NC STATE UNIVERSITY

Physics of incubation

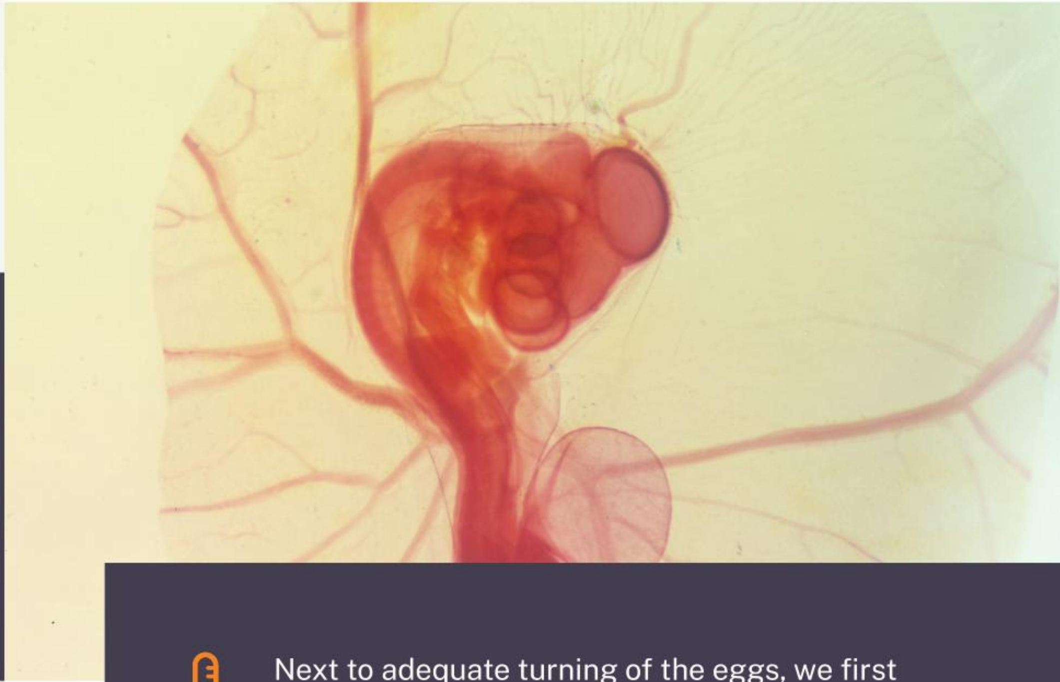
Ron Meijerhof

Poultry Performance Plus, the Netherlands

Successful incubation depends largely on the conditions we create in our setters and hatchers.

When these conditions meet the demands of the embryo, conversion of egg content into embryo and with it the development of the embryo will be optimal, resulting in good quality day old chicks and good hatchability.

Although the biological process of turning an egg into a chicken is nothing less than a miracle, the **creation of these optimal conditions is based on relatively simple physics.**



Next to adequate turning of the eggs, we first of all need to control the internal temperature of the eggs at a very precise level. This temperature determines the development of the embryo and with it the need for nutrients and oxygen and the production of carbon dioxide and metabolic water.

The **second priority is to control the moisture loss of the eggs.**

- During the development of the embryo metabolic water is formed, and the eggs need to lose sufficient water to create a big enough air cell for the hatching process.
- Relative humidity (RH) in combination with temperature is the driving force for the moisture loss of the egg. We can control the RH in a machine by the humidity of the incoming air, by the amount of ventilation of the machine and by the evaporation of water through a spraying system in the machine. Although these factors influence the RH in the machine, they will also influence the temperature.
- Evaporation of water costs energy and therefore has a cooling effect.
- Also the level of ventilation influences temperature as warm air in the machine is replaced by relatively cold air.

Last but not least, **the embryo needs oxygen (O_2) and produces carbon dioxide (CO_2), so the machines need to exchange the air to provide this.**

Temperature of the eggs

For optimal incubation the internal temperature of the eggs is of utmost importance.

