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Analysis and optimisation of dynamic facility ventilation in recirculation aquacultural systems

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ABSTRACT

Facility ventilation is one of the main energy consumers in a recirculation aquacultural system (RAS).In this work, operating points have been optimised in order to maintain an acceptable facility climate on the one hand but an energy input as low as possible on the other hand. The energy savings have been quantified by evaluation of energy input into the ventilation stream at various flow rates. Moreover, additional measurements have been undertaken in order to understand the correlation between air humidity in the facility, ventilation rate, humidity production of the RAS and ambient climate.

The main findings are that dynamic facility ventilation offers a significant potential for energy savings up to 85% compared to a static operation at design flow rates according to DIN EN 13779. Air humidity–as a major constraint–is predominantly affected by ambient climate conditions. Based on the main findings, a first approach for a dynamic ventilation strategy (i.e. for automation) has been made.

1. Introduction

Recirculating aquaculture systems (RAS) require a higher technical infrastructure than open systems. Especially water treatment, temperature control and oxygen supply are the major challenges. Energy costs in RAS are rated as major constraints which may prevent this technology from widespread application (Singh and Marsh, 1996).

Many of the RAS are installed indoors. Especially in indoor marine systems, a very corrosive atmosphere is caused by humidity in combination with salt content. In order to keep an acceptable atmosphere inside the facilities, ventilation or air conditioning plants are widely in operation. It is obvious that these installations use a significant amount of electrical power and offer a decent potential for energy savings. Since ventilation plants have no direct impact on the growth results of fish and other creatures, this part of RAS technology may be a little “out of focus”.

Even the subject ‘energy’ had been treated as a “side-effect” in RAS systems for many years. The reason may be that the production costs mainly depend on the costs for food and larvae/fingerlings (Losordo and Westerman, 1994; Mozes et al., 2003). Therefore, very few publications focused on the subject energy in RAS systems before 2014. One of the few exceptions is published by Kucuk et al. (2010) who made an exergetic analysis. Only in recent years, scientists have reported about energy efficiency in aquaculture systems. Griffin et al. (2015) have reported about the cooperation of a mussel farm and an offshore wind park, other scientists have been focusing on basin temperature control (Farghally et al., 2014).

In in the field of building services engineering, cost and energy optimisation in HVAC (i.e. heating, ventilation and air conditioning) systems is a very active area of research. Many authors have published various optimisation strategies for the control of HVAC systems in various types of buildings. A comprehensive overview over the research regarding HVAC control and optimisation strategies is given by Wang and Ma (2008). However, the investigated HVAC systems are rather complex and not related to aquaculture buildings. In order to connect the current state of research in HVAC optimisation with the specialised environment in ventilated aquaculture facilities, it should be pointed out, that the complex optimisation strategies reported in literature may be ‘over the top’ for simple ventilation systems used in RAS. Very often, ventilation systems in RAS have rather basic control algorithms, which are mainly control loops for volumetric air flow rates and temperature. The design settings for the ventilation controllers are made in a way that inadmissible atmospheric conditions inside the facilities are avoided. What may be rated as “operator-friendly” settings at first

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glance, often turns out to be inefficient in terms of power consumption, because the set-values for air flow rates are much higher than necessary.

The objective of the current work is the development of an “expert system” for energy-efficient operation, which can be easily implemented into rather basic controllers of typical RAS ventilation systems. The expert system reported here mainly addresses the air flow rates and therefore the electric power input of the ventilation blowers. Heating or cooling of the investigated RAS facility is mostly done indirectly by the temperature control of the aquaculture tanks. Only for a short time (several weeks) during winter, additional heating of the facility is necessary.

Since the ventilation rate in combination with the outside weather conditions has direct impact on the facility climate in terms of temperature and air humidity, the adjustment of set-points for the air flow rate has to follow certain (heuristic) rules. These rules can be interpreted as an “expert system” as mentioned above. In contrast to other expert systems, which are based on operational experience only, the optimisation rules developed here are based on facility climate measurements and physically predicted system behaviour. Therefore, the expert system presented here has also a general validity.

It should be pointed out that the energy savings reported here are obtained by optimised operation only. Rebuilding or substantial modification of the ventilation installations have been avoided.

In this study, the energy analysis and optimisation has undergone the following stages:

- Data acquisition of both ventilation plant and facility, determination of the original operating conditions which have been defined by design
- Analysis of the main parameters affecting the facility climate
- Optimisation of operating points in terms of energy consumption and facility climate
- Derivation of general rules (i.e. an expert system) for an automated and energy-efficient operation of the ventilation plant

2. Methodology

The energy optimisation reported here has been conducted at the Gesellschaft für Marine Aquakultur mbH in Büsum, Germany (GMA). The RAS is in operation (for R&D purposes) since 2009. During operation, the significant energy consumption has become evident.

