JAMESWAY
The Incubator Company

Whitepaper

Why single-stage poultry incubation will gradually take the upper hand

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Contents

1. Introduction

In the 1990s, single-stage incubators re-emerged in the poultry industry as a promising alternative to the widespread use of multi-stage systems. Incubator producers offering single-stage systems encourage hatcheries to make the transition to single-stage in order to increase productivity and profitability. However, most incubator producers still offer both solutions, since preferences differ among customers. Indeed, according to Agri Stats[i], a substantial majority of the poultry industry in North America still uses multi-stage systems and intends to continue doing so, despite the reported benefits such as hatch rates, hatch window reduction and post hatch chick quality improvements for single-stage systems.

This whitepaper discusses the differences between multi-stage and single-stage systems and provides accurate information on the advantages and drawbacks of both systems. We put the single-stage versus multi-stage dilemma in a historic perspective and discuss known reasons for hatcheries to choose one or the other technology. In addition, we highlight recent trends in single-stage incubator design that are meant to promote transition. Our conclusion is that single-stage will gradually take the upper hand as incubator producers succeed in facilitating the transition process.

2. History of poultry incubation systems

2.1. Early 1900s to 1950s: single-stage incubation

While single-stage incubation was presented to the poultry industry in the 1990s as a novel technology, the technique was hardly new. In fact, single-stage incubation was in general use prior to the 1950s and well before the advent of multi-stage systems as we know them today[ii]. In the early days of poultry industrialization, single-stage incubation seemed to be the most straightforward method. It meant fully loading the machine with batches of fresh fertile eggs and carefully controlling temperature and humidity throughout the 18 days incubation period.

However, these early to mid-20th century single-stage machines were not quite as efficient as one might have hoped. They were controlled by mercury filled thermostats or a mechanical means of managing temperature. Most of them used electric heat (which was highly inefficient at the time) and were rather expensive to operate.

Operating costs were especially high in the initial stages of the incubation cycle when the incubator had to be heated for the embryos to develop (endothermic phase). In contrast, the machine had to be cooled down in the last stages of the development cycle when the developing chicks produce excess heat (exothermic phase).

2.2. Mid 1950s to 1990s: multi-stage incubation

Multi-stage systems were a step forward in many respects. The idea for multi-stage systems stems from the American inventor and writer Milo Hastings (1884-1957) who, in the early 20th century, envisioned a ‘million egg incubator’ and reflected on the challenge of maintaining the correct temperature and humidity in such a huge machine[iii].

One of his innovations was to load/unload his machines several times during the three week incubation cycle, experimenting with various schemes. This meant that the incubator would always contain both eggs requiring heat and eggs producing heat. Hastings built several large-scale incubator prototypes but none of them were a commercial success.

However, his ideas were taken up again in the 1950s when the poultry industry faced a rapidly increasing demand for poultry meat. The largest single-stage machines of the time had a capacity of around 10,000 eggs[iv]. Hastings' concept offered the possibility of building incubators of capacities well above 50,000[v] while at the same time keeping energy consumption under control.

Technological advances also enabled incubator producers to more carefully control temperature and humidity values and to simplify machine operation; hence the large-scale commercial breakthrough of these systems by the end of the 1950s.

2.3. 1990's to present day: both multi-stage and single-stage incubation

At the end of the 1980s, the continuous search for improving performance and further technological advances resulted in a renewed interest in the single-stage technique. Indeed, extensive research dramatically improved our knowledge of the incubation process and the optimal environmental parameters for each breed according to the needs of embryos at each stage of the development cycle.

Since multi-stage systems always contain eggs at different development stages, the incubator environment (including temperature, humidity and CO_2 level) must be 'averaged'. In this respect, the single-stage technique clearly offers more opportunities to optimize the environment, which is further facilitated by advances in energy-efficient heating and cooling, electronics, instrumentation and control, and digital systems.

As a result, large-scale single-stage systems entered the market in the 1990s and won a considerable market share. However, the multi-stage technique continues to attract poultry producers and hatchery managers. Both techniques are currently in use.

3. Single-stage versus multi-stage: a comparison

3.1. System operation and management

Due to the fact that single-stage and multi-stage systems have fundamentally different loads (homogeneous versus heterogeneous), the systems must be managed in an entirely different fashion.

