Next generation design for the modern hatchery

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In a previous article entitled Circadian incubation – the next generation of modular single stage technology (International Hatchery Practice, Volume 24, Number 4), the effects of thermal stimulation on subsequent post hatch performance were discussed.

Research shows a positive and sustained effect on hatchability, robustness, final bodyweight and feed conversion ratios, when periodic temperature increases are administered during the last days of incubation (maturation phase).

This article discusses progress in the development of modular single-stage equipment for circadian incubation – equipment that supports the use of thermal stimulation for the production of uniform batches of robust, high quality chicks in the modern hatchery.

Temperature homogeneity

Thermal stimulation can only be applied in practice when incubation equipment delivers a homogeneous climate for uniform embryonic development. Only the smallest variations in temperature and therefore in heat transfer can be tolerated, which is largely determined by air temperature and velocity around the eggs.

For incubator manufacturers, the challenge today is to design incubators capable of supporting uniform, optimised embryonic development for each egg at every stage of its development.

This means providing every one of a very large number of eggs in a closely packed environment with an optimal airflow for uniform temperature distribution. Air must move freely around the eggs at all times.

This challenge is complicated by the trend towards larger capacity incubators.

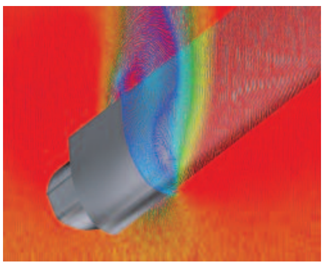
Because of increased heat production by modern embryos, it is more difficult to maintain homogeneity in egg shell temperature and air movement rates for each egg in such large incubators.

Fig. 1. Building a 3D simulation model of a separately controlled incubator section.

Further complications can arise as a result of airflow obstruction in the incubator. The even distribution of temperature and humidity within the incubator depends on the ease with which air can pass through the setter trays and over the surface of the eggshells. Poorly designed trolleys and trays can result in air passing around the mass of eggs, rather than passing evenly between them, which leads to non-homogeneous temperature distribution.

There are three additional sources of non-uniform air temperature in incubators:

Fig. 2. The most effective method of exchanging energy, carbon dioxide/oxygen and moisture in the incubator, is to generate as many vortices as possible of a specific dimension and intensity in the wake of the air pump blade (colours in Figs. 2-5 indicate difference of airspeed).



- The ambient temperature and relative humidity of inlet air usually differs from average temperature and relative humidity inside the machine, resulting in localised temperature and humidity variation at the point of intake.
- Both cooling and heating in the incubator generate localised temperature variations.
- The evaporation of water to control humidity levels for optimum egg weight loss can lead to temperature differences.

The challenge of modern incubator design is to exchange energy, carbon dioxide/oxygen and moisture without affecting homogeneous temperature around the eggs.

A redesign of the incubator can improve homogeneous temperature distribution, creating the ability to operate within the strict parameters required to successfully apply circadian incubation.

Application of CFD

Traditionally, new developments in the design of airflow systems have relied upon the actual, physical development of a prototype and in-practice testing: a lengthy and expensive process, limited by the number of practical situations and product alternatives that can be physically tested.

While looking at ways to optimise temperature uniformity, Pas Reform started to implement Computational Fluid Dynamics (CFD) to simulate the airflow and the heat transfer inside the incubator.

CFD is a scientific discipline, in which the flow and the heat transfer of any gaseous or liquid medium can be simulated within a virtual environment. It uses numerical algorithms to calculate airflow and temperature distribution, thereby

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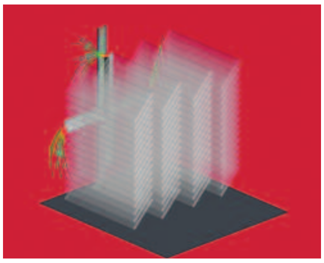

Fig. 3. The Vortex draws in an optimum amount of fresh air from the setter room and circulates it through each separate section of the incubator.

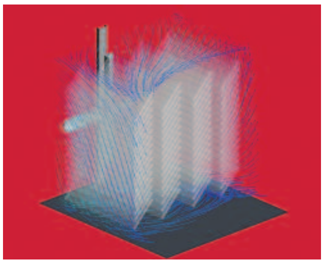

Fig. 4. The inlet air moves around the eggs along the side of the setter trolleys, to avoid ambient air from making contact directly with the eggs.

