

# HIGH TECHNOLOGY IN GEOTHERMAL FISH FARMING AT SILFURSTJARNAN LTD., NE-ICELAND

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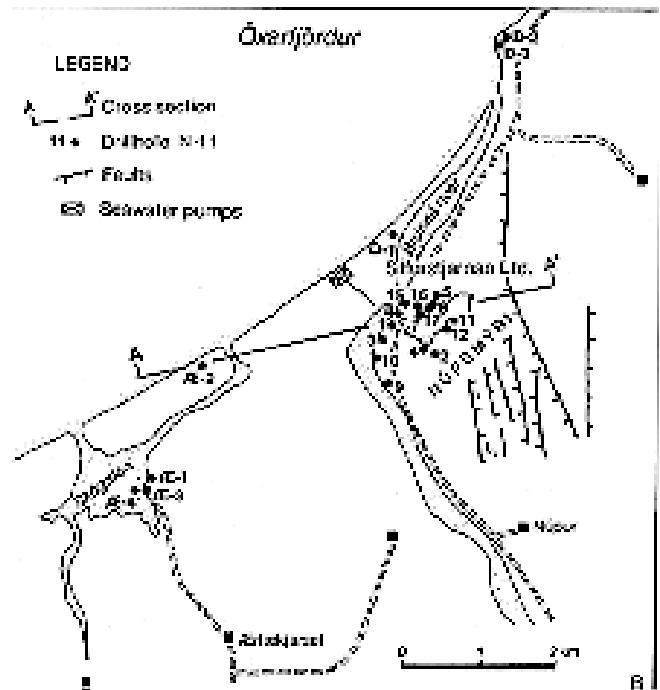
## INTRODUCTION

Land-based fish farming in Iceland relies on good resources of freshwater and seawater with thermal energy to warm it up. In Öxarfjörður, NE-Iceland plentiful cold groundwater exists and geothermal manifestations are found at many locations. Seawater resources are, apart from the unstable sand shore, limited to a pillow lava formation close to the shore. During 1986-1990, Orkustofnun - the National Energy Authority of Iceland joined with local authorities in Öxarfjörður to study the potential of the area for fish farming. The project led to the forming of the company Silfurstjarnan Ltd., which built and presently runs a fish farm in Núpsmýri in Öxarfjörður. Fridleifsson, et al. (1995) have described the fish farm in its initial phase and the research project. While the present article is based on that paper, here we focus on the present status and future possibilities and expand on some of the technological aspects.

The Öxarfjörður region, at the coast of NE-Iceland, is within the active zone of rifting and volcanism which crosses Iceland from southwest to northeast. Three northerly trending fissure swarms, parts of active volcanic systems further inland, cross the region. While most of the volcanic zone is characterized by volcanic products of some sort, the Öxarfjörður delta is chiefly a graben zone filled by shallow marine fjord sediments and glacial outwash from Jökulsá river. The sedimentary thickness in the central outer part of the graben approaches 1 km (Georgsson, et al., 1989; 1993a and Ólafsson, et al., 1993).

Groundwater from a large area drains into the Öxarfjörður basin, where the three fissure swarms play a key role in the flow and distribution of springs. In all, about 40 m<sup>3</sup>/s surface within them at the margin between the porous post-glacial lava horizons and the sedimentary basin (Georgsson, et al., 1989).

Most of the surface geothermal activity is confined to the gravel plain and the Krafla fissure swarm. During the Krafla volcanic and tectonic episode in 1975-1984, geothermal activity increased considerably, but is now slowly decreasing again. Resistivity survey delineated a low-resistivity area of about 10 km<sup>2</sup> within the Krafla fissure swarm which is explained by the existence of a high-temperature geothermal area (Georgsson, et al., 1993a; 1993b). Another geothermal area is at Skógalón, close to the coast (Figure 1). There, results from shallow exploration wells lead to the drilling of the production well AE-3 in 1988 (Figure 1), which yields 40 - 50 l/s of 96°C hot water in free flow (Georgsson, et al., 1989; 1993a). This well is now utilized by the Öxarfjörður Heating Services.



