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GEOTHERMAL ENERGY IN AQUACULTURE

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ABSTRACT

In a fish farming plant the growth rate of the fish can be increases by 50 to 100% by controlling the rearing temperature. Water quality and disease control are important in fish farming and need to be considered when using geothermal fluids directly. A total of 22 countries reported geothermal uses in aquaculture in 2010. The leading countries were China, USA, Italy, Iceland, and Israel. Tilapia, salmon and trout are the most common species. There are about 70 fish farms in Iceland of which 15-20 use geothermal water. The total production was about 7,000 tons in 2013, mainly salmon and arctic char. An important part of this sector in Iceland is the ongoing development of a fish farm that uses surplus hot water from the Reykjanes geothermal power plant to breed 2,000 tons of Senegalese sole annually.

1. INTRODUCTION

The aim of geothermal aquaculture is to heat water to the optimum temperature for aquatic species. This involves the raising of freshwater or marine organisms in a controlled environment to enhance production rates. The geothermal water is commonly used to heat water in raceways, ponds and tanks. The water temperature depends on the species involved, ranging from 13 to 30°C. By controlling the rearing temperature the growth rate of the fish can be increased by 50 to 100%, thus increasing the number of harvests per year (Figure 1). The heating requirement for a typical outdoor pond in a temperature climate zone can be about 2.5 MJ/hr/m^2 and a 2.0 ha facility might require an installed capacity of 14 MWt. With a load factor of 0.60 the annual heating requirement would be 260 TJ/yr. Water quality and disease control are important in fish farming and need to be considered when using geothermal fluids directly in the ponds (Lund, 2011).

According to data presented at the World Geothermal Congress in Bali 2010 (WGC2010) the total geothermal energy used in aquaculture worldwide increased slightly in the five year period 2005-2010. However, the numbers presented in Bali were lower than previous estimates from 2000 and 2005. In the period 2005-2010 the installed capacity increased by 6% to 653 MWt and the annual energy use increased by 5% to 11,521 TJ. A total of 22 countries reported geothermal uses in aquaculture. The leading countries were China, USA, Italy, Iceland, and Israel. Tilapia, salmon and trout are the most common species, but tropical fish, lobsters, shrimp, and prawns, as well as alligators are also being farmed. Based on data from the USA it has been estimated that the energy demand when using geothermal water in uncovered ponds is 0.242 TJ/year/ton of fish (bass and tilapia). Thus, using the reported energy use of 11,521 TJ/year in 2010 it can be estimated that the total annual production in that year was 47,600 tons. A few parameters describing the worldwide development in geothermal uses in the fish farming sector in the period 1995-2010 are presented in Table 1 (Lund et al., 2010).

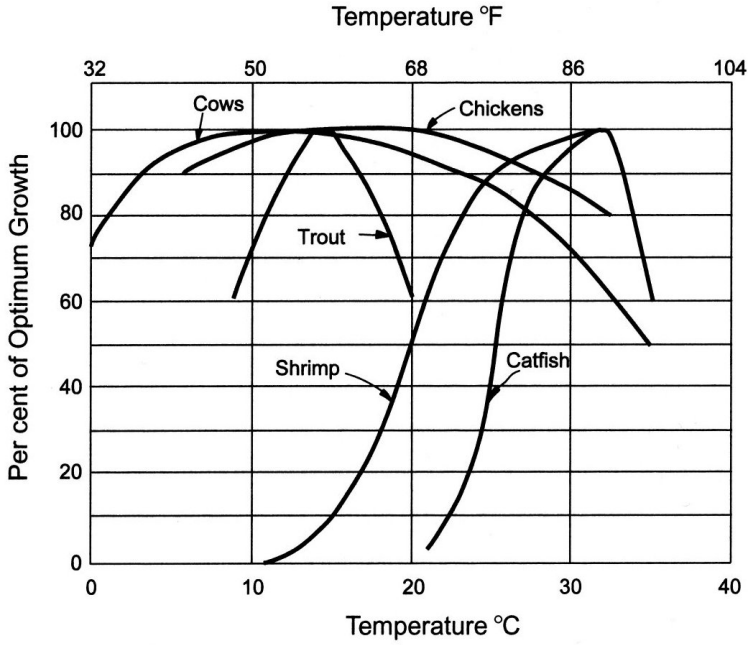


FIGURE 1: Optimum growing temperature for selected animal and aquatic species (Dickson and Fanelli, 2005)

TABLE 1: Geothermal uses in the fish farming sector worldwide (data from Lund et al., 2010)