3.1.1. Loading/unloading

Multi-stage incubators are typically loaded/unloaded twice a week, depending on the scheme[vi]. While the ready-for-hatch eggs are taken out of the incubator, an equal number of fresh fertile eggs are loaded into the machine. This is done by swapping trays (fixed-rack machines) or entire racks; the latter involving moving the remaining racks further downstream. In single-stage incubators, however, all eggs are loaded at day zero and unloaded at day 18.

3.1.2. Production planning and organization

The different loading/unloading schemes have a profound impact on the production planning of the entire hatchery and hence on the daily responsibilities of the hatchery manager. While single-stage systems have a long production cycle of eighteen days, multi-stage systems produce ready-for-hatch eggs and accept fresh fertile eggs twice weekly. This means that multi-stage systems generally require a more intensive scheduling of activities, including the egg supply process and the hatching process. In addition, multi-stage systems require greater tracking and tracing administration to meet food safety regulations.

3.1.3. Controlling the incubation parameters

Each type of system takes an entirely different approach to controlling incubation parameters.

3.1.3.1. Environment control in multi-stage systems

Environmental control in **multi-stage** systems relies in part on a natural temperature exchange between eggs requiring heat (first stages of development or endothermic phase) and eggs producing heat (last stages of development or exothermic phase). During the entire cycle, the machine is controlled (heated, cooled and ventilated) in such a way that first phase eggs are heated to approximately 100 °F (37.7 °C)[vii] and the egg temperature of last stage eggs is prevented from rising above 101 °F (38.33 °C) to avoid late embryonic mortality.

This involves, among other things, air flowing through the machine from the late-stage eggs to the fresh eggs in order to maintain a uniform temperature distribution. Nevertheless, egg temperature differences up to 2 °C (depending on the type of strains) are unavoidable. This can lead to significant differences in the development of embryos and increased mortality rates.

Meanwhile, air composition parameters such as humidity and CO_2 concentration are kept within acceptable limits for all eggs. For example: the relative humidity in multi-stage incubators is set to an indicative average of between 58% and 60%, depending on standards. Ventilation is constant in a range between 2.5 and 4.0 ft^3/minute/1, 000 eggs (0.07 to 0.11 m^3/minute/1, 000 eggs, depending on the manufacturer) so that the volume of CO_2 does not exceed 0.4% and proper air temperatures are maintained. In other words: the incubation environment in multi-stage systems is a compromise since it must simultaneously **address the needs of each of the varying stages of embryonic development** present in the machine.

It is also important to note that environment control in multi-stage systems is **disturbed during each loading/unloading activity** and that thorough cleaning is not possible in a multi-stage incubator unless it is shut down and completely emptied. As a result, there is a higher risk of contamination (see also 3.1.4 below). Furthermore, the typical temperature-exchange mechanism in multi-stage systems has its drawbacks regarding hygiene and food safety. Indeed, the eggs in the advanced development stage not only produce heat but are also a source of micro-organisms such as fungi and bacteria. These micro-organisms can contaminate the newly set eggs and may contribute to lower performance and higher embryo or chick mortality.

3.1.3.2. Environment control in single-stage systems

The environment in **single-stage** systems is controlled in such a way that temperature, humidity and CO_2 level are **always perfectly adapted to the needs of the embryos at a given embryonic development stage**.

A target egg temperature profile is defined for the entire cycle, for example 100 °F (37.7 °C) during the first two days, then 99.5 °F (37.5 °C) until day 12, then gradually decreasing by 0.1 °C per day until hatching. The heating/cooling equipment is controlled to precisely follow that profile, in some cases supported by an array of sensors placed between eggs. Heating is required in the first stages of the cycle while cooling is necessary in the last stages of the cycle. At each moment, a uniform temperature is maintained inside the machine.

Furthermore, incubator humidity is varied throughout the cycle. In Jamesway single-stage systems, for example, the damper is closed in the first half of the incubation cycle, resulting in high humidity levels (70-75%) but also in a very stable and uniform temperature distribution. Over the second half of the cycle (once the heart is functional and blood circulation takes over), incubator humidity levels may drop as low as 20 to 30% to ensure the necessary embryo water loss. In addition, CO_2 levels are varied throughout the cycle based on studies[viii] indicating the positive effect of increased CO_2 concentrations during incubation.

