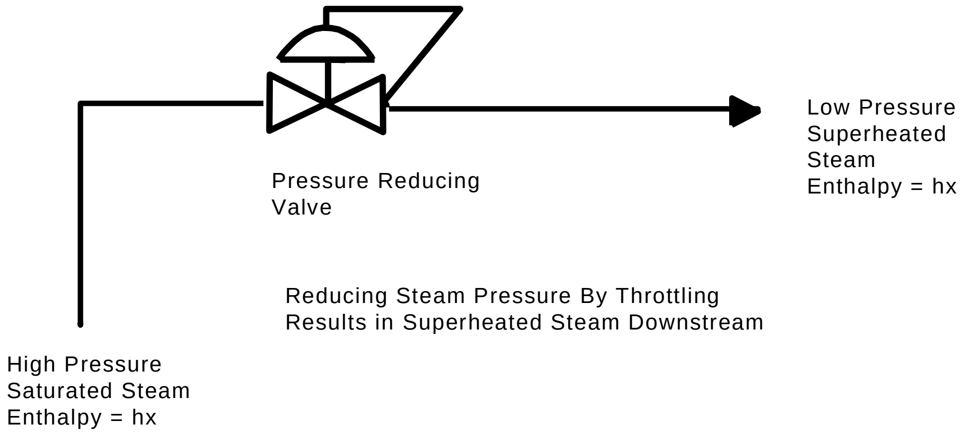

Figure 5 Steam Pressure Reducing Schematic

Table 2 shows the temperature that results when saturated steam is throttled to a lower pressure. Note that if the initial steam is superheated, the leaving temperatures will be even higher, and you would need superheated steam tables to determine the leaving condition. We will cover this in the lab session that you attend.

Table 2

Temperature of Steam Resulting From a Throttling Process

Inlet Press (psig sat)-->		50	60	75	100	125	150	175	200	225	250
Saturated Temp., °F---->		298	308	320	338	353	366	378	388	399	406
Inlet Enthalpy, h_g, btu/#->		1180	1182	1186	1190	1194	1197	1199	1200	1202	1203
Final Pressure											
psig	Sat.Temp., ° F	Leaving Temperature, ° F									
5	228	277	280	289	298	310	311	316	318	322	324
10	240	280	284	291	299	308	314	318	320	324	326
15	250	282	285	294	302	310	316	320	322	326	328
20	259	284	288	296	304	312	318	322	324	328	330
25	267	286	291	298	306	314	320	324	326	330	332
30	274	289	294	301	309	316	322	326	328	332	334
40	287	295	298	305	313	321	326	330	332	336	338
50	298		304	310	317	325	331	334	336	340	342
60	308			314	321	329	334	338	340	344	346
70	316				326	333	338	340	344	347	349
80	324				330	337	342	346	348	351	353
90	331				334	341	346	349	351	355	356
100	338					344	349	353	356	358	360
125	353						358	362	363	367	368
150	366							370	372	375	377
175	378								380	383	385

Example: With an initial pressure of 125 psig saturated steam, throttled to 5 psig, the leaving steam temperature is 310 deg-F

Example 13:

Saturated steam at 100 psig is reduced to 10 psig using a PRV. What is the leaving steam temperature? How many degrees of superheat does this represent?

Enter Table 2 at 100 PSIG at the top of the table and follow down to 10 PSIG in the left column. You should read a final temperature of 299°F. *From the table we see a saturation temperature at 10 PSIG of 240 °F. So we say that the leaving steam has 59 degrees of superheat (299°F -240°F).*

When dealing with steam that has been reduced from high pressure steam, we really should keep in mind that the calculation of steam flows in heat transfer applications is not as simple as dividing the load by the latent heat of the steam. The proper calculation is shown in Example 14.

Example 14

Look at example 10. Now assume that the 15 PSIG steam in that example is produced by throttling 150 PSIG saturated steam thru a PRV. How much steam will be required by the unit heater?

Enthalpy of steam at 150 PSIG saturated = 1196 BTU/#

Enthalpy of steam at 15 PSIG leaving the PRV = 1196 BTU/#

To determine the steam required by the unit heater, use Equation 2, which is:

#/HR = Q/(Enthalpy of steam at start of process – Enthalpy of condensate at end of process

So, #/Hr = 250,000/1196 BTU/# - 218 BTU/#) = 256 #/HR

Note that this compares with 264 #/HR had we just divided that load by the latent heat of 15 PSIG steam? Is this difference significant enough to worry about? Possibly---possibly not. Let's assume that instead of 250,000 BTUH heating load that we have calculated a 25,000,000 process load. Now instead of an 8 #/HR difference, we are talking about 800 #/HR. This may, indeed, be significant. So simply be aware of this if you are working with "reduced" steam and use your judgment accordingly.