	1995	**2000**	**2005**	**2010**
Installed capacity (MWt)	1,097	605	616	653
Energy utilization (TJ/year)	13,493	11,733	10,976	11,521
Capacity factor	0.39	0.61	0.57	0.56

2. FISH FARMING IN ICELAND

Fish farming has been a slowly growing sector in Iceland for a number of years. After a rapid growth from 2002 the total production reached about 10,000 tons in 2006, mainly salmon. The dominating species are now salmon and arctic char followed by trout. There are about 70 fish farms in Iceland and the total production was about 7,000 tons in 2013. Of these fish farms between 15 and 20 utilize geothermal water. Initially, Iceland's fish farming was mainly in shore-based plants. Geothermal water, commonly 20-50°C, is used to heat fresh water in heat exchangers, typically from 5 to 12°C for juvenile production. The beginning of the 21st century saw growing interest in developing sea cage farming of salmon in the sheltered fjords on Iceland's east coast. Two large farms were established and remained in operation for a few years, but today only two small cage farms are in operation. The main use of geothermal energy in the fish farming sector in Iceland is for juvenile's production (char and salmon). In land-based char production geothermal energy is also used for post-smolt rearing. Geothermal utilization in the fish farming sector is expected to increase in the coming years (Ragnarsson, 2010).

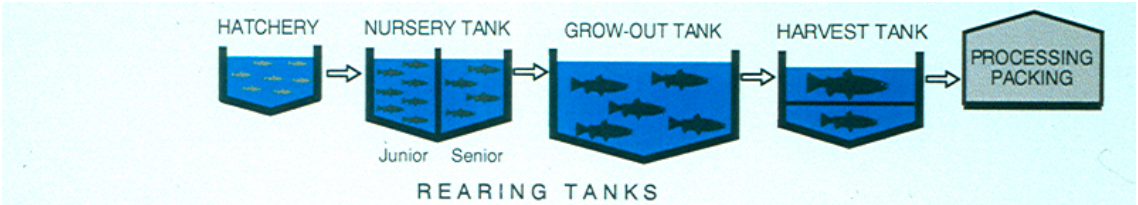
A fish farming plant owned by the company Stolt Sea Farm started breeding warm-water Senegalese sole at Reykjanes peninsula, Iceland, in 2013. It is the first stage of a large indoor land-based plant that is planned. The 22,500 m^2 plant is located close to a 100 MWe geothermal power plant owned by the energy company HS Orka Ltd. The power plant uses a large amount of sea water for cooling and after the cooling process a part of the water, which is then at a temperature of 35°C, flows by gravity to the fish farming plant. There it is mixed with sea water that is pumped from wells and used in the farming at about 21°C, which is the optimum temperature for the fish. The water temperature can be kept

constant throughout the year without any influences from the environment. Currently, there are about 1.2 million juveniles in the plant and that number is increasing. They are grown to about 400 g before the Senegalese sole is slaughtered and transported fresh to markets in Europe. The production capacity of the first stage is 500 tons per year, but the planned production after reaching the final stage is 2,000 tons per year. The current number of 14 employees is expected to increase to 60-70 in the final stage.

3. SAMHERJI'S FISH FARMING PLANTS

Samherji is one of the largest fishery and seafood companies in Iceland. Their activity within aquaculture is comprised of most aspects of fish farming, i.e. hatching, juvenile production, the on-growing of marketable fish, harvesting, packaging and marketing of the products. The fish farming operations are situated in several places in Iceland. It is all land-based but not shore-based as is most common in salmon farming. Samherji is among the largest land-based fish farms producing salmon in the world. This has been made possible by using geothermal water (Samherji, 2014).

Íslandslax is the name of Samherji's fish farming plant located at Núpar in South Iceland. There they have juvenile farming and hatchery facilities specially designed to hatch and grow salmon and arctic char from the roe stage until they reach approximately 70-100 g. All the salmon and char roes used in Samherji's farming are hatched at this plant. The farm is situated in a geothermal area with excellent access to high quality water and very stable water temperature. The total fish farming area is about 2,000 m^2 and the total volume about 1,500 m^3. The total consumption of fresh water at 5.5°C is 240 l/s where about one third is pumped from wells and one third flows by gravity to the plant. The consumption of geothermal water is 7-10 l/s of 90°C hot water coming from two wells. A part of the geothermal water is mixed with cold water and used directly in the farming, while another part is used to heat up fresh water in heat exchangers. In spite of the relatively low concentration of oxygen in the geothermal water the experience has shown that it can be mixed with fresh water and thus heat exchangers are not always needed (Haraldsson and Ketilsson, 2010). The water temperature in the juvenile farming is in the range of 6 to 16°C (Figure 2). The growth rate depends strongly on the water temperature and thus the production can be regulated by the temperature. About 300,000 juveniles produced annually at Íslandslax are transported by special trucks to Samherji's on-growing farm called Silfurstjarnan. Then they weigh about 70 g. (Smáradóttir, H., pers. comm., 2014).



