Approaches to saturation

ATM 210 – Fall, 2023 – Fovell

The vapor supply (VS) of subsaturated air is smaller than its vapor capacity (VC). Bringing this air to saturation involves increasing its VS and/or decreasing its VC. There are a variety of ways of decreasing the VC of air, but only one way of increasing the air's VS: by evaporating liquid into the air. There is no practical way of increasing VS without also decreasing VC, since evaporation is a cooling process.

There are three basic approaches to saturation for a subsaturated air parcel. They are the *adiabatic expansion approach*, the *dew point approach*, and the *wet bulb approach*. The first two involve decreasing VC for fixed VS, the third increases VS while simultaneously decreasing VC. The adiabatic approach involves changing the pressure of air; the other two are *isobaric*, or constant pressure, processes. Two new kinds of temperature are introduced as the three are described below.

Adiabatic expansion approach to saturation: Consider a subsaturated air parcel with a certain VS. Lifting it towards lower pressure permits the parcel to expand, cooling the air within. As the temperature decreases, so does VC. Thus, for fixed VS, relative humidity (RH) is increasing as the parcel is lifted. The parcel cools at the dry adiabatic lapse rate until saturation is achieved.

While lifting is the most familiar way of getting air to expand, there are other ways of changing an air parcel's temperature adiabatically. Example: let moist but subsaturated air escape from a pressurized tire. As the air passes through the nozzle, it expands because it is moving towards an environment with lower pressure. The air cools, as if it were lifted, and some vapor within the escaping air can be forced to condense if the cooling is sufficient to result in saturation.

Dew point approach to saturation: Adiabatic expansion is one way of cooling the air to saturation. Another is to extract heat from the air by conduction and/or radiation at constant pressure. This may be generally referred to as *diabatic or direct cooling*, and note we're *not* employing air parcel assumptions here. Those assumptions typically apply to air that differs in density with respect to its surroundings and is moving too quickly through the environment for mixing and heat transfer via conduction and radiation to be appreciable. Here, we are permitting air to lose heat via conduction, by making it come in contact with a colder surface and giving it the time for conduction to proceed.

The classic example of the dew point approach involves placing a chilled can of soda in a warm, moist room. Room air is cooled on contact with the can; that is, it loses heat to the can via conduction. As this air is diabatically cooled (i.e., by heat transfer, not via expansion), its VC decreases. As in the adiabatic approach, VS remains fixed as RH rises. When saturation is reached, liquid drops start forming on a convenient surface – that being the outside of the can. Dew has formed.

In this situation, we say that the room air in contact with the can has been chilled to its *dew point*. The *dew point temperature* T_d *is the temperature the air would have if brought to saturation via diabatic (direct) cooling without change of vapor supply or pressure*. Thus, say we have subsaturated air with a temperature of 20°C and a dew point temperature of 5°C. If we could directly cool that air down to 5°C, it would be saturated and condensation (dew) would start to appear.

We now have two temperatures: the regular temperature T, also known as the *dry bulb* temperature for reasons discussed presently, and the dew point temperature T_d. Both yield important information about moisture. The dry bulb tells us VC: how much vapor the air can hold. **The dew point temperature reveals the VS.** Whether saturated or not, T_d is a characteristic property of the air. The now familiar table relating T and VC is also used to relate T_d and VS, and this information applies to insulated air parcels as well.

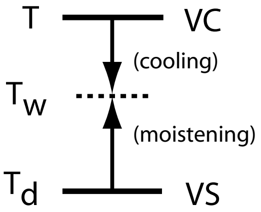
Examples:

- Say there is 8 g/kg of vapor (VS) in your room air. What is T_d? The table reveals this to be 10°C.
- Say this same air has a regular (dry bulb) temperature of 25°C. If you don't change its VS or pressure, how far must you cool the air by direct cooling to bring it to saturation? You need to cool it down to its dew point, or 10°C.
- An air parcel has a VC of 12 g/kg and a RH of 25%. What is its T_d? It is -5°C.
- At saturation, VS = VC, and thus $T = T_d$.
- You can directly compare the moisture contents of air parcels by considering their dew points. Consider a foggy Minnesota winter day and a dry Death Valley summer day. The former's air is 0°C and saturated, and thus $T_d = T$. Suppose now the latter's T_d is 5°C. No matter what its RH is, the Death Valley air has a larger VS because its dew point is higher.

Table 1: Air at sea level

T or T_d (°C)	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40
VC or VS (g/kg)	0	0.5	1	1.5	2	3	4	6	8	12	15	22	28	40	50

Wet bulb approach to saturation: The third way of bringing air to saturation is to increase its VS by evaporating liquid water into the air at constant pressure. The act of increasing VS forces the air's T_d to rise, since T_d reflects vapor content. However, evaporating liquid requires heat energy and this energy is taken from the air you're trying to saturate. Therefore, temperature and VC will have to decrease (actually hastening saturation). In this process, the *wet bulb approach to saturation*, VS/T_d increases as VC/T falls, and saturation is achieved when the two meet at some intermediate value. That intermediate point is called the *wet bulb temperature* T_w, *the temperature air would have if brought to saturation via isobaric moistening and evaporative cooling*.



This has an important implication. Say you have air with T and T_d of 15°C and 10°C, respectively. That means the air has a VC of 12 g/kg, but is only holding 8 g/kg of vapor. Can you actually force another 4 g/kg into the air? **NO.** The act of evaporating liquid into the air causes it to cool, decreasing its vapor holding capacity. In this case, because of the evaporative cooling effect, perhaps only another 2 g/kg will fit into the air by the time it is saturated. When evaporative cooling (rather than direct diabatic cooling) is used, the temperature cannot decrease all the way to the air's original dew point. It can only be cooled to its wet bulb temperature.

The wet bulb temperature can be measured with a wet bulb thermometer. This is a thermometer with a piece of gauze placed over the thermometer bulb. The gauze is saturated with water and the thermometer is swung around in order to force air into the space between the gauze and bulb. The air trapped in that space is cooled to saturation via evaporation, causing the thermometer to read the air's T_w. Without the gauze, it is a regular "dry bulb" thermometer.

At saturation, $T = T_w = T_d$. *For subsaturated air, the wet bulb is always lower that the dry bulb temperature, but also higher than the dew point*. Thus, $T_d < T_w < T$. Being able to explain why this is true demonstrates understanding of the wet bulb approach to saturation.

Synthesis: The three routes to saturation all involve *cooling* the air. Adiabatic expansion relies on the cooling that results when the pressure on a gas is decreased. The other two approaches are isobaric. Air can be directly cooled, by conduction or radiation, down to saturation without changing its VS. It becomes saturated when it reaches its dew point T_d. Alternatively, air can be cooled via evaporation, which also acts to moisten the air. During this process, the air's original VC and VS meet at an intermediate value, reflecting the air's wet bulb temperature. Every subsaturated parcel can be described by three unique characteristic temperatures, T, T_w and T_d. At saturation, all three temperature values coincide.