Fysical parameters in incubation

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Incubation is about controlling the environment that the embryo is growing in. The control of this environment is done by influencing the climate around the eggs, in the machines and around the machines. This paper deals with some of the physical parameters that we are facing in incubation.

I first go into the amount of ventilation an embryo needs, and some of the practical aspects we are dealing with. Then we look at the Mollier diagram and how we can use it in understanding how air works. At the end we look at some of the aspects of cooling by evaporation.

Ventilation

There is a number or reasons why machines do need ventilation. We expect that the main reason is to provide oxygen and to remove carbon dioxide. Next to that, also the removal of water and heat plays a role. A role which sometimes can be substantial.

But first of all, lets take a look at refreshing the air, so replacing oxygen and carbon dioxide. For normal living animals, we normally consider a minimum ventilation norm of about 0.35 m3 of air per hour per kg of bird (animal). Although for real replacement of oxygen en carbon dioxide this is actually too high, it's a good starting point.
This 0.35 m3 is for animals that move around and use a lot of energy (and therefore use oxygen and produce carbon dioxide) for movement. Embryos don't move in the egg, and we have to consider them more anaeroob (not living on free oxygen in the air) then aeroob. Normally we assume that anaeroob processes take only 10-20% of the requirements of aeroob processes, but lets stay on the safe side and use 30%.

This means that embryos use 0.105 or roughly 0.1 m3 of air per kg embryo per hour.

If we have 100.000 eggs in a machine of 60 grams, that is 6000 kg of eggs. However, the embryos are only a fraction of that. Lets assume that at 18 days the embryo is already fully grown and weighs 40 grams (in reality it will be more like 35 g and not all eggs will be fertile, but lets again stay on the safe side).
100.000 eggs times 0.04 kg is 4000 kg, times 0.1m3 is 400 m3 per hour for a single stage machine at full capacity at 18 days of age.

How much will that be for a multi-stage machine?
Lets consider the average weight of the embryos between 0 and 18 days of incubation to be 50% of the maximum weight, then a 100.000 egg machine should ventilate 200 m3 per hour.
What does it mean for a hatchery? A hatchery that produces 1.000.000 chicks a week and sets 1.2 million eggs a week will have on every given moment have a little bit over 3 million eggs in the setters, of 20 gram embryo each. The total ventilation capacity for the setters should then theoretically be: 3.000.000 x .02 g x 0.1m3 is 6000 m3 per hour. Most hatcheries do more….
For hatching, we have to calculate with live chicks, so a hatcher of 20.000 egg places will actually hold 20.000 40g chicks (100% hatch, good job) that need 0.35m3 per hour, what gives 280m3 per hour. With this ventilation rate, the carbon dioxide level in the machines will

not exceed 2500-3000 ppm. In fact we can ventilate less, because carbon dioxide levels up 4000-5000 ppm don't seem to cause problems, but I prefer to stay on the safe side again.

But why do most hatcheries ventilate much more?
First of all, not all the air that comes in the hatcheries goes through the machines, and secondly, a lot of machines actually use the air for cooling, not only for ventilation. But if we refresh the air, we also have to consider the replacement of humidity if we want to keep the humidity on lets say 55%.

To calculate the effect of ventilation on air parameters, we can use the Mollier diagram or Hx diagram.

The Mollier diagram

In ventilation of houses, hatcheries etc, we have to work with the physical properties of air, which is influenced by temperature, humidity, air velocity etc.
A well known diagram that is used all over the world is the Mollier diagram, also called the hx or ix diagram, This diagram describes the relation between temperature, moisture and energy in air and can be of help when problems with cooling, moisturizing or sweating occur. The diagram looks very complex, but in fact is very easy once you understand how it works.

First some facts.

- The Mollier diagram works with kg of air. A cubic meter of air at sea level pressure weighs approximately 1.3 kg. For normal calculations, we often assume that 1 m^3 weighs 1 kg, but this sometimes gives misunderstandings, as will be shown in one of the examples.
- Relative humidity (RH) is defined as the ratio between how much water vapour is in the air, and how much water can be hold in the air at that temperature.
- If there is more water damp in the air than that the air can hold, the RH is 100% and the rest of the water will condensate into mist or rain.
- The constant factor is always the grams of water in the air. If temperature changes, the quantity of water in the air doesn't change (unless you replace the air by other air, more dry or more wet).
- Any cold or warm surface in the air will act as a very local cold or warm area, as a sort of a micro climate. This is important to understand condensation.