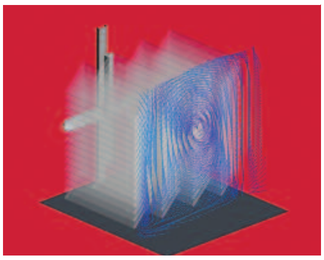

Fig. 5. The mixing zone minimises remaining variations in air temperature.

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allowing deeper insights into the internal physics of the incubator and other environmental factors.

Despite its proven accuracy and dependability in highly specific and demanding arenas, Pas Reform is the first to apply CFD for new product development in the hatchery sector. In its application of CFD for incubator design, the company worked in collaboration with FlowMotion, an engineering company that specialises in fluid dynamics for industrial applications, with a proven track record in food technology.

The application of CFD in product development can be separated into three phases: pre-processing, solving and post-processing:

- In the first phase, pre-processing, a 3D model of an incubator section is created. With a completed 3D model, the calculation region is divided into millions of small cells, for which the governing equations need to be solved numerically (see Fig. 1)

Boundary conditions are prescribed for all incubator surfaces, inlets, outlets and fans – all the areas that are instrumental in generating airflow and producing heat transfer, including the hatching eggs.

The design of the calculation grid and the definition of all boundary conditions are the most critical processes in CFD, because they have the largest influence on the viability and accuracy of results. This phase requires sophisticated expertise and experience in fluid dynamics.

- In the second phase of CFD, solving, the computer calculates governing equations for each grid cell. And there are millions of cells. This process can take anything from a couple of hours for a small number of cells, to a number of days for complex flows.
- The final phase of CFD is post-processing where the data produced in the previous two phases is visualised. Crucially, this is where the expertise of Pas Reform Academy's R&D team, with its detailed understanding of the needs of the growing embryo – joined forces with the expertise of FlowMotion to fulfil these needs in terms of aerodynamics, to analyse the huge amount of simulation data produced against the real world air flow requirements of modern incubators.

A new airflow principle

From conception, Pas Reform's Smart modular single stage incubators were designed to overcome the drawbacks of conventional incubation.

Smart's modular single stage design creates sectional environments, each with the capacity for up to 19,200 hen eggs. During incubation, each section climate can be individually controlled – the only way to guarantee homogeneous incubation temperature in incubators containing more than 100,000 eggs. Separate temperature, heating, cooling, humidification and ventilation systems in each section of the incubator provide a homogeneous environment around the incubating eggs.

Smart is a trusted system in hatcheries around the world. As an innovator in the hatchery industry, it was logical for Pas Reform to look for ways in which this established platform could be further improved, to fully maximise the benefits of homogeneous climate control for circadian incubation.

The application of CFD made it possible to gain valuable further insights into the airflow pattern and temperature distribution produced in each separate section of an incubator. With this data, the detailed investigation of various incubator designs became viable – and Pas Reform has focused its attention on a number of variations, including the number and shape of air pump blades, air inlet principles, section partitions, size of mixing zone, air pushing or pulling principles, trolley and tray design, heating, cooling and humidifying principles, air tightness and footprints.

After three years of intensive and varied flow simulation, Pas Reform has developed a fully optimised airflow and air redistribution system – with the following aerodynamics:

- **Air pump blade principle.**

The basis of the new airflow and air redistribution system is Pas Reform's 'Vortex', a newly designed air pump named after the vortical movement of airflow it produces (see Fig. 2).

With the intensive analysis of many different, simulated air pump blade shapes, it is clear that the most effective method of exchanging energy, carbon dioxide/oxygen and moisture in the incubator, is to generate as many vortices as possible of a specific dimension and intensity in the wake of the blade.