Although the optimal temperature is slightly dependent on the availability of oxygen for the embryo, **we normally consider a temperature of 37.8°C, measured as temperature of the shell, as optimum.** This temperature is influenced by a number of factors, as it is the result of a balance between the heat production of the embryo and the heat loss by the eggs.

The **heat production** depends on stage of development of the embryo and to some extent on egg size and genetic background.

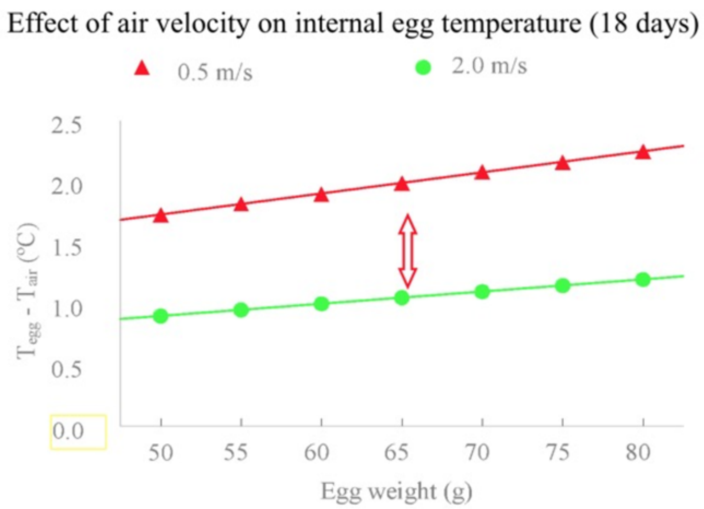
The **heat loss** depends on the temperature difference between egg and air, on the air velocity over the eggs and on the heat loss through evaporation.

AIR VELOCITY

The design of an incubator determines the air velocity and especially the uniformity of air velocity over the eggs. **If the air velocity is low, the heat loss of the eggs will be low as well and especially at the end of incubation the resulting egg temperature will be high.**

This means that air velocity should be as uniform as possible, which is a challenge for incubator manufacturers.

However, also factors like turning and egg size influence air velocity, as it interferes with the space between eggs and therefor with the resistance against air movement.



EVAPORATION

- **Eggs need to lose moisture,** approximately 12-14% of the initial egg weight until moment of hatching. **We normally check the moisture loss by weighing trays of eggs at setting and at 18 days of incubation,** and at that moment we want to have minimum 10% weight loss (moisture loss).

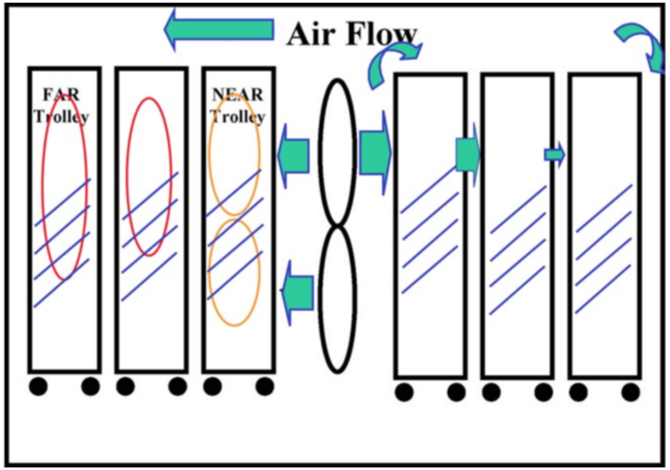
- **This moisture loss is a result of the resistance of the egg shell against gasses passing through the pores,** the so-called conductance of the egg shell, and the water vapor pressure deficit over the egg shell, the difference in water vapor pressure inside and outside of the egg. **Air velocity does not influence moisture loss.**

- The water vapor pressure is a result of temperature and RH and can be calculated/determined with the Mollier diagram. As the RH in the egg is approximately 100% and the temperature inside and outside of the egg is more or less constant, **we can influence the moisture loss by changing the RH of the air around the egg.**

- Evaporation of water costs energy, and therefor has a cooling effect. Eggs evaporate water to lose moisture, for an incubator of 100.000 eggs, on average about 1.7 l per hour, which results in an egg shell temperature slightly lower than the air temperature, a difference of about 0.1-0.2ºC.