How to use it.

- On the bottom axis the grams of moisture per kg of dry air is given, connected with the vertical lines in the graph. In the Mollier diagram presented this axis runs from 0 to 55 g of moisture per kg of dry air, but the presented values are given from 0.005 to 0.045 kg/kg moisture.
- On the vertical left axis, the temperature of the air is given, connected with the more or less horizontal lines in the graph. This axis runs from –25 to +55 °C.
- The curved lines in the diagram represent the relative humidity (RH), given a RH figure for each combination of temperature and grams of moisture in the air. These curves run from 0.10 at the top left side to 1.00 at the bottom. Relative humidity is as the word says, relative: it is the ratio between the actual amount of water in the air and the amount the air can hold. Because it's a ratio, a value of 0.10 actually means 10%, which is better

recognized by most of us, as we normally do not present relative humidity as a ratio. Below 1.00 or 100% the diagram is blank, because then the amount of water that is in the air would be higher than the amount that can be in the air, the excessive water comes out and it starts to rain.

- At any given point in the diagram you can determine the heat content of the air, by drawing a line through that point that connects two figures of equal value on the outside axes. These outside axes go from –2 kcal/kg in the bottom left corner to +40 kcal/kg in the top right corner.
- On the bottom curve, the humidified air temperature is given, connected with the diagonal lines running from top left to bottom right. These lines describe the resulting difference in temperature and RH if moisture is added.
- To work with it, you choose a temperature and RH setting, for instance 21.4°C and 69% RH. At that level, the air contains 11.9 kcal of energy and 11.2 g of water per kg. The humidified air temperature 17.6°C, meaning that if you add water to 100% RH, the temperature of the air will go down to 17.6°C. The dew point temperature is 15.5°C. In other words, if the temperature drops below 15.5°C the air can't hold more than 11.2g of water in evaporated form and condensation will occur.

Examples:

Ventilation:
What will the RH be in a setter room of 27°C if we bring in air of 5°C and 95% RH from outside. And How much water do we need to add to get 60% RH.
Answer: Air of 5°C and 95% RH contains 5.1 g water/kg. 5.1 g water at 27°C give a RH of 23%. Air of 27°C and 60% RH contains 13.4 g water/kg, so per kg we need to add 13.4-5.1 = 8.3 g water/kg air

Humidity increase:
How much water is needed to increase the humidity in a setter room from 40 to 60%, given a temperature of 27°C and a ventilation rate of 1000 m^3 per hour.
Answer: air of 27°C and 40% R.H contains 8.9g of water per kg. Air of 27°C and 60% R.H contains 13.4g of water per kg, so per kg of air we have to add 4.5 g/kg. Air weight under these conditions at sea level is approx. 1.3 kg/ m^3, so per m^3 we have to add 4.5 x 1.3 = 5.85 g per m^3. We ventilate 1000 m^3/h so we have to add almost 6 liters of water per hour. Some people will give the answer of 4.5 liter of water, because often the weight of air is assumed to be 1 kg/ m^3.

Cooling by evaporation:
How much will the temperature drop of 30°C air with 30% RH when we bring 3 g of water in the air.
Answer: Air of 30°C and 30% RH contains 8.9 g water/kg air. Adding 3 g of water results in 11.9 g water/kg air. The temperature drops to 21°C, the RH increases to 75%.

Warming and humidification:
How much heat and water do we have to add if we want to increase the temperature from 21°C and 75% RH to 30°C and 75% RH
Answer: air of 21°C and 75% RH contains 11.9 g water/kg air and 12.3 kcal/kg. Air of 30°C and 75% RH contains 20.8 g water and 19.8 kcal per kg air. So per kg 8.9 g water and 7.5 kcal has to be added.

Condensation
What is the dewpoint (condensation) temperature of eggs when brought into a setter room of 27°C and 60% humidity.
Answer: eggs will condensate when their temperature is so low that the air can't hold the water anymore and thus RH reaches 100%. At 27°C and 60% the air contains 13.4 g water/kg air. With that water content, RH will be 100% when temperature drops to 18.4°C. So eggs will start to sweat when they are 18.4°C or colder.