**Figure 1. a) The Öxarfjörður region and the geothermal pipeline of the Öxarfjörður Heating Services, and b) The location of drill holes and the Silfurstjarnan Ltd. fish farm.**

Results of drilling at Skógalón were encouraging, and concentrated the research for a suitable site for the fish farm on the coastline east of Skógalón. Drilling of exploration wells at the coast confirmed that seawater had to be collected at or close to the surface, but unexpectedly led to the discovery of warm groundwater. Further drilling revealed a large reservoir of brackish 35 - 36°C warm water at 60 - 200 m depth in Núpsmýri close to the coast, at the eastern margin of the sedimentary basin. Furthermore, it turned out that from the same Núpsmýri field at least 400 l/s of cold groundwater could be pumped from the uppermost 50 - 60 m with only a minor drawdown (Fridleifsson, 1989; Georgsson, et al., 1989). The quality of this water proved excellent for fish farming. When experiments with shallow drainpipes dug into the sand at the seashore, showed that seawater of good quality could safely be collected, Núpsmýri was chosen as the site for the Silfurstjarnan fish farm (Figure 1).

## THE NATURAL CONDITIONS

The main results of the research on natural conditions for fish farming were that both cold freshwater and warm brackish water could be harnessed from the Núpsmýri field. Altogether, 17 wells have been drilled in the field. The location of the wells is shown in Figure 1. The fish farm was built on top of the reservoir, neatly located close to the main road in NE-Iceland. One branch of the Jökulsá river also runs close by, and is used for disposing effluent water from the fish farm.

The water reservoir is composed of very porous and permeable pillow lava breccia which is a part of a subglacially formed hyaloclastite ridge of late-Pleistocene age covered by a 20 - 60 m thick blanket of sediments in Núpsmýri. Beneath a thin layer of sandy soil, the sediments are composed of a river delta and eolian sand in the upper part, and a beach sand and shallow marine mud in the lower part, which cap the pillow lava reservoir formation (Figure 2). All water is pumped from the wells with a fixed 1 - 2 m drawdown, yielding 60 - 230 l/s per well (200 - 830 m<sup>3</sup>/h) depending on pump size and well width.

The natural state of the thermally- and chemically-layered water reservoir is such that cold freshwater (5 - 7°C) extends to a depth of about 100 m in the eastern part of the well field, the freshwater lens there being about 60 - 80 m thick (Figure 2). West of the fish farm only brackish warm water (>30°C) was met, from below 60 m to at least 220 m depth. A fault control is inferred for the warm water (Figure 2).

