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Improved Use of the Fluidized Bed Dryer for *Artemia* Cysts

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ABSTRACT

A fluidized bed dryer for processing Artemia *cysts at temperatures above 40°C is described and evaluated. The design is directed towards electronic temperature regulation and optimal design of the drying unit. The described fluidized bed dryer proves to be reliable for cyst processing, using inflow air temperatures up to 90°C. The use of this elevated temperature ensures a higher drying rate, resulting in a drying capacity more than 4 times higher than when using inflow air of 40°C. Electronic temperature regulation resulted in a large flexibility of the temperature regime inside the drying unit.*

INTRODUCTION

Proper processing and drying of *Artemia* cysts is of crucial importance to obtain a storable product with maximal hatching quality. The different processing steps of cleaning, dehydration and packaging of the cysts have been described in detail by Voronov (1974), Rakowicz (personal communications) and Sorgeloos *et al.* (1986). With regard to dehydration of the cysts, the drying rate, drying temperature and the final water content of the cysts appear to be the most important factors affecting the hatching quality of the cysts.

Godeluck (1980), Vanhaecke and Sorgeloos (1982) and Vanhaecke (1983) investigated different drying methods and showed that the drying rate has a significant effect on the hatching quality of the cysts. A slow drying resulted in decreased hatching efficiencies as well as in a delay of hatching after storing the cysts for more than 1 month.

Sorgeloos *et al.* (1986) recommended 35–40°C as the optimal drying temperature for cysts. They cautioned against higher drying temperatures because these have been shown to cause mortality at least in fully hydrated cysts (Voronov, 1974; Versichele and Sorgeloos, 1980). Miller and McLennan (1988) observed considerable mortality in hydrated cysts when these were exposed to temperatures above 48°C.

For numerous strains sufficient dehydration is an efficient way to interrupt diapause in dormant cysts (Dutrieu, 1960; Versichele and Sorgeloos, 1980; Lavens and Sorgeloos, 1987). Furthermore it is indispensable to assure long-term storability of the resulting quiescent cysts. Versichele and Sorgeloos (1980) suggested that diapause may be inhibited when cysts are dehydrated to a water level below 20%. Although there are no reports on the optimal water content in stored cysts, several authors observed a slow decrease in the viability of cysts containing more than 10% of water (Vanhaecke, 1983; Sorgeloos *et al.*, 1986; Lavens and Sorgeloos, 1987). Similarly Clegg and Cavagnaro (1976) detected a drop in the ATP concentrations of cysts containing 9·1% water. Below a water content of 4·8% no net change in ATP occurred.

Traditional drying methods such as air drying and oven drying have often proven to yield cyst products with a suboptimal hatching quality and shelf life because of slow, heterogeneous and insufficient dehydration or even uncontrolled rehydration of cysts. In addition, such traditional systems have a limited processing capacity and present upscaling difficulties due to their poor drying efficiency.

Vanhaecke and Sorgeloos (1982) described an experimental fluidized bed dryer that consisted of a vertical cylindrical tube in which the cysts are dried in a continuous air-stream generated by an air ring compressor (blower). This system provided a fast and homogeneous drying, however with limited capacities: a maximum of 20 g of cysts can be dried in 2 hr (Vanhaecke, 1983). The cylindrical drying chamber, while ensuring adequate lifting of hydrated cysts at the beginning of the drying process, caused rapid clogging of the sieve connected to the top of the cylinder when cysts become progressively dehydrated, eventually creating a reduced air-flow and suboptimal drying efficiency. In this system the temperature was kept at 38–40°C during the entire drying process.

Considering the temperature reduction inside a fluidized bed dryer caused by the evaporation of water from the wet cysts, and in view of the observation that partially dehydrated cysts are much more resistant to temperatures exceeding 40°C (Hinton, 1954; Voronov,

1974), the use of a fluidized bed dryer with inflow air temperature above 40°C could be considered in order to optimize the drying capacity.

In the present study a new fluidized bed dryer is proposed that is designed to process about 20 kg of crude cysts in less than 3 hr. Compared to other experimental fluidized bed dryers the present system aims at the optimization of the capacity and drying rate through the use of heated inflowing air, electronic temperature regulation and a more optimal design of the drying unit. Experiments have been conducted to assess the effects of different temperature regimes on the drying capacity, drying rate and hatching quality of the cysts.

