

Steam: The delicate balance heat and temperature

Steam is the hot gas given off when water boils, but to ensure it is generated and used in the most efficient and effective manner in feed mills, especially for making feed pellets, a basic understanding of exactly what steam is and what its functions are, is essential.

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Operating with steam requires knowledge of physics. Most of what needs to be known about steam is in the steam tables (*Table 1, Figure 1*), but in practice these figures need some explanation. The basis for steam is water. Steam tables contain information on water as well as steam and they begin almost as low as 0°C and at a pressure of approximately minus 100 kPa, which is the absolute vacuum.

This is surprising because steam is normally associated with the boiling of water at 100°C, but that is at atmospheric pressure. At pressures lower than atmospheric water will boil at lower temperatures than 100°C and vice versa. The reason steam tables begin this low is that water (and not ice) must be used to generate steam and it is also assumed that at 0°C water contains no heat energy (or in correct scientific terminology: *enthalpy*).

The specific enthalpy of water is approximately 4.19 kilojoules per kg per °C (kJ/kg °C). This means that if we want to raise the temperature of 1 kg of water with 1°C, we will need 4.19 kJ. To raise the temperature of 1 kg of water from 0 to 100°C we need $100 \times 4.19 = 419$ kJ, which gives us the enthalpy of water (the heat content). This figure can be found in the steam table opposite 100°C. It is also true that when water is cooled down from 100°C to 0°C 419 kJ will be released (or an equivalent of the temperature difference $\times 4.19$ kJ).

At atmospheric pressure (0 kPa), when the water reaches 100°C, the heat being added will no longer increase its temperature, because the water will evaporate into gas. This change of state requires a considerable input of heat energy or *enthalpy of evaporation*. To change water of 100°C into steam of 100°C the enthalpy of evaporation is 2257 kJ/kg. So the heat content of steam or enthalpy of steam (at atmospheric pressure) is equal to the enthalpy of water plus the enthalpy of evaporation or $419 + 2257$

between moisture,

= 2676 kJ/kg. This emphasises the very considerable amount of heat contained in steam, which is of course why steam is such a useful heating medium.

The effect of pressure

The greater the pressure on the surface of the water, the more reluctant the water will be to change state into steam. Pressure restricts the boiling effect and the release of steam bubbles. So with increased pressure more energy must be added to the water before it will boil. Consequently the boiling temperature will be higher and also the enthalpy of water. But once the boiling point is reached, because the water now contains additional heat energy, less enthalpy of evaporation will be required to turn water into steam. This also means that the enthalpy of steam only increases slightly. *Figure 2* shows the relationship between pressure and enthalpy. However, the specific volume of the steam decreases substantially.

Condensation

When the steam subsequently loses heat it condenses back into water and releases its enthalpy of evaporation. In a direct injection process such as into a meal mixture to make pellets the steam will, as soon as it condenses, release its enthalpy of evaporation and simultaneously form water – every kg of steam will form one kg (litre) of water.

Most injection processes occur at atmospheric pressure so the water is formed at 100°C. This water contains the enthalpy of water and this will now be transferred to the product, but is of course accompanied by a temperature drop, but only down to the final temperature mix. In pelleting this is usually around 82°C (at the point where the meal enters the pellet die). So the extra heat given off by the water is $(100 - 82) = 18^\circ\text{C}$, multiplied by 4.19 kJ/kg. This equals 75.42 kJ/kg and is almost negligible compared to the 2257 kJ/kg of enthalpy of evaporation released at the instant each kg of steam condenses.

The steam used so far is also called ‘saturated’ steam. Saturated means that the steam is not superheated, i.e., its temperature corresponds to its pressure and if it loses any heat condensation will immediately occur. Steam that is additionally heated to above the saturation temperature is called superheated steam. When this type of steam loses its heat at first only the temperature drops until it has dropped to the saturation steam temperature.