ARCTIC CHARR				1 - 2 kg
Temperature °C	6	12	10	9.5
Salinity ‰	0	0	10	10
Year	0.4	1.2	1	0.02

SALMON				2 - 4 kg
Temperature °C	8	10	10	9.5
Salinity ‰	0	10	10	10
Year	0.5	1	1	0.02

FIGURE 2: Breeding of salmon (Georgsson, 2013)

Silfurstjarnan in Öxarfjördur, North Iceland, is an on-growing farm where the bulk of the production is salmon. The farm is ideally situated in an area very rich in geothermal water, close to the sea. This location was chosen after large geothermal exploration efforts in late 1980s to find good sites for fish farming in Iceland with good accessibility to lots of cold and warm water, and also seawater where possible. At the north-eastern border of the Öxarfjördur delta the Silfurstjarnan fish farm was established after exploration had revealed favourable conditions with both fresh water and brackish warm water available in large quantities at very shallow levels and seawater close by at the coast. Many wells on site at Silfurstjarnan and the access to seawater make it possible to use different water temperatures and salinities in different tanks at the same time (Samherji, 2014). They utilize several geothermal wells with different water temperature and salinity. The water from the different wells is mixed to get the appropriate temperature at the given conditions, but the rearing water temperature is about 9-11°C. The total production is about 1,000 tons per year of salmon and about 100 tons per year of arctic char (Figures 3 and 4). The current market price for Silfurstjarnan salmon (in USA) is now at about 6 USD (4.5 USD from factory) compared to general market price of about 4 USD (Georgsson, 2013). Silfurstjarnan operates a harvesting plant on site where all the production is processed and packed (Smáradóttir, H., pers. comm., 2014).

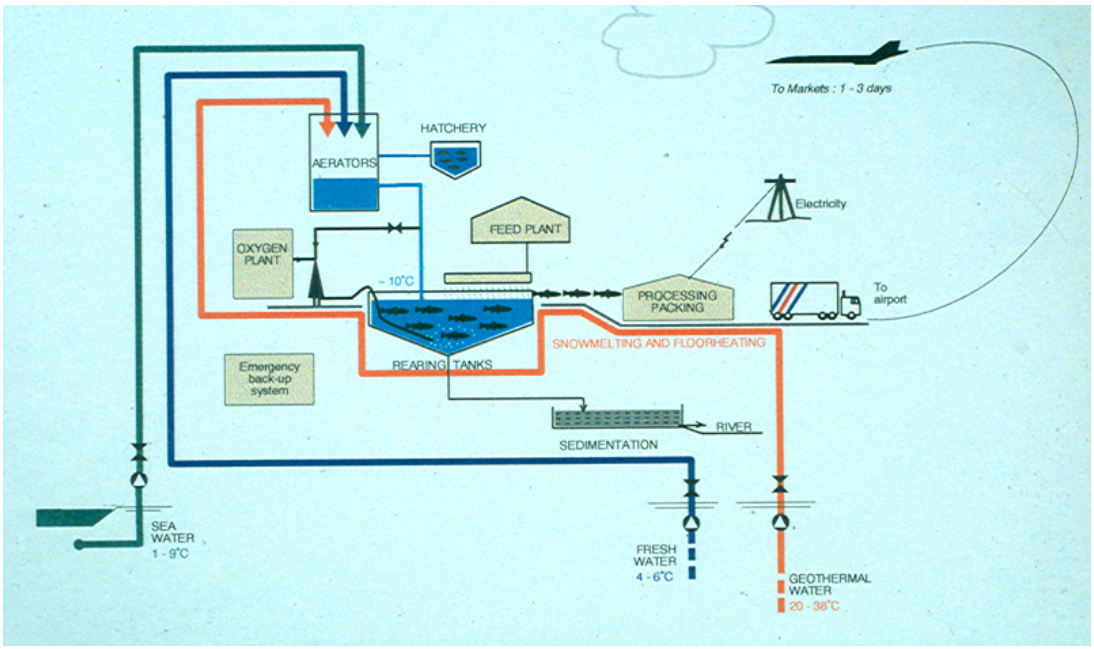


FIGURE 3: Schematic diagram of the main processes at the Silfurstjarnan fish farm, Öxarfjördur, North Iceland (Georgsson, 2013)

FIGURE 4: Silfurstjarnan fish farm, Öxarfjördur, North Iceland (Georgsson, 2013)

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