On the internet there are several websites that do the calculations for you.
An example is: www.coolmark.nl/mollier/mollier.htm

However, in incubators we don't only deal with air, we also deal with eggs. Especially for the cooling aspects, that is very important.

Cooling by spraying

First some numbers, to be able to do some calculations.

Specific heat of eggs:	3.5 kJ per oC per kg
Specific heat of air:	1 kJ per oC per kg
Evaporative heat loss:	2260 kJ per liter of water

When working in incubation, we often find that we can control the temperature in setters and hatchers better if the machines ask for a certain amount of spraying, especially if the cooling capacity of the machines is (too) limited. Some machines don't even have any other cooling possibilities than exchanging air and spraying. When the machines spray and evaporate water, we see that they hold their temperature better and don't get overheated so easily.
At first sight, this seems logical. Evaporation of water costs energy and therefore has a cooling effect. Evaporative cooling systems are based on this effect, and everybody who has ever walked in the rain will agree with it. Spraying of water will reduce the temperature and therefore cool the egg mass in a machine, and if overheating problems occur in a machine an increase in spraying of water by changing the humidity settings will bring the temperature down.
However, if we do some calculations and look at the total system we might have to add some remarks to these conclusions.

How much water is needed for effective cooling?
If we have a machine of 100.000 eggs of 60 grams, we are dealing with egg mass of about 6000 kg. The specific heat of eggs is approximately 3.5 kJ per oC per kg. This means that if we want to cool the egg mass in the machine 1oC, we need to extract 6000 x 3.5 = 21.000 kJ or about 5000 kcal of energy from this egg mass.
Evaporation of water costs energy. To evaporate one litre of water, 2260 kJ of energy is needed. If we have a 100% effective system, so all energy used to evaporate water is coming from the eggs, we need to evaporate almost 10 litre of water to cool the eggs with 1 oC.

Is this in line with what we know? Natural evaporative cooling cools the eggs with about 0.3oF, or about 0.1-0.2oC. Eggs evaporate about 12-14% moisture during incubation, that is 0.6-0.7% per day, or 0.025-0.03% per hour. For 6000 kg of eggs that will be 1.5 liter water per hour. 10 liter cools 1°C, 1.5 liter cools 0.1-0.2°C. Pretty close….

Although this doesn’t seem to be a large quantity, a machine has to spray quite frequently to use 10 litre of water, as the amount of water used by the sprayer is not that big. However, it shows that the machine can cool quite substantially if it sprays a lot of water. But will all eggs in the machine be cooled evenly?

What is the effect on temperature distribution?
If we spray water in the machine, not all eggs provide the same amount of energy for evaporation and are cooled to the same level. The sprayer is often located close to the ventilator, so that the high air velocity takes away the water rapidly. This means that the water is sprayed on the eggs within that high air velocity, and they will provide the energy for evaporation and will be cooled the most. Eggs away from that air velocity will benefit much less, or not at all. The eggs in the high air velocity already lose a lot of heat through the wind chill effect of air velocity. This means that these eggs were already cool, and will get even colder if the sprayer comes on. Eggs away from the air velocity were relatively warm, and will stay warm.

Fooling the sensors
The temperature sensor in a machine is normally located in an area with high air velocity. This is by itself correct, as the sensor will pick up temperature differences rapidly. However, if the machine sprays so much water that it isn’t all evaporated before it hits the sensor, the sensor will be cooled by the water, the machine will think the temperature drops and in extreme situations will even start heating. Although we often think that the water is evaporated if we don’t see droplets anymore, we have to realise that the water first needs to pick up energy before it can evaporate, and if it didn’t pass enough eggs before it hits the sensor, the sensor will be cooled. But the eggs away from the air velocity and the water spray will still be warm, and will even get warmer as the machine starts heating. It is as if we put the thermometer in a room in a glass of cold water when we feel hot..

Spraying of water in machines helps to bring down the temperature, but we have to realise it brings down especially the temperature reading on the display, not so much the temperature of the eggs. Spraying a lot of water will often increase the spread in temperature experienced by the eggs in the machine, and sometimes will even increase the temperature in the hot places.