Figure 1 - Steam tables presented in graphical form - temperature - volume

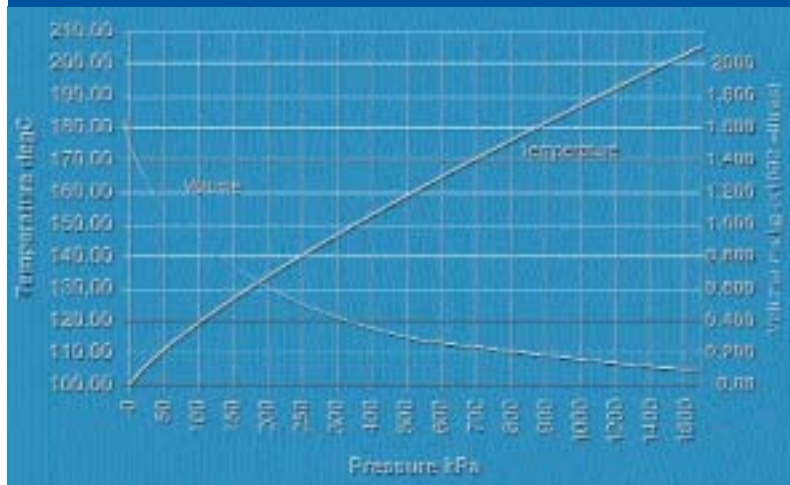
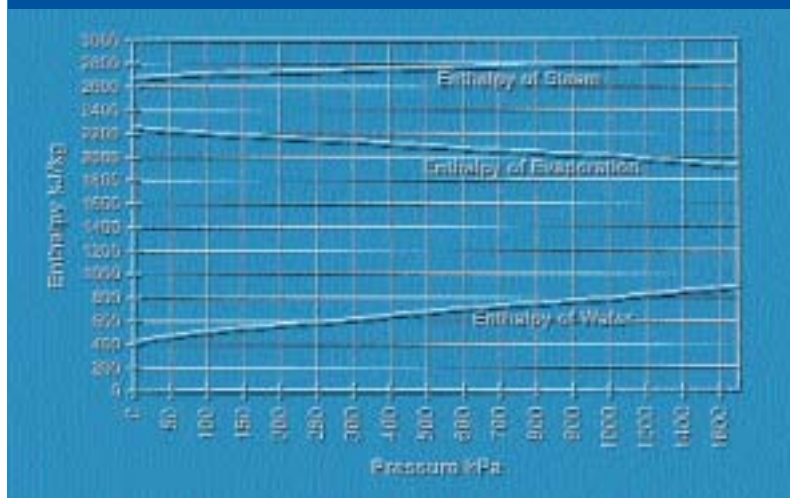


Figure 2 - Steam tables presented in graphical form - Enthalpy



In practice superheated steam gives off less heat readily than saturated steam, mainly because until saturation temperature the heat can only be released by conduction and temperature drop. The rate at which this occurs is significantly less than when steam condenses.

Steam's volume

Volume changes when generating steam are dramatic. One kg of water occupies a volume of one litre. When boiled into steam at atmospheric pressure, the volume will increase to 1673 litres, and expan-

sion of almost 1700 times. If instead that steam is generated at 700 kPa, the expansion will be only to 240 litres. If the steam at 700 kPa is now reduced to 100 kPa, each kg of steam will expand to 881 litres, an expansion of 3.7 times.

The volume changes brought about by different steam pressures explain why different sized pipes are required for steam at different pressures and especially why very large pipes are required at low pressures. Also, the concentration of the steam into such a small volume of water explains how air, water and other material can be so easily sucked into steam plant and pipe work when the steam is turned off and the residual steam condenses.

The actual operating pressure of the boiler has an influence on the dryness or wetness of the steam. The boiler should be operated at the maker's maximum designed working pressure. This is basically because of the larger volume of steam at lower pressures.

Most modern boilers are designed to produce large quantities of steam from the smallest possible space. If not operated properly they tend to produce wet steam, i.e., steam carrying a notable amount of water droplets and mist. Wet steam - or wet saturated steam - is measured by the proportion of water in one kg of steam. If each kg carries 100 grams of moisture it is 10% wet. This can also be referred to as a dryness fraction (0.9, i.e., 90% dry). This figure is not uncommon in a modern industrial steam plant.

Steam for pelleting

When properly generated we should have a supply of high-pressure steam that is very close to being dry saturated. But what do we *really* want from the steam in the pellet press? It is of course required to provide both heat and moisture to the meal, so that the meal is in the most suitable condition for the formation of pellets. The added steam will increase the moisture of the formulation and the temperature of the meal entering the die. The heat from the steam will also do some cooking of the meal (gelatinisation, for example). So we are really trying to

do three things with the steam:

- Add moisture
- Add heat to raise the meal's temperature
- Add heat to do some cooking of the meal

The first two are generally the most important from a steam control point of view. Moisture content, heat content and temperature are all very closely related and you can't get one without the

other. Expressed bluntly, if you add twice as much steam so as to double the moisture content, you cannot avoid also adding twice the amount of heat, so you'll get more cooking and a higher temperature too. Or, let's say our meal temperature is too high, so you reduce the amount of steam being added - but this will also reduce the amount of moisture you're adding.

Experience has shown that for every 1% moisture addition by steam, the meal temperature will be raised

by approximately 14°C and that (in Australia) steam will rarely be used to add more than 5% moisture. For example:

Press throughput = 10 tonnes/hour, moisture addition by steam = 5%. So the quantity of steam required = 5% of 10 tph = 500 kg/h. The meal temperature prior to the die will rise by $5 \times 14^\circ\text{C} = 70^\circ\text{C}$. So if the initial temperature of the meal was 15°C, the temperature before the die will be $15 + 70 = 85^\circ\text{C}$, approx. If the meal is too moist it will choke the die. Typically, a total moisture content of 16 to 17% (18% absolute max.) will cause the die to choke.

Delicate balance

In addition to varying the amount of steam being added, you can also vary its pressure. But whilst it is true that raising or lowering the steam pressure at the press will affect the fine balance between moisture, heat and temperature, the differences are so small that in many cases there will be little or no effect on the meal. By lowering the pressure the enthalpy of steam barely changes, but the temperature will drop considerably and the volume will go up exponentially. So the pipe work would have to be big enough to cater this.