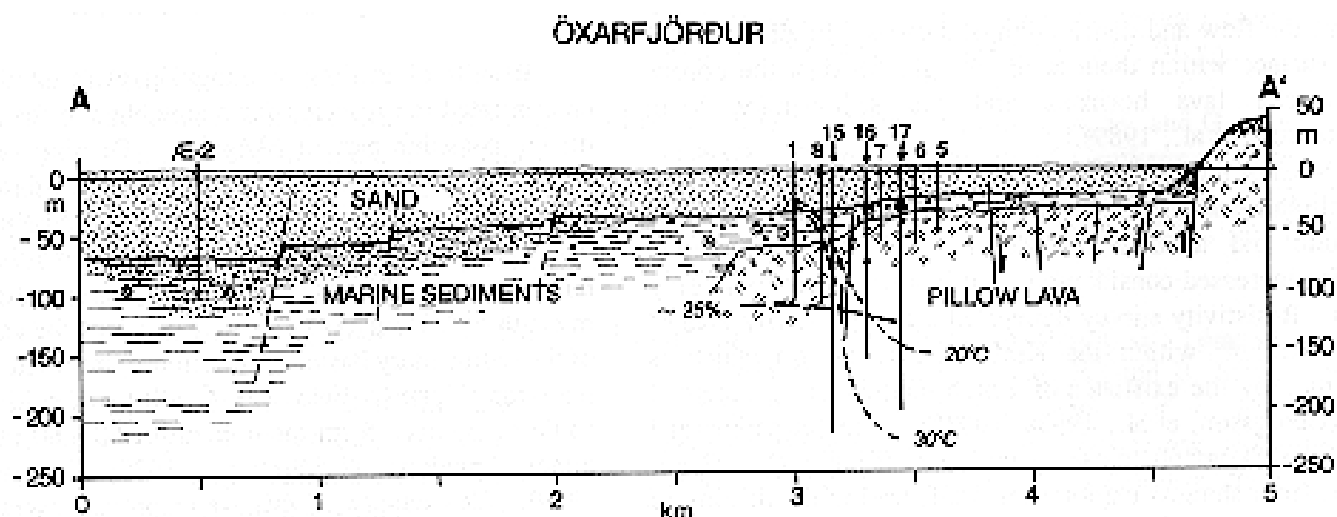
The salinity of the cold water is <1 ppt (parts per thousand) above 100 m depth, appears brackish (3 - 6 ppt) from there to 120 - 130 m, and strongly saline (>25 ppt) approaching seawater salinity below that depth. The warm water in the western part of the reservoir, on the other hand,

is brackish (4 - 8 ppt) from 60 m down to about 120 m depth, below which depth the salinity increases sharply to above 25 ppt (Figure 2). An example of the chemistry of different waters from the area is shown in Table 1.

**Table 1. Chemical Composition of Representative Water Types (mg/l)**

Water Type Well No.	Cold N-6	Brackish N-12	Warm N-1	Seawater Drainage	Hot AE-3
Temperature (°C)	5.4	7.6	34.2	2.3	96
pH/°C	9.6/16	8.8/25	7.8/15	8.6/24	7.9/24
Diss. oxygen (O <sub>2</sub> )	9	-	0.1	-	0
Carbonate (CO <sub>2</sub> )	42.5	42.9	58.6	50.9	24.3
Sulphide (H <sub>2</sub> S)	<0.03	<0.03	<0.03	<0.03	0.07
Silica (SiO <sub>2</sub> )	18.3	16.1	36.5	2.4	129.1
Sodium (Na)	64	1790	1865	7940	833
Potassium (K)	3.7	63	86	295	44
Magnesium (Mg)	1.3	173	60	905	0.42
Calcium (Ca)	1.4	103	152	301	154
Iron (Fe)	0.025	-	0.1	-	<0.02
Manganese (Mn)	<0.05	-	0.2	-	-
Sulphate (SO <sub>4</sub> )	11.2	477	390	1930	97
Chloride (Cl)	48.1	3490	3937	14300	1534
Fluoride (F)	0.2	0.25	0.36	0.8	0.27
TDS	174	6859	4430	27765	2709
Salinity (ppt)	0.09	6.3	5.3	25.8	2.8

The lack of a large saline groundwater reservoir was solved in a unique manner by installing a drainage system into the sandy sea bottom at the shore in Öxarfjörður. The best results were reached by digging 12-m long, 254-mm slotted steel pipes into the sea bottom on the lowest tide to a depth of



**Figure 2. The geological cross-section A-A' through the Núpsmýri drill field (location see Figure 1); also shown are isotherms and the 25 ppt salinity isoline.**

1.5 - 2 m. Seven such slotted liners are now connected with plastic pipes to seven centrifugal pumps. With this system, a constant amount of about 800 l/s of clean seawater can be pumped towards the fish farm, about 1 km inland. The temperature ranges from about 1°C in January to 8 - 9°C in July/ August. Consequently, the need for hot water increases in the winter as the rearing water needs to be kept at a constant temperature of about 10°C the year round.