Also, to achieve an accurate heat exchanger selection, the manufacturer should be made aware of superheat quantities if they approach 100 degrees or *greater, as "standard" selection procedures assume saturated steam. In reality superheat degrades the performance a bit, as the heat transfer from the steam to the tube is less efficient for dry, superheated steam. Convention is to ignore this effect except where superheat exceeds 75 to 100 degrees and in situations where littler margin for error exists.*

Miscellaneous Heat Balance Equations

The following equations cover most such instances can be used to calculate heat loads for most HVAC and process applications:

- Air Heating Coils: BTUH = 1.085 X SCFM X Air ΔT
- Heat Exchangers, Water: BTUH = 500 X GPM X Water ΔT
- Heat Exchangers, Fluid, GPM Known: BTUH = 500 X GPM X SH X SG X Fluid ΔT
- Heat Exchangers, #/Hr Known: BTUH = #/Hr product X SH X Product ΔT

Where, SCFM = standard cubic feet per minute, ΔT = temperature change in °F, SH = specific heat and SG = specific gravity.

Wrap Up

Understanding the thermodynamics of steam is essential to understanding most of what follows in this course. Congratulations! You have completed the reading for the first session of this course. The next page contains representative problems. Try your hand at them to check your understanding!

Self Quiz, Session 1

1. What is the saturation temperature of 100 PSIG steam?

2. Steam quality refers to the absence of pipe scale and the proper chemical content of the steam. True or False

3. How much steam will flash when 5,000 #/HR of saturated condensate at 80 PSIG is drained to an atmospheric receiver?

4. How much heat is required to generate 1,000 #/HR of 5 PSIG steam from boiler feed water at 160 degrees?

5. A client wishes to heat 40 GPM of a liquid food additive from 70 degrees to 140 degrees F. The specific heat of the additive is 1.10 and the specific gravity is 0.88. 2 PSIG saturated steam is available. How much steam will be required?

Mind Teaser-A

You have been called as a steam expert to help solve a problem at UW-Platteville. You have been called there by Phil N. Tropy, the manager of the physical plant. He is at his wits' end. He has a number of older buildings, served by his central steam plant. These buildings utilize a perimeter heating system using low pressure (5 PSIG) steam, which comes from pressure reducing valves located in each building. The steam is piped to fin tube radiation, which is equipped with Taco self-contained valves for temperature control. The problem is that the elastomer rings in the valves seem to fail as fast as Mr. Tropy can replace them. At one point, he was upset with Taco for building a valve that didn't last, but his brother-in-law, Farron Hite, runs the local junior college's heating plant, and he as a couple hundred identical valves operating on 5 psig steam, and they last forever. Farron has always used this fact as evidence that he is the better manager of heating systems, a fact that leaves Phil depressed on days of family get-togethers. He suspects that there is something in his steam that is chemically attacking the O-Rings. You suspect something else, and ask Phil, "At what pressure is the steam being generated, and how far away is the steam plant"? When you find that the steam plant is next door, and generating at 150 PSIG (saturated), the mystery is solved. You happen to know that the O-Rings in the valves are good to 230 °F. Explain what is happening to Phil.

Mind Teaser -B

Phil is on a roll, now, and figures he'll get you involved in another problem that has been bothering him. He recently replaced the Taco heat exchanger that heats the water for the showers over at the gym. The budget was tight, and the salesman who sold him the replacement told him that since the gym had both 150 PSIG and 3 PSIG steam, that he could get by with a smaller heat exchanger if he would use the higher pressure steam. No doubt about it, that new heat exchanger heats like crazy, even though it is quite a bit smaller than the old Taco. But according to the flow meter, it actually seems to take a lot more steam, which doesn't make sense to Phil, because as everybody knows, it ought to take less high pressure, high temperature steam to heat a given amount of water than low pressure steam. You ask Phil to take you over to the gym, and when he does, you note that the steam trap drains to a vented receiver. Realizing that this can be tricky to explain, you decide to first make a point visually, before you attempt to explain why Phil is using a lot more steam. You take Phil up to the gym roof, and point out the vent line from the condensate receiver. He nearly topples off the roof, as he sees what looks like a steady stream of steam exiting the gym like a geyser. Phil immediately gets furious, saying, "I'm going to fire that Jimmy Bellows. I told him to repair that trap, but look at what's happening. That thing is blowing steam like an old steam engine. I bet he never even took that trap apart". However, you suspect that the trap is fine. Why doesn't Phil need to fire Jimmy?

Mind Teaser C

A plant engineer has installed a shell and tube heat exchanger. It operates on 75 PSIG steam, and is equipped with a modulating control valve. It heats process water for a chicken processing plant. In periods of low process demand, the system works great. However, when the load is high, the equipment room fills with vent steam from the condensate pump serving the heat exchanger. The maintenance people feel that they know what the problem is. Their theory is that when the steam control valve goes wide open to meet the process demand, that steam somehow overpowers the steam trap. They have repaired the trap. They have installed a bigger trap. They have installed a new type of trap. They have installed different brands of traps, but they all seam to leak when the control valve goes wide open. What is going on here?

Appendix 1, Steam Tables

Deleted-refer to internet resources.