The only serious drawback of single-stage systems is the **higher energy cost** due to the fact that the incubator must be heated during the initial stages of incubation. However, heat recovery and energy savings systems help to minimize this cost as well.

3.1.3.3. Ease of monitoring and control

Monitoring and control is a highly sophisticated process in both multi-stage and single-stage systems. However, there is a fundamental difference in day to day operation.

Single-stage systems require intervention only when finishing a cycle and starting up a new one. The manipulations to be done at that time are quite straightforward: stopping the incubation process, transferring all eggs to the hatcher, cleaning the machine, loading fresh eggs and restarting the normal incubation process. During the cycle, the system runs pretty much in automatic mode, following the profiles and parameters defined at start-up. In normal circumstances, no manual interventions are required.

Multi-stage systems require manual intervention at least every week and the manipulations to be done are a little bit more complex and error-prone. These include interrupting the incubation process, transferring part of the eggs to the hatcher, moving trolleys downstream, cleaning part of the incubator, performing basic housekeeping activities in accessible areas, and resuming the incubation process. This means that multi-stage systems more strongly depend on operators being familiar with and strictly adhering to operational procedures. As a consequence, more people may be needed to operate the system and the required training program may be more intense.

3.1.4. Cleaning, disinfecting and maintenance

The organization of cleaning and disinfecting are fundamentally different between single-stage and multi-stage incubators. Single-stage machines are cleaned and disinfected entirely after unloading every eighteen days. Likewise, maintenance activities can be easily scheduled to take place at the end of a cycle.

This is not possible with multi-stage machines, since they are rarely completely empty. Therefore, multi-stage systems require specific cleaning and maintenance programs. For example, various cleaning and maintenance strategies have been developed at Jamesway multi-stage hatcheries. Some hatcheries vacuum clean once a week at the entrance and exit end and under racks of the Jamesway tunnel machine, performing a scheduled comprehensive cleaning and maintenance program perhaps once a year during a production standstill.

Other Jamesway hatcheries have set up a routine where they raise the room temperature in the hall, temporarily remove the racks from the incubator to sit in the hall while a team cleans and sanitizes the machine. Another possibility is to temporarily place the racks into the exit end of several other machines during the cleaning and/or maintenance activities. It is important to note that this kind of procedures is not possible with fixed rack machines. These machines are generally very difficult to clean and usually require a complete shutdown for cleaning and maintenance.

3.2. Output differences

While it is far from easy to compare the productivity of current or legacy multi-stage systems with new generation single-stage systems, several studies and benchmarks have been carried out to assess the output differences between both systems. In the following paragraphs, we summarize the outcomes of these studies and benchmarks.

3.2.1. Hatchability and livability

Hatchability rates are generally higher in single-stage systems compared to multi-stage systems. A comprehensive analysis of results from hatches of identical flocks incubated in Jamesway single-stage or multi-stage machines[ix] showed the following differences:

	Single-stage	**Multi-stage**	**Single-stage benefit**
Hatchability	86.60 %	84.01 %	2.59 %
Hatch of Fertile	93.78 %	90.98 %	2.80 %
1st grade chicks	85.92 %	83.23 %	2.69 %

The higher hatchability rates in single-stage incubation are attributed to the more even temperature distribution and the more precise control of temperature and CO_2 level, which can be tuned to meet the requirements of the embryos at each stage of development. Benchmarks between machines of different manufacturers showed similar results.

Livability rates generally are also higher in single-stage incubation. The above-mentioned analysis also compared first week mortality rates and grow out results of the chicks, showing the following differences:

	Single-stage	Multi-stage	Single-stage benefit
7-day mortality	0.770 %	0.945 %	0.175 %
Livability	95.79 %	94.20 %	1.59%