Putting it all together

Lets suppose we want to have the machines running at 37.5oC (99.5 oF) and 55% relative humidity. (99.5oF), and the machines have a capacity of 100.000 eggs. If the machine ventilates at its expected rate, so lets say 400 m3 per hour in single stage mode at 18 days and 200 m3 per hour in multi-stage mode, what will be the consequences of choices that we made.

Temperature
At 37.5oC and 55% R.H., the air holds about 22 kcal/kg, lets say 22 kcal/m3. if the incoming air would be 25oC and 50% R.H., that air would hold about 12.5 kcal/kg (12.5 kcal/m3).
That would mean that the air would take out: 22-12.5 = 9.5 kcal/m3
If we list the heat loss per parameter, the following shows:
25oC – 50% R.H.: heat loss is 22 - 12.5 = 9.5 kcal/m3
25oC – 70% R.H.: heat loss is 22 – 14.5 = 7.5 kcal/m3
20oC – 50% R.H.: heat loss is 22 – 9.5 = 13.5 kcal/m3
30oC – 50% R.H.: heat loss is 22 – 15.5 = 6.5 kcal/m3

What this calculation shows is that if we change the setpoint of the setter room, both on temperature and on humidity, we have to realise that the cooling of the machine by ventilation will change as well, and that effect has to be compensated by cooling capacity or water spraying.

Relative humidity

If we ventilate 100.000 eggs in a multi stage machine, so with 200m3 per hour, these eggs (6000 kg) will loose approximately 1.5 liter of water per hour. This water will increase the humidity with 7.5 grams per m3 of air. Air of 37.5oC and 55% R.H. means that it holds 22-23 grams per m3. If we want the machines to be constant, we have to bring in air that holds 22-7.5 = 14-15 grams of water, which is for instance 25oC and 70% R.H.. If we ventilate the machine only for refreshment of air, and we use air of 25.C and 70% R.H., the humidity will be in balance and the sprayer will not come in.

If we do the same in a single stage machine, at the end of incubation with 400 m3 per hour, we still loose 1.5 liter of water, but it will be only 3.5 grams per m3 of air (more ventilation). The air in the machine still holds 22-23 grams of water per m3, so to keep the machine in balance we must feed the machine air with 19-20 grams of water, which means 30oC and 70% R.H.

If we feed the machines more air, or we bring in the air more cold or dry, the machine has to start spraying to keep up the conditions.

Practical situation:

Our hatchery runs in wintertime, and the outside air is 5oC and 90% R.H. Our multi-stage machine doesn’t have enough cooling capacity, and therefore the air in the setter room is warmed to 22oC, to feed the machines.

The outside air contains 5 grams of water, if we bring it up to 22oC the relative humidity drops to 30%. That condition can holds about 8.5 kcal/m3 of energy, so we can remove 22 (heat capacity of 37.5-55%) – 8.5 is 13.5 kcal/m3.

If we have not enough cooling capacity in a multi stage machine to work with that 13.5 kcal/m3 of heat removal, we have to ventilate it for instance with 400 m3 of air. We want air with 22 g of water/m3 (37.5 and 55%), the air holds only 5g and the eggs provide 1.5 liter per 400 m3 is 4 grams/m3. then we still have to add 22 – 9 is 13 grams of water per m3, or we ask the machine to spray roughly 5 liter of water per hour.

If a group of 20.000 eggs in the machine provide the energy for that evaporation, because of their position in the machine, that machine will drop the temperature of these eggs.

How much? 100.000 eggs take 10 liter of water to cool 1oC. We are adding 5 liter on 20.000 eggs, so their temperature will drop with 2.5oC.

If we install more cooling, and we can limit the ventilation of the machine to 150 m3 per hour with the same incoming air parameters, we have to add 13 g x 150 m3 = 2 liter of water, and the temperature will only drop with 1oC.

If we increase the relative humidity in the room to 60%, the air at 22 oC and 60% holds 10 gram of water, we only have to 22 – 10 – 4 is 8 gram/m3, which is a little bit over 1 liter on a well ventilated machine, and the drop is only 0.5oC

This is theoretical, because we are calculating with a situation of ideal evaporation, taking all the energy from the eggs, but it gives an idea about the parameters in machines.

And it shows why cooling by evaporation is so effective if there is not enough cooling capacity. And why high carbon dioxide levels (limited ventilation) are so positive on your hatchability (temperature uniformity) if the machines do have enough cooling capacity.