MATERIALS AND METHODS

The fluidized bed dryer, outlined in Fig. 1, consists of a conically shaped drying unit fixed in a metal support, a heating unit, an air ring compressor and an electronic heating control unit. The air ring

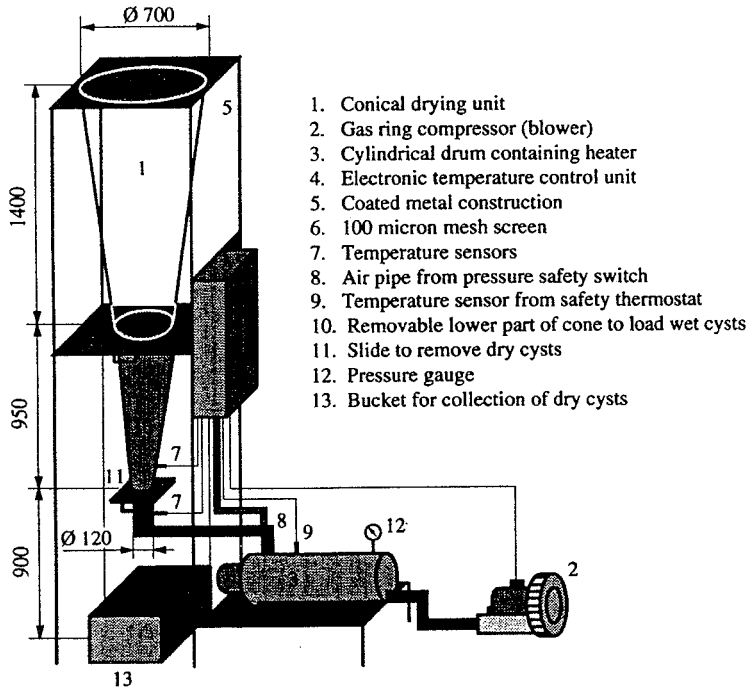

Fig. 1. Scheme of fluidized bed cyst dryer.

compressor blows heated air into the conical drying chamber at a flow rate of 310 m^3/hr at 0 mbar gauge and 240 m^3/hr at 100 mbar gauge. The heating unit, basically a cylindrical galvanized steel drum including a 6 kW resistance, permits a temperature increase from 20°C (ambient temperature) to 90°C at a flow rate of approximatively 260 m^3/hr. A fine mesh screen (100 μm) at the top and the bottom of the drying unit permits free air flow without dissipation of air-suspended (fluidized) cysts. The diameter of the top and bottom of the drying unit measures 70 and 12 cm, respectively. The total height of the cone is 2·35 m. The upper part of the drying unit is constructed in transparent polymethylmethacrylate (PMMA) to enable visual inspection of the drying process. The lower part of the cone, constructed in polypropylene (PP), can be removed to load wet cysts. Temperature regimes, including both inlet air temperature and temperature inside the drying unit, are electronically controlled. Two temperature sensors, one fixed inside the drying unit 10 cm above the lower screen, the other one fixed below the lower screen, are connected to a PID controller. The PID controller compares the actual temperature with the pre-set temperature and regulates the electrical output of the heating element by the so called pulse-pause control (i.e. modulation of the on/off time) of a triac (solid-state power switch). The use of a PID-triac temperature control thus permits a very precise temperature regulation. Two built-in securities avoid overheating of the system, i.e. in case of a blower failure a differential pressure switch connected to the air duct detects the pressure drop and activates a switch to interrupt the electric current of the heating unit. Furthermore, a thermostat set at 100°C prevents overheating of the resistance in case of failure of the electronic regulation.

Four drying experiments were conducted with commercial *Artemia* Great Salt Lake cysts (EG-type, INVE Aquaculture, Baasrode, Belgium) which were rehydrated to a water level of 50–55%. For this, dry cysts were soaked in freshwater for 20 min and subsequently centrifuged for removal of excess water. In the first experiment the inlet air temperature was set at 40°C to simulate temperature conditions as used and recommended by other authors (Versichele and Sorgeloos, 1980; Vanhaecke, 1983; Sorgeloos *et al.*, 1986). In the second and third drying experiment, the inlet air temperature was set at 90°C and eventually adjusted by the PID controller not to exceed temperatures inside the dryer of 40 and 50°C, respectively. In the fourth experiment, the inlet air temperature was set at 80°C, while the temperature inside the dryer was allowed to rise to a maximum of

50°C. For each experiment 21·5 kg of hydrated cysts were processed with the fluidized bed dryer.

During the drying process samples were taken at 30–60 min intervals to determine the water content of the cysts, according to the procedures of Sorgeloos *et al.* (1986).

Inlet air temperatures and exhaust air temperatures were monitored during the drying process. In the second drying experiment the temperature inside the dryer (10 cm above the lower screen) was compared with the exhaust air temperature by an additional temperature control.

Samples of dry cysts produced in experiments 2 and 3 were stored under nitrogen and then used for determination of hatching percentage after 24 and 48 hr of incubation in seawater as described by Sorgeloos *et al.* (1986). Oven-dried cysts (4 hr at 38°C, layer thickness 1 mm) served as a control. Hatching percentages of dry cysts were analysed for statistical differences by Student's *t*-test.