Extra geothermal energy for house heating is now provided by Hitaveita Öxarfjörður or the Öxarfjörður Heating Services, which started operation in late-1995. Then, geothermal water replaced electricity as the main energy source for house heating in the region. The first phase of construction involved a pipeline from well AE-3 at Skógalón to the village of Kópasker with about 170 people, located at the coast about 19 km north of Skóglón (Figure 1), providing geothermal water for its inhabitants and the farms, and minor industries along the way, such as the Silfurstjarnan fish farm. The free-flowing 96 - 98°C water from the well is pumped towards Kópasker through a 4 ½-in. polybutylene pipeline, insulated with polyurethane and asphaltic paper cover, which can carry about 7 l/s. The initial part (1.2 km) of the pipeline is not insulated to reduce the temperature, which is slightly too high for the polybutylene. On the way, the water cools to 79 - 82°C; but, at Silfurstjarnan, it arrives 88 - 90°C warm. Due to its salinity (Table 1), plate heat exchangers are necessary to avoid corrosion in the radiators. The second phase will include a pipeline south, to the school village at Lundur, farms close by, and further south towards Ásbyrgi (Figure 1).

### THE SILFURSTJARNAN FISH FARM

The Silfurstjarnan fish farm is a land-based system where fish are reared in a number of individual tanks of various sizes. Construction began during the autumn of 1988. Building of

the fish tanks was more or less completed a year later. A small hatchery for arctic char was built elsewhere in Öxarfjörður in the same year. At the hatchery, artesian cold and hot waters from springs or drill holes are used. The temperature can be adjusted to increase or reduce the fish growth, which is important in order to secure delivery of the same size fish product throughout the year. Early on, the company hired an additional hatchery for salmon in S-Iceland with similar conditions. Now, the salmon smolt is bought from Stofnfiskur Ltd., where a breeding research programme based on Norwegian stocks has produced the best salmon stock in Iceland for fish farming. The main fish farm now consists of the following utilities (Figure 3):

Freshwater supply	Seawater supply
Warm water supply	Aeration system
Oxygenation system	Tank rearing system
Effluent/filtering system	Feeding system
Monitoring/control and alarm system	Electrical supply and emergency back-up system
Fish handling and grading system	Fish processing and packing plant

Water is pumped from the boreholes by downhole submersed pumps of 80 - 300 l/s capacity. Seawater is pumped by standard horizontal centrifugal pumps of 125 l/s each. Pumping head is variable, generally in the range of 20 - 30 m. Presently, about 700 l/s of seawater are mixed with about 700 - 800 l/s of cold groundwater and 100 - 200 l/s of warm water, yielding a total of 1500 - 1600 l/s (5400 - 5700 m<sup>3</sup>/h) for the main fish farm of the Silfurstjarnan Ltd. in Öxarfjörður. Electricity cost is high; at present, about 800 kW are required. The fish farm is equipped with two reserve diesel engines, both with the capacity to produce 750 kW in case of electrical failure.