3.2.2. Weight, rate of growth and feed conversion

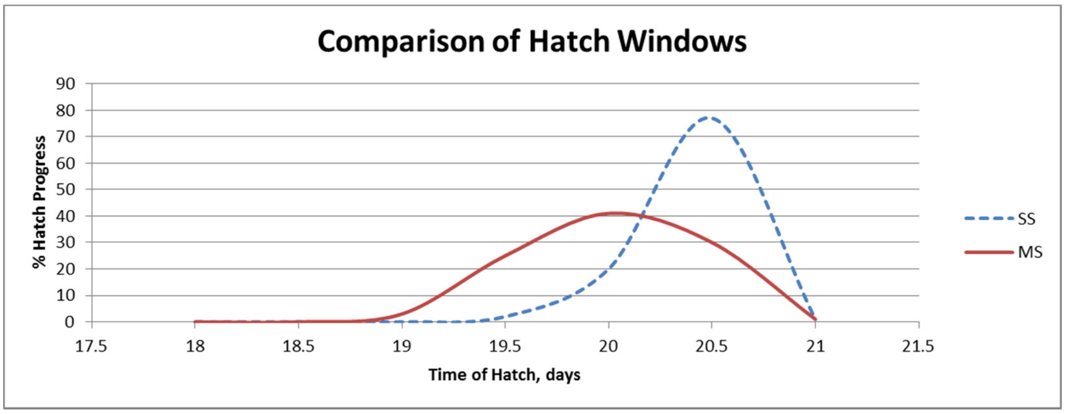
Similar differences occur in the average weight of the new born chicks, confirming the observation that the single-stage chicks are generally healthier. This is further confirmed by data showing the average weight of the chickens at processing time.

	Single-stage	Multi-stage	Single-stage benefit
Average chick weight	44.84 g	43.63 g	1.21 g
Average chicken weight	6.05 lbs / 2.74 kg	5.92 lbs / 2.69 kg	0.13 lbs / 0.59 kg
Avg. daily gain	59.9 g/day	59.1 g/day	0.8 g/day

From an economic point of view, this means that single-stage offers a lower feed conversion ratio (1.894 versus 1.951) and thus more meat.

3.2.3. Uniformity of incubation and efficiency of hatch

The precise environmental control of single-stage systems also leads to a more uniform incubation of eggs, resulting in a shorter hatch-window. While the hatching of a batch of multi-stage incubated eggs typically lasts around 50 hours, this can be significantly reduced in the case of single-stage incubation.



3.2.4. Return on investment

Jamesway estimates that switching from multi-stage to single-stage means increasing productivity by 3 to 5%, depending on the age and type of the multi-stage machines. The table below summarizes what this may mean for an average US hatchery, **assuming a 4.18% increase**[x] in hatches and weight to market.

Average US hatchery with an egg supply of 1,000,000 eggs per week	
4.18 x 1,000,000	41,800 more birds per week going to market
41,800 x 6 lbs (average weight of bird)	250,800 lbs more meat marketed per week
250,800 x 0.95 (US $ per pound)	$ 238,260 more revenue per week
238,260 x 0.10 (10% profit)	$ 23,826 more profit per week
23,826 x 52 (weeks per year)	$ 1,238,952 more profit per year

An investment in new single-stage equipment for this hatchery is estimated around $ 3,000,000. This would mean a return on investment in less than three years, except for possible additional expenses to make the transition (see also 4 below).

3.2.5. Conclusion

Single-stage incubators generally outperform multi-stage systems in most respects. While they generally consume more energy, they clearly produce more and healthier chicks, eventually leading to more salable chicken meat.

4. Obstacles that prevent hatcheries from making the transition

Despite the obvious advantages of the single-stage incubation technique, multi-stage incubation is still currently favored by many hatcheries around the world. There are several reasons for this:

- **Slow replacement rates**—Hatchery equipment, if properly maintained, lasts for a long time. The typical productive lifetime of an incubator installation is around 30 to 40 years and sometimes reaches to 50 years. Potential productivity increases by 3 to 5% are not likely to accelerate replacement.
- **Additional investments**—Replacing an incubator installation with a new system (often from another manufacturer) may not only mean investing in the new machine but also in bricks and mortar. Indeed, the new machine will most likely have an entirely different footprint than the legacy system. In addition, to change to another machine often means to change to another type of egg flat, requiring the investment in new support equipment, farm racks, and handling equipment. It is for this reason that many hatcheries decide to invest in a replacement system produced by the same manufacturer and employing the same technology rather than switch supplier and make the transition to single-stage. It is estimated that a new hatchery complete with bricks and mortar and support equipment is an investment five times as large as the cost of new incubator equipment alone.

- **Organizational changes**—Making the transition towards single-stage means reorganizing operations. Although this can be seen as an opportunity to make the organization more efficient, quite a number of hatcheries are reluctant to change, especially when other organizational entities are impacted by the decision (egg supply, availability of a pool of trained personnel, et cetera). In addition, organizational efficiency may not be a primary concern in countries with low labor costs.