RESULTS

Figure 2 shows the course of inlet and exhaust air temperature for drying experiments 2–4. The inflow air temperature increased rapidly to the pre-set value of 80 or 90°C and then stabilized with virtually no fluctuations until the exhaust air temperature reached the pre-set limit of 40 or 50°C. Consequently the inlet air temperature decreased gradually to level off the temperature in the dryer. The temperature measured inside the cone during experiment 2 was virtually identical to the exhaust air temperature (results not presented). Despite the high inlet air temperature, the exhaust air temperature increased rather slowly. Working with inflow air temperatures of 80°C, 100 and

TABLE 1
Temperature settings in fluidized bed cyst drying experiments

Experiment	*Inlet air temperature (°C)*	*Temperature inside dryer (°C)*
1	40	—
2	90	40
3	90	50
4	80	50

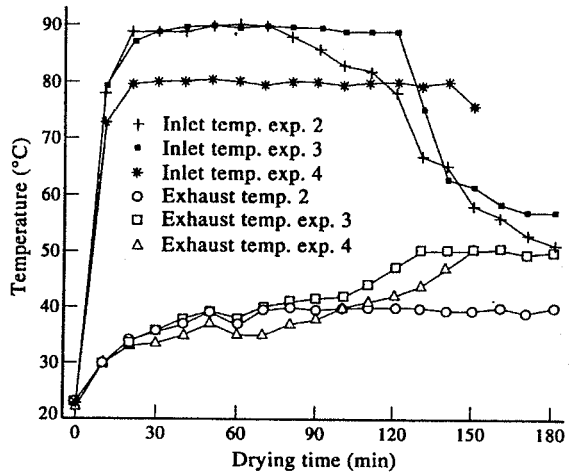

Fig. 2. Inlet and exhaust air temperatures during drying in fluidized bed dryer experiments 2–4

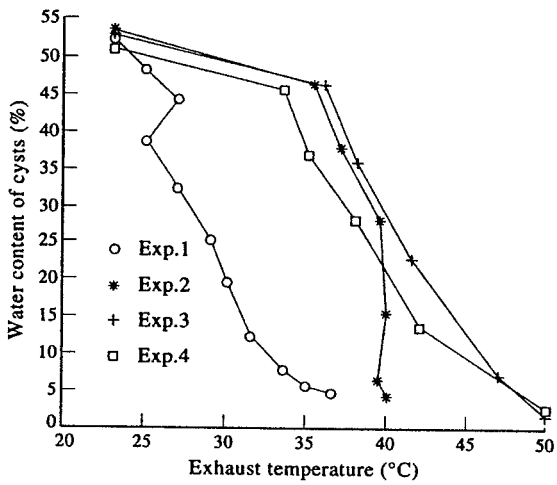

Fig. 3. The water content of cysts in function of the exhaust temperature of the drying unit during the drying process.

150 min were required to reach exhaust air temperatures of 40 and 50°C, respectively; at inflow air temperatures of 90°C these exhaust temperatures were obtained about 20 min faster. In any of the drying experiments, temperatures of 40°C inside the dryer were only exceeded once the cysts had attained a water content of less than 30% (Fig. 3). As could be expected however, the relation between exhaust temperature and water content of the cysts depends on the

inlet temperature, i.e. a higher inlet temperature resulted in a higher water content of the cysts for the same cone temperature (Fig. 3). For example, at a cone temperature of 42°C, the water content of the cysts dried in experiments 3 (90°C) and 4 (80°C) was 22 and 15%, respectively.

As compared to experiment 1 where cysts were dried at 40°C (inlet air temperature), the drying time required to obtain a cyst water content of 5% (595 min) was reduced by almost 80% when using the highest temperature regime (experiment 3: 135 min; Fig. 4). Decreasing the temperature inside the drying unit (experiment 2) or the inlet temperature (experiment 4) prolonged the drying time. The need for extra heating (experiment 2 to experiment 4) did not increase the energy consumption required to dry the cysts to a water content of 5% (Table 2).

As shown in Table 3, the hatching percentages of the cysts produced in experiments 2 and 3 were high; no significant differences in hatching could be observed between the experimental samples and the respective oven-dried controls.

DISCUSSION

The major difference and advantage of the present cyst dryer as compared to traditional drying systems is that it can operate at much higher temperature regimes, thus improving the drying rate without

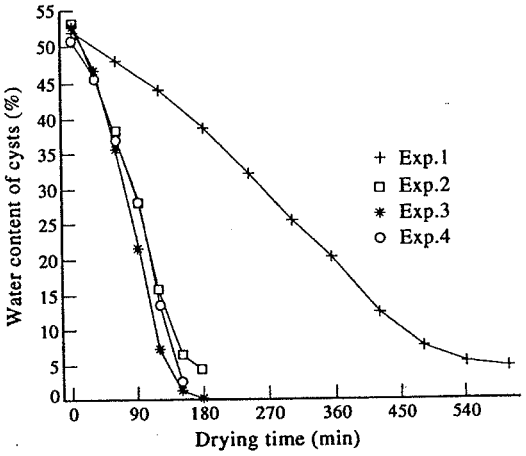

Fig. 4. Dehydration rate of cysts in fluidized bed drying experiments.