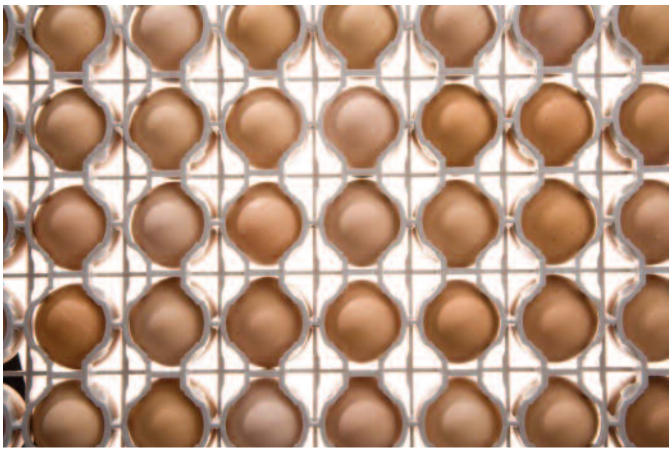
The shape of the air pump blades also positively influences the pumped flow rate of fresh air, the amount of torque required to achieve maximum temperature uniformity, the electrical power consumption of the system and the flow along the cooling/ heating elements of the incubator.

- **Air preparation principle.**

Through the inlet in the ceiling of each incubator section, the Vortex draws fresh air from the setter room, which flows through a vertical channel and through the hub and inner structure of the air pump blades, creating a radial pump for the air (see Fig. 3).

Fig. 6. Principle drawing showing how the Vortex pulls the mixed air in vortices through the setter trays and over the eggs.

Fig. 7. The redesigned setter tray allows the free movement of air vortices to reach every individual hatching egg.



Each separate section of the incubator is equipped with a Vortex, that circulates the 'fresh air' from the tip of its air pump blades to partitions on each side of the incubator section.

The partitions direct the air along the side of the setter trolleys, into the so-called 'mixing zone' of the incubator. The primary advantage of this flow pattern is that ambient air never makes contact with the eggs directly, so avoiding significant, localised changes in egg temperature (see Fig. 4).

- **Air mixing principle.**

Once the air has passed the trolleys, it reaches the 'mixing zone', where remaining variations in air temperature are minimised by mixing the air before it is drawn over the eggs. The size of this mixing zone is crucial for its impact on egg temperature homogeneity within each separate incubator section (see Fig. 5).

- **Exchange principle.**

The Vortex pulls the mixed air in vortical spirals through the egg trays and over the eggs, back towards the centre of the air pump (see Fig. 6). This has two significant advantages over conventional airflow systems. By pulling (instead of pushing) vortices over the eggs, the surface of the hatching egg is exposed for an optimum exchange of heat and humidity.

The specific flow direction along the eggs changes constantly, ensuring that uniform egg shell temperature is created and maintained for each egg throughout incubation.

Additionally, the vortices move in parallel with the turning direction of the setter trolleys, managing airflow such that it reaches the entire surface of the eggshells. This prevents the development of 'dead spots' where there is little air movement, to provide unique, homogeneous air distribution within each incubator section.

To further reduce obstruction by the setter trays, new tray design incorporates an open, spacious grid that prevents the development of dead spots and allows the free movement of air vortices through the trays, to reach each individual hatching egg (see Fig. 7).

When the vortices finally flow out of the trays, they reach the 'exchange zone' of the incubator section. Here the primary target of the fan is to exchange energy, carbon dioxide/oxygen levels and moisture, to condition the air before recirculation throughout the incubator section, for homogeneous egg temperature distribution.

The shape of the Vortex has explicitly been optimised to mix 'old' air coming from the incubator section with 'fresh' air from the tip of the vortex and the integrated heating/cooling of the incubator, by its specific vortices in the wake of the blade (see Fig. 8).

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The advancements in airflow design produce an environment that can be precisely controlled: a prerequisite for thermal stimulation – or the deployment of circadian incubation.

Maximising uniformity

Adaptive Metabolic Feedback (AMF) enables the control parameters of the incubation process to be adapted, according to the time-varying metabolism of a specific batch of embryos in the incubator. Ultimately AMF maximises uniformity, by optimising airflow and air redistribution such that circadian incubation can be applied.

Incubators must ventilate, to allow enough oxygen to come in and to allow the gases produced during the process of incubation to escape. The ventilation system controls the rate of air refreshment and, consequently, the level of carbon dioxide and relative humidity in the incubator. Carbon dioxide percentages and relative humidity increase when the valves are closed and ventilation is zero. Levels of carbon dioxide and relative humidity are strongly associated and should ideally be controlled simultaneously, with equal sensitivity.