- **As all the eggs contribute to this evaporation, the cooling effect is evenly distributed throughout the machine. This is not the case if the relative humidity is increased by spraying water.**

- If the RH in the machine is kept on a level that is higher than produced by water in the incoming air and evaporation of the eggs, the machine needs to spray to maintain that RH. That water needs to be evaporated and will have a cooling effect, but as not all the eggs in the machine will be equally contributing to that evaporation, local cooling can be the result. The more we spray and the more we ventilate, the more uneven the egg shell temperature in the machine might become. But in some machines, especially older ones, high levels of spraying and ventilation are needed to keep the temperature under control, as the cooling capacity is limited.



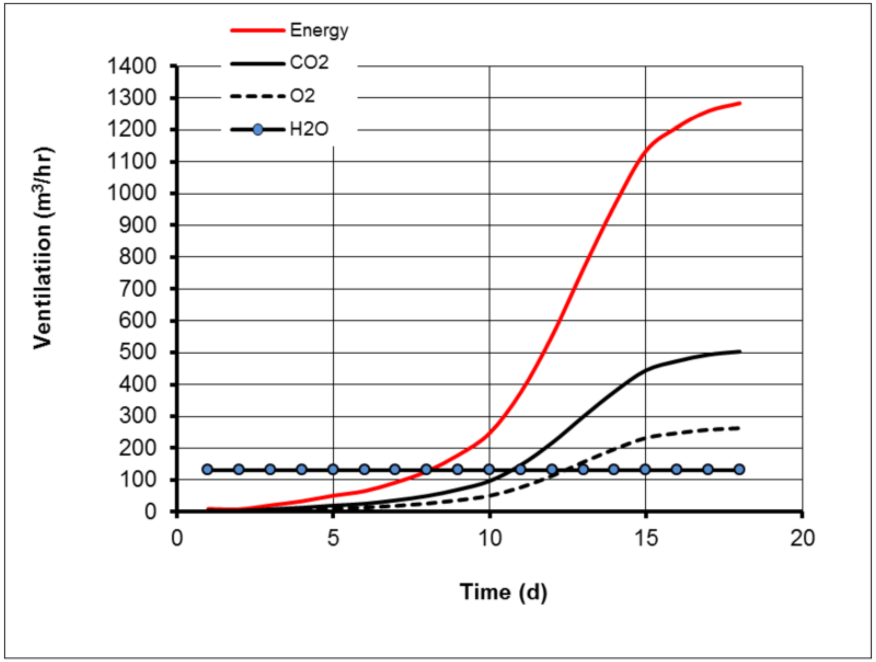
VENTILATION

Ventilation plays an important role in incubation, as it facilitates not only the exchange of O_2, CO_2 and humidity, but also can influence temperature. To get a good understanding of the requirement of ventilation, we need to take all these factors in consideration.

This means that **optimum ventilation is not equal for all machines, but depends on the factor that becomes limiting first.** If a machine has enough cooling capacity to keep the temperature under control and remove all the embryonic heat, the amount of ventilation that is needed will be dictated by the production of CO_2. We normally do not have to worry about controlling the O_2 level in a machine as the level of CO2 will be more limiting.

But **if a machine does not have enough cooling capacity we need to ventilate more to remove the excessive heat produced by the embryo's.** If we request the machine to keep a high level of RH, the machine will spray more, and with it the cooling will be even more effective due to evaporation of water.

In a ***single stage machine*** we have to calculate with the maximum embryonic mass at 18 days of incubation. If we would try to keep the CO_2 at a maximum of 4000 ppm in a single stage machine containing 100.000 eggs with living embryos, we need to ventilate approximately 500 m^3.



Graph: theoretical ventilation requirements during incubation in m^3/hr for a machine with 100.000 fertile eggs, based on ventilation required for heat removal (energy), carbon dioxide control, oxygen control and relative humidity control (Meijerhof and Lourens, 2018).