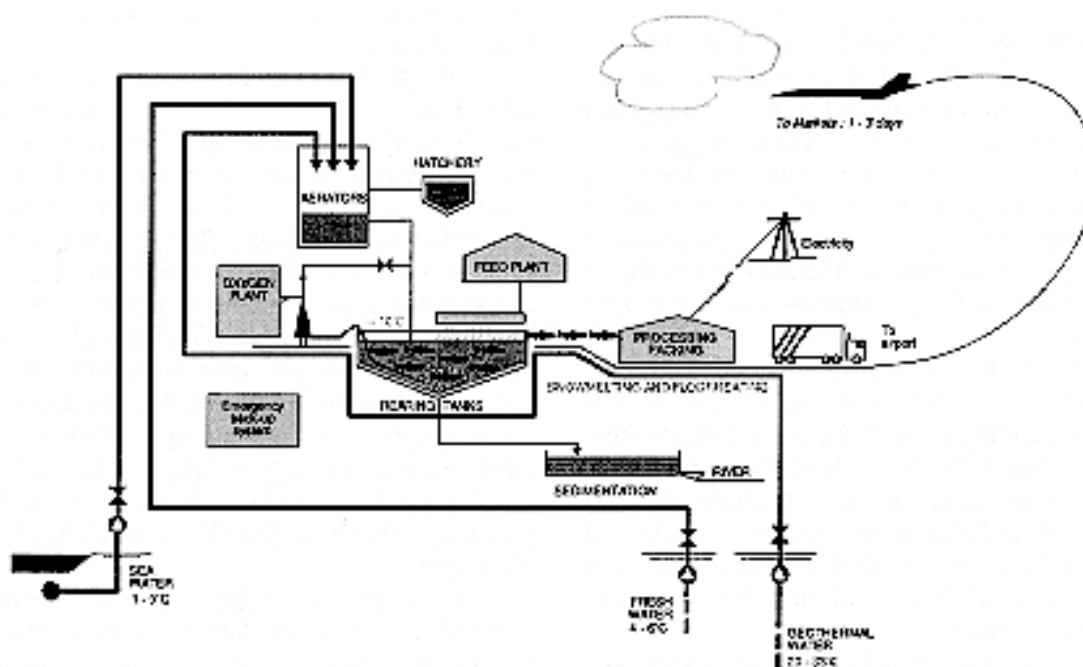


Figure 3. A schematic diagram of the Silfurstjarnan Ltd. Fish farm in Öxarfjörður, NE-Iceland.

Whereas, only about 10% of the water resources are of geothermal origin, a cascaded usage of the warm water is of interest. The hottest water (35 - 37°C) is first used for domestic heating in the floors of the fish farm. For heating the houses, only a minor addition of heat from external sources is required, now provided by geothermal water from well AE-3. The hot water pipes then extend into a dense pipeline network in concrete pavement between the outdoor fish tanks, where it serves for snow-melting before being mixed with the water used for the fish.

Water is connected to the farm through several mains, made of PEH plastic pipes. On arrival to the farm, the three basic water types (cold/fresh, warm/geothermal and cold/sea water) are mixed in different ways to suit the different fish sizes/types. Before the mixtures are admitted to the tanks, de-aeration/aeration takes place in order to equalize nitrogen, which otherwise would reach supersaturation due to the mixing with warm water. Nitrogen in supersaturation may kill fish. Following de-aeration, water flows by gravity to the tanks. Flow rate to each tank is adjusted by valves to suit the respective biomass; this being primarily governed by the oxygen needs, but also by other factors such as CO<sub>2</sub> level, self-rinsing of fish excrements and food leftovers, suitable water velocities for proper swimming exercise, etc.

In nature, fish is generally offered oxygen saturated waters. In tank farming, this is not possible, and certainly not without separate oxygenation. Since oxygen is the key factor, total water pumping can be reduced if oxygen levels, and thereby, reducing stress which again improves fish health and growth rate. The oxygen is partially produced on site by molecular sieves and partially bought liquified in bottles. The oxygen generating plant has a total capacity of 70.8 Nm<sup>3</sup>/h. The oxygen is introduced to the tank water mainly by pressure injection in the water supply prior to admittance to the tank. The principle behind is the following. The pressure on part of the water to the tank is increased by sending the water through a narrow port by an extra pump. The 2-in. port is at a top of a fiberglass cone with a 1.2-m diameter at the bottom. The water is released into the cone and oxygen blended into it at the top. With the pressure fail the water and oxygen mix. The water is then led from the cone into the tank through a 110-mm plastic pipe with a minimum length of 18 m to ensure complete mixing. In some of the smaller tanks, the oxygen is introduced by defusers at the bottom. The complete mixing of the oxygen in the water is of major importance for the optimal growth of the fish.