The aspect of increased humidity is often neglected – despite the fact that increased levels of relative humidity in the incubator limit the evaporation of water from the eggs, decreasing egg weight loss and the effects of evaporative cooling. High levels of relative humidity have physical as well as physiological influences on embryo development.

The evaporation of water is a physical process that uses heat – and therefore the eggs lose heat during that process, also known as evaporative cooling. The continuous evaporation of water from the eggs during all stages of the incubation process – measured as egg weight loss – is essential for maintaining mineral balance in the different embryonic compartments at a physiological level.

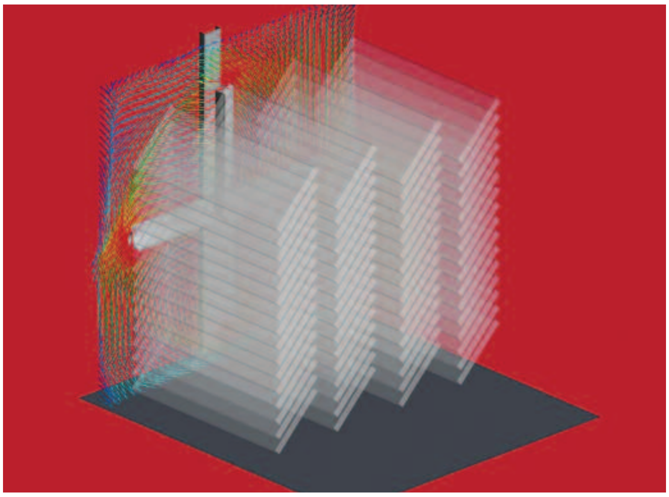

Fig. 8. The exchange zone conditions the air before recirculating throughout the incubator section, for homogeneous egg temperature distribution (colours indicate difference of airspeed).

In non-ventilated incubators, actual relative humidity rises above set points and as the incubator humidifiers are not in operation, cold spots are avoided. Embryo temperatures increase because evaporative cooling is limited as a result of increased moisture content in the incubator air. However, increased moisture content in the non-ventilated incubator limits egg weight loss, affecting embryo development to finally increase the risk of poor chick quality, bad navels and large yolk sacs.

The control of the moisture carbon dioxide couple in commercial incubators must therefore follow physical as well as physiological rules. It is important that the modern incubator has the ability to operate according to varied moisture carbon dioxide profiles, suited to local circumstances.

This knowledge formed the essential background for the development of Pas Reform's 'Adaptive Metabolic Feedback' system for ventilation.

Based on the actual metabolism of the incubating eggs in a commercial incubator, the uniquely adapted moisture – carbon dioxide couple determines the ventilation rate of the incubator, in line with the rate of development of the incubating eggs.

Because both moisture and carbon dioxide are monitored continuously against specific setpoints, AMF optimises incubation by minimising cold spots from ventilation and humidifiers, while simultaneously avoiding the excessive build-up of carbon dioxide. The fine control delivered by AMF ensures that the natural evaporation of water from the eggs is unaffected, while the incubator meets the time varying needs of the growing embryo in its different stages throughout the cycle.

Adaptive Metabolic Feedback achieves this continuous control over both recirculated and fresh air by listening to the embryo's metabolism, as reflected in the production of moisture and carbon dioxide. In this way energy, carbon dioxide/oxygen and moisture are exchanged without affecting the incubator's homogeneous temperature.

Conclusions

Since the circadian incubation principle greatly challenges the incubator's homogeneity, new design concepts are needed to further improve homogeneous temperature distribution. Three years of intensive (flow) simulations and empirical field studies have shown that the combination of a modular incubator design, a new airflow principle based on the creation of vortices and Adaptive Metabolic Feedback, produce the highly precise environmental controls that are a prerequisite to the successful use of thermal stimulation.

The combined use of these three components makes it possible to exchange energy, carbon dioxide/oxygen and humidity without affecting homogeneous temperature around the eggs. This delivers significant advantages for the modern hatchery, including homogeneous egg temperature distribution in the maturation phase of incubation.

Short, accurate increases in temperature for each of the embryos is possible, to deliver the benefits of circadian incubation on hatchability, robustness, final bodyweight and feed conversion ratios. ■