A machine with the same amount of eggs but in ***multi stage mode*** will produce a lot less CO_2 as the embryos are on average much smaller. If we calculate the average heat production in a multi stage machine and the resulting CO_2 production, a ventilation rate of less than 200 m^3 per hour would be sufficient.

In practice, multi stage machines often ventilate much more, as they do not have sufficient cooling capacity.

Similar calculations can be made for heat exchange and relative humidity as well, if we know the correct parameters and the underlying laws of physics.

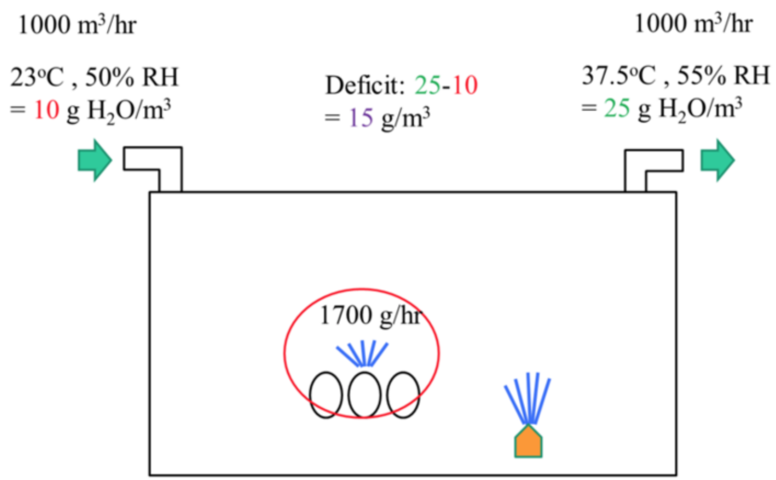
When we do the calculations, we can come up with a ventilation level dictated by each of the involved parameters.

If we only take heat out by ventilation and by the evaporation of the water loss of the eggs, we need to ventilate approximately 1300 m^3 of air per 100.000 eggs at 18 days of incubation.

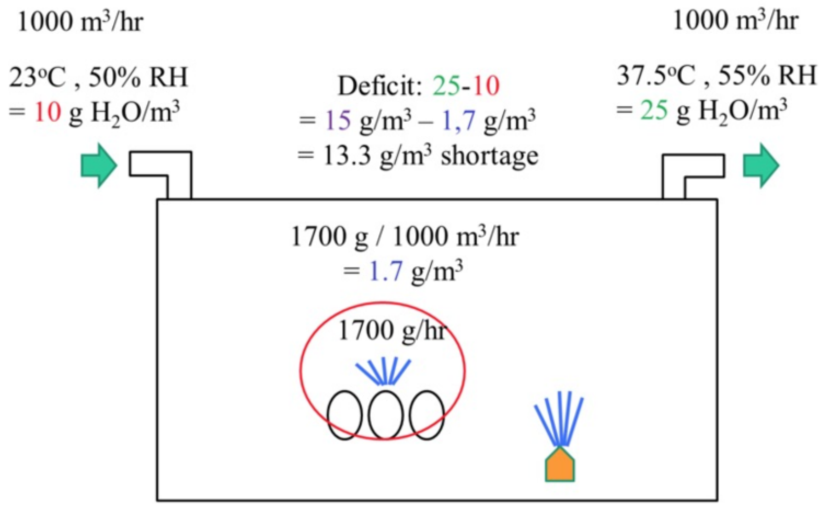
But this holds for a machine that has no additional cooling by cooling coils or by evaporation through the sprayers. If the machine would have sufficient cooling coils to take out the heat, the graph shows that than the first limiting factor is the level of CO_2 in the machine.

If we want to keep the level of CO_2 in the machine at 4000 ppm max, than we need to ventilate a little bit over 500 m^3 per hour for a machine of 100.000 eggs at 18 days of incubation. **We can also see that at this level of ventilation to control the CO_2, the O_2 will never become limiting.**

The level of RH is only limiting until approximately 8 days of incubation, if we want to keep a constant level of 55% RH in the machine. After 8 days, other factors as CO_2 and heat will dictate the level of ventilation. That means that if we want to keep a level of 55% RH in the machine after 8 days of incubation, the machine has to evaporate water to keep the humidity up. If we do not want to spray in the machine, the RH in the machine will go down as the CO_2 and later the heat production requires more ventilation than the control of RH will do.