WHAT DO WE REALLY WANT FROM STEAM IN THE PELLET PRESS? IT PROVIDES HEAT AND MOISTURE AND COOKS THE MEAL, READY FOR PELLETING

Altering the throughput of the press also affects the balance of the three parameters. For example, if the throughput of the meal were doubled, the steam flow rate would also have to be doubled, but the meal would then pass through the press at twice the speed; conditioning time halves. So twice the quantity of steam would have half the time in which to do its work before the meal hits the die.

The optimum time for the meal to spend in the conditioning chamber is usually 40 seconds. Also the revolution speed of the screw through the conditioner needs to be such as to ensure thorough mixing of the meal with the steam, in particular, it should be fast enough to ensure that the meal efficiently cascades over and above the injection points. Typically this will be about 200 rpm.

What should be recognised is that in most cases, sufficient steam should be added to reach the temperature at which the pellets can be produced in the right quantity and that any additional moisture needed has to be met by separate control of the moisture content of the ingredients, or injection of additional water into the steam or direct into the conditioning chamber. The addition of oils and/or tallow can also help to achieve optimum conditioning of the meal.

The problem of superheat

Saturated steam condenses readily, but superheated steam is reluctant to condense. It will only do this with the pressure at the point where it is condensing. This is the pressure within the conditioning chamber. It will be atmospheric pressure or only marginally above atmospheric pressure, since any higher pressure would blow the meal back up the supply hopper. So if the steam is to condense and thereby readily give up its moisture and heat, it must in theory be at 100°C. However, in practice, it has been determined that the actual temperature of the steam as it issues from the injection nozzles or holes in a conditioning chamber may be around a degree or two higher without compromising ready condensation.

If superheated steam is injected into the conditioning chamber, it is most likely that the meal will be insufficiently heated and/or moistened and that uncondensed steam will blow out from openings on the chamber or even through the feed hopper. In such cases, the only solution may be to slow down the throughput of the press to encourage a longer retention time during which the superheat hopefully will be lost and condensation takes place. ●

Table 1 – Steam tables

SPECIFIC ENTHALPY					
Pressure	Temperature	Water (hf)	Evaporation (hfg)	Steam (hg)	Specific volume steam
kPa	°C	kJ/kg	kJ/kg	kJ/kg	m ³ /kg
-100.3	7.0	29.32	2485.1	2514.4	129.208
-98.3	24.1	101.00	2444.6	2545.6	45.662
-91.3	45.8	191.83	2392.8	2584.7	14.674
-81.3	60.1	251.40	2358.3	2609.7	7.649
-71.3	69.1	289.23	2336.1	2625.3	5.229
-61.3	75.9	317.58	2319.2	2636.8	3.993
-51.3	81.3	340.49	2305.4	2645.9	3.240
-41.3	85.9	359.86	2293.6	2653.5	2.732
-31.3	90.0	376.70	2283.3	2660.0	2.365
-21.3	93.5	391.66	2274.1	2665.8	2.087
-11.3	96.7	405.15	2265.7	2670.9	1.869
0	100.00	419.06	2257.0	2676.0	1.673
10	102.66	430.2	2250.2	2680.2	1.533
20	105.10	440.8	2243.4	2684.2	1.414
30	107.39	450.4	2237.2	2687.6	1.312
40	109.55	459.7	2231.3	2691.0	1.225
50	111.61	468.3	2225.6	2693.9	1.149
60	113.56	476.4	2220.4	2696.8	1.088
70	115.40	484.1	2215.4	2699.5	1.024
80	117.14	491.6	2210.5	2702.1	0.971
90	118.80	498.9	2205.6	2704.5	0.923
100	120.42	505.6	2201.1	2706.7	0.881
110	121.96	512.2	2197.0	2709.2	0.841
120	123.46	518.7	2192.8	2711.5	0.806
130	124.90	524.6	2188.7	2713.3	0.773
140	126.28	530.5	2184.8	2715.3	0.743
150	127.62	536.1	2181.0	2717.1	0.714
160	128.89	541.6	2177.3	2718.9	0.689
170	130.13	547.1	2173.7	2720.8	0.665
180	131.37	552.3	2170.1	2722.4	0.643
190	132.54	557.3	2166.7	2724.0	0.622
200	133.69	562.2	2163.3	2725.5	0.603
250	139.0	585.0	2147.6	2732.6	0.522
300	143.75	605.3	2133.4	2738.7	0.461
400	151.96	640.7	2108.1	2748.8	0.374
500	158.92	670.9	2086.0	2756.9	0.315
600	165.04	697.5	2066.0	2763.5	0.272
700	170.50	721.4	2047.7	2769.1	0.240
800	175.43	743.1	2030.9	2774.0	0.215
900	179.97	763.0	2015.1	2778.1	0.194
1000	184.13	781.6	2000.1	2781.7	0.177
1500.0	201.45	859.0	1935.0	2794.0	0.124