TABLE 2
Time and energy requirements for fluidized bed drying of cysts to a final water content of 5%

Experiment	*Drying time (min)*	*Energy consumption[a] (kWh)*
1	595	21·8 (blower)
2	175	23·9 (blower and heater)
3	135	18·5 (blower and heater)
4	145	17·4 (blower and heater)

[a] Calculated for maximal inflow air temperatures throughout the drying process, i.e. 90°C (6 kW) for runs 2 and 3 and 80°C (5 kW) for run 4.

TABLE 3
Hatching percentage and final water content of fluidized bed and oven-dried cysts

Experiment	*Hatching % (24 hr)*	*Hatching % (48 hr)*	*Final water content (%)*
2	—	84·2±2·9	4·43
2 (control)	—	84·0±4·5	< 5
3	72·3±4·9	77·3±3·5	1·70
3 (control) <	71·0±5·3	78·0±4·4	< 5

affecting the hatching quality of the cysts. The system uses heated air that is, however, immediately cooled down at the initial phase of the drying process to temperatures well below 40°C, due to the strong evaporation effect in the dryer. As cysts dehydrate rapidly, evaporation decreases, as a result of which the temperature inside the dryer raises slowly until it attains a pre-set limit.

In the present study the temperature inside the drying unit was limited to 40 or 50°C, while the inlet air temperature was as high as 80 or 90°C. None of these temperature regimes appeared to have a negative effect on the hatching quality of the Great Salt Lake cysts. Given the higher temperature tolerance of partially dehydrated cysts (Hinton, 1954; Voronov, 1974; Sorgeloos *et al.*, 1986), this is not unexpected because even at the highest temperature regime (experiment 3), cysts had already been dehydrated to a water level below 30% before being exposed to temperatures above 40°C in the fluidized bed dryer. This implies that at least for the Great Salt Lake cysts, higher drying temperatures than those applied in the present study are not excluded and could be further investigated in order to

maximize the drying capacity. Nevertheless, care should be taken when working with other strains. Strain specific differences in temperature tolerance have been found not only for fully hydrated cysts (Sorgeloos *et al.*, 1986) but also for partially dehydrated cysts (Bosteels, unpublished). Ideally, drying temperatures should be adjusted in relation to the specific temperature resistance of the cysts, while maximizing the drying rate. The double temperature control of the present cyst dryer offers in this regard a large flexibility because it enables not only the maximum temperature to which the cysts will be exposed to be controlled (by regulation of temperature inside the dryer) but also the dehydration rate and consequently the evolution of the drying temperature in relation to the dehydration level of the cysts (through regulation of the inlet air temperature, Fig. 3).

Aside from the application of higher drying temperatures, a second feature optimizing the drying capacity of the fluidized bed dryer is the conical shape of the drying unit. Compared to a cylindrical drying unit, the conical design results in a differential air velocity that enables to process larger quantities and to obtain faster dehydration of the cysts. The small inlet diameter of the cone gives a high air velocity in the lower part of the dryer. This optimizes lifting and mixing of the cysts, and avoids the creation of bypasses and critical temperature variations inside the dryer. On the other hand, the large diameter in the upper part results in a progressively lower air velocity which causes a downward movement of the cysts, thus preventing clogging of the top sieve and reduced air-flow rates.

CONCLUSION

Fluidized bed drying of cysts has been recommended by Vanhaecke and Sorgeloos (1982), Vanhaecke (1983) and Sorgeloos *et al.* (1986) because it assures a fast and homogeneous drying which they found critical in producing cysts of optimal hatching quality. The cyst dryer proposed by Vanhaecke and Sorgeloos (1982) and Vanhaecke (1983) had, however, a very limited capacity and could only be used for experimental purposes. In this study a fluidized bed dryer is described that guarantees an improved drying efficiency and that can be used for commercial-scale applications. Using Great Salt Lake cysts with an initial water content of 50–55%, we were able to dry 21·5 kg of cysts to a final water content of less than 5% in 2·25 hr. The flexibility and precision in temperature settings obtained through a PID-triac controlled heating unit permits adaptation of the temperature

regimes to the specific temperature resistance of the cyst strain being used. The use of such a heating unit proves to be interesting as it may provide a more than four-fold increase of the capacity without increasing the energy requirements, and ensuring an optimal hatching quality of the cysts.

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