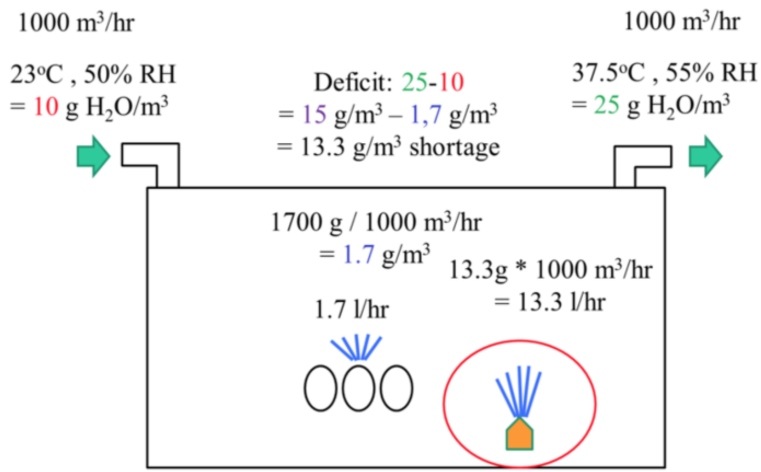
In the graph the ventilation for RH is represented as a straight line. **This is the result of the old system of having a constant RH throughout incubation, which means that ventilation is required until 8 days to control RH and that spraying is required in the second half of incubation to keep up the RH.**



In **single stage incubation** we use nowadays more often so-called **non-linear moisture loss:**

- By closing the machines at the beginning the RH goes up and the moisture loss goes down.
- At the end of incubation we have to open the ventilation because of CO_2 production, but if we keep the sprayers off the RH will drop and the total moisture loss will still be the required minimum of 10% at transfer (but more moisture will be lost at the end of incubation than at the beginning: non-linear).
- But because the sprayers do not need to be used at the end of the incubation, the machines will remain more constant in temperature.

This graph is based on assumptions on the condition of the incoming air, the fertility of the eggs and the conditions we want to create in the machine.



Fine tuning for specific conditions can be done for instance by using calculation programs as can be found on www.poultryperformanceplus.com or www.hatchability.com

Depending on the type of machine and the conditions, the actual ventilation will be determined by the first limiting factor.

Summary

Ventilation during incubation is a complex matter. However, **with a systematic approach of the situation and a basic understanding of the underlying physics, this complex matter can be brought back to basics.**

This will change it from a black box into a system that can be analyzed with a calculator or an excel sheet.

The complicating factor is that if we change one parameter, it can have an influence on other parts of the equation as well.

A good example is the CO_2 level, if we change the CO_2 level in the machine, we change the ventilation levels but with it also the relative humidity and the function of the sprayer, which as a result will change the temperature distribution in the machine. **It is therefore important to consider the interactions between the different parameters, to fully understand the logic of the system.**

FOR FURTHER INFORMATION

Lourens, A., R. Meijerhof, B. Kemp, H. van den Brand (2011) Energy partitioning during incubation and consequences for embryo temperature: A theoretical approach. Poultry Science 90 (2), 516-523

Meijerhof, R. and G. van Beek (1993) Mathematical Modelling of Temperature and Moisture Loss of Hatching Eggs. Journal of Theoretical Biology 165 (1), 27-41

Meijerhof R. and S. Lourens (2018). Ventilation during incubation is a complex matter. Poultry world magazine 14/2/2018

www.poultryperformanceplus.com

www.hatchability.com

Thank you!

Grupo de Comunicación Agrinews S.L.

*Avinguda de Jaume Recoder, 17, 08301 Mataró,
Barcelona (España)*

info@grupoagrinews.com

Tel: +34 93 115 44 15