5. Evolution in single-stage systems to facilitate the transition

Large investment costs and organizational considerations tend to retain hatcheries from making the transition to modern single-stage incubation, even when current equipment has reached end-of-life. Unfortunately, this can lead to overly conservative investment decisions that deprive the organization of the quality and productivity benefits of these new systems for years and indeed decades. That's why single-stage incubator manufacturers increasingly focus on facilitating such a transition. New solutions include:

- **Matching footprints**—Incubator producers develop single-stage systems with the same physical footprint as legacy multi-stage systems, either from their own brand or from competitors. For example, Jamesway recently launched its P105 single-stage incubator. This machine measures 12' x 22', which matches the footprint of competitor Chickmaster's multi-stage system within 1 inch. As a result, switching from Chickmaster MS to Jamesway P105 is perfectly possible without changing building infrastructure.
- **Matching equipment**—Incubator producers develop single-stage systems that accept egg flats, trolleys and/or racks from a competitor's legacy multi-stage machine. For example, Jamesway's P105 incubator accepts Chickmaster style 54-egg and 165-egg flats in addition to the Jamesway style 84-egg flats.

It is clear that these new developments aim at markets currently occupied by legacy multi-stage machines that are likely to reach end-of-life within ten or fifteen years from now. It is expected that incubator manufacturers targeting these markets will be increasingly successful, especially when they also offer excellent support and services for these new machines, including fast installation routines, easy access to spare parts, and transition training programs[xi].

6. Conclusion

Today the majority of hatcheries still run on multi-stage equipment, being the system of preference of quite a number of poultry producers and hatchery managers despite the improved profitability and clear advantages that the second generation of single-stage systems brings to an operation. Single-stage incubators are easier to operate, have lower manpower requirements, generally show higher hatchability and livability rates and eventually produce more meat.

The transition from multi-stage to single-stage is clearly hampered by the high costs involved with a technology switch. However, incubator producers increasingly facilitate the transition by offering single-stage systems that match the footprint of legacy multi-stage systems and accept legacy egg trays and trolleys. While this will not mean the death of multi-stage systems in the short term, it will no doubt allow single-stage systems to gradually take the upper hand as incubator producers succeed in facilitating the transition process.

[i] Agri Stats Inc., www.agristats.com

[ii] In fact, the history of artificial incubation goes back to ancient Egypt, see CEVA Sante Animale, Artificial Incubation of Poultry Eggs – 3,000 years of history, http://www.thepoultrysite.com/focus/contents/ceva/OnlineBulletins/ob_2005/Article-No2-Sept05.pdf

[iii] Wikipedia: http://en.wikipedia.org/wiki/Milo_Hastings

[iv] The Jamesway 1080 machine was one of the largest first-generation single-stage incubators on the market with a capacity of 10,800 eggs. It was patented in 1952.

[v] In 1964, Jamesway patented a multi-stage machine with a capacity of 77,740 eggs.

[vi] The loading/unloading depends on the number of machines and throughput. Small facilities get by with hatching twice a week while large hatcheries will hatch up to six times week. In some instances the limiting factor may be the size of processing rooms which may not have expanded as machines were added.

[vii] CEVA Sante Animale, Hatchery Expertise Online, Multiple stage / Single stage systems of incubation – advantages and drawbacks. (http://www.thepoultrysite.com/focus/contents/ceva/OnlineBulletins/ob_2009/Article-No22-Jan09.pdf)

[viii] Laurentiu Cârlea, Vasile Miclea, Marius Zahan, Study on the Influence of Carbon Dioxide on Embryonic Development in Chickens, University of Agricultural Sciences and Veterinary Medicine, Faculty of Animal Science and Biotechnologies (http://journals.usamvcluj.ro/index.php/zootehnie/article/view/5260).

[ix] The analysis is based on comprehensive data from hatches between 1 March and 30 June 2009 at farms using either single-stage or multi-stage incubators from manufacturer Jamesway. These results have been confirmed by more recent benchmarks and small-scale analyses.

[x] Based on the above-mentioned benchmark with 2.59% more hatch and 1.59% more livability.

[xi] For example, Jamesway strongly emphasizes the quality of their service in the campaign for the P105 single-stage machine.