From the technical data sheets and estimations by the operation personnel, the facility ventilation has been identified as a main energy consumer in the RAS facility.

In the following sections, the ventilation plant and parts of the RAS affecting the ventilation are described in detail. The experimental programme is reported, afterwards. Furthermore, special operational constraints regarding the facility climate are discussed.

2.1. System description

Most of the technical devices of the RAS are installed indoors in two separate facilities. Heating and ventilation of the facilities are realised by two identical ventilation plants with integrated heaters (one for each facility). In the following sections, the specifications and results for one of the two identical ventilation plants are described.

In Fig. 1, a simplified flow scheme of the ventilation plant (Menerga) is shown. The system supplies one of the two facilities which have the same size (facility volume: 3000 m^3).

Due to the lack of experience in aquaculture, the ventilation system had been designed on the basis of indoor swimming pool systems. The ventilation system is designed for an in- and outlet flow rate of 6300 m^3/h, which results in a minimum air residence time of approx. half an hour.

Incoming ambient air is passed through a filter (class M5, according to DIN EN 779, 2012) and a heat recovery unit (65 kW by design). Behind the heat recovery unit, the inlet blower is located passing the air through an additional heating unit (53 kW by design) which is operated with hot water coming from a heat pump. The air is passed through another filter (class F7) before being distributed in the facility. The outlet air is passed through a filter (class M5) and enters the outlet blower, afterwards. During winter (more precise: heating period) the air is passed through the heat recovery unit before leaving the system. During summer (ambient temperature higher than facility temperature), the heat recovery unit can be bypassed.

The blowers are equipped with frequency converters (FC) by the manufacturer. FC is the main requirement in order to adjust the air flow rates in an energy-efficient way. Most recently installed ventilation devices are equipped with FC's.

Air residence times in the facilities can be varied from 0.47 to 1.15 h, which is equal to volumetric flow rates ranging from 2700 to 6300 m^3/h.

Inside the devices and along the piping, measurement devices for flow rate (F), temperature (T), relative humidity (H) as well as pressure differences (Δp) are installed. With the measurement of temperature and humidity, the in- and outgoing heat and the mass flow of water vapour can be balanced (see Section 3.2). The measurement of pressure difference is important for (i) identifying the necessity of filter exchanges (pressure difference filter) and (ii) measuring the whole pressure loss in the piping and calculating the blower power input (pressure difference blower).

The ventilation system is operated in a way that the flow rate of the inlet air is always slightly (100 m^3/h) higher than the flow rate of the outlet air. This leads to a slightly higher pressure (several mbar) in the facility compared to the environment. In this way, air is always leaving the facility when a door is opened. Consequently, germs are prevented from being transported into the facility in an uncontrolled way.

The additional heating unit is in operation only during winter. Most of the year, it is switched off, which means that the additional heat (resulting from the RAS) together with the heat recovery is sufficient to keep the facility temperature in the desired range.

From the point of view of a ventilation system, every heat and mass flow which is neither inlet nor outlet flow is summarized to the so-called “room load”. In Fig. 1, the room load is depicted as a simple box called “RAS”.

In Fig. 2, a simplified flow scheme of the RAS system at the GMA is shown.

The RAS installations can be basically subdivided into 3 sections or functional groups, i.e. the seawater supply, the RAS module and a central supply of heating and cooling water.

Filtered seawater is stored in an underground tank outside the facilities. The pump P1 passes the seawater through a circulation pipe, where ozonisation is taking place.

In both facilities, more than one RAS module is installed (2 modules in facility 1 and 1 module and smaller aquarium systems in facility 2).

Seawater is passed through a buffer tank into a pump pit. From here, pump P2 passes the water via a pure oxygen injector into the fish tanks, whereas pump P3 enables a direct seawater supply. From the fish tanks, the seawater is passed into a rotating filter sieve through an open channel, before entering the pump pit again. Pump P4 supplies seawater to the biological water treatment (moving bed biofilter, nitrification only). Pump P5 passes seawater through a heat exchanger for temperature control.

From a ventilation system point of view, interesting installations are those which affect the room load regarding heat and/or air and/or humidity. These installations have been highlighted in Fig. 2.

The exhaust air of the biofilter is rated as the main source of water vapour (approx. 100 m^3/h air per module, exhaust air can be estimated as being saturated with vapour). The inlet air to the biofilters is taken from inside the facility. In facility 1, one of the two biofilters has been retrofitted by installing a covering and an exhaust pipe leading outside