The tanks are circular, different in diameter and depth, from few m<sup>3</sup> in volume up to some 1500 m<sup>3</sup>, the smaller tanks generally used for fingerlings and the biggest for fish in the 1 - 5 kg size. The smaller tanks are made of fiberglass; whereas, the bigger ones are assembled from precasted concrete elements, held together by tensional steel cable girths and surrounding soil (Figure 4). Installed fish tank capacity at present is about 15,000 m<sup>3</sup> in the mail plant; but, additional tanks are under construction.

By introducing the inlet water from the oxygen injectors in a tangential direction and at variable rates with depth, water movement is optimized in order to provide a suitable



**Figure 4. Some of the larger fish tanks at Silfurstjarnan fish farm (photo by G. Ó. Fridleifsson).**

swimming velocity and also a self-rinsing effect, where the bottom velocity is high enough as to sweep fish excrements towards the centrally located outlet, without stirring up the water. Tank effluent flows by gravity through traditional sewage piping system towards a settling pond, where the bulk of fish excrements and food leftovers settle for periodic removal. From the settling pond, effluent is channeled to the nearby Jökulsá glacial river.

Fish feed, partly made on site from fish trash, fish oil, vitamins and binding agents, and partly purchased ready-made, is dispersed in the form of pellets over the water level. Pellet size is chosen to suit fish size. About 85% of the feeding is automatic through feeders programmed to feed the fish at proper rate and at selected times of the day. The remaining 15% is done by hand depending on the appetite of the fish, which varies with weather and daylight, preferably at sunrise and sunset. Thus, it is possible to maximize the growth rate of the fish and at the same time, decrease the feed waste and water pollution.

Fish are transported from the smaller tanks to the bigger ones as size increases, usually every two months. This is done by a special fish pump which is basically a pressure vessel connected to the tank in question by a flexible tube. The vessel is then subjected to vacuum; whereby, water and fish will eventually fill it. Then the process is reversed, the vessel is now pressurized, a suction valve closes and a discharge valve opens for flow in the discharge tube, through which the fish is piped to a second tank, generally passing through a fish grader, or if the time is right, towards the finals at the processing plant. The graders are connected directly to computers, thus ensuring automatic control on the fish growth. The tanks are cleaned thoroughly before smaller fish are put into them again. One of the advantages of the 90°C hot water provided by the Öxarfjörður Heating Services is in rinsing and disinfecting.

The fish processing plant is 450 m<sup>2</sup>, including the offices of the Silfurstjarnan Ltd. Here the fish are slaughtered, gutted and processed (filet) for the needs of the different customers and packed with ice in styrofoam boxes before being sent to the markets. The ice is produced at the site.

Emergency alarms are connected to the most sensitive parameters for the fish to avoid accidents. Oxygen levels in the outlet water from each tank are monitored continuously, raising alarm if the values deviate out of present boundaries. Alarms are connected to the water system indicating if pumps go out. Every oxygen pressure injector is monitored continuously and the alarm is raised if it is not working properly. Finally, the temperature of the inlet water to the tanks is monitored raising alarm if it becomes too high.

#### THE PRODUCTION OF THE SILFURSTJARNAN LTD.

Two main species have been raised from the beginning: Atlantic salmon (*Salmo Salar*) and arctic char (*Salvelinus Alpinus*). The farming temperature is kept more or less constant the year around and accordingly, the demand for hot water diminishes during summers. The optimal temperature for salmon are at 8 - 10°C varying with size (Figure 5). The arctic char starts in colder water, 6°C, but is later on reared in the same 10°C water. It is worth mentioning that a small number of arctic char is kept in the tanks with the salmon (7% of the total fish number). In this form of cohabitation, the arctic char lies at the bottom and lives mainly on leftover fish feed. Thus, the waste of fish feed is minimized. The salinity of the farming water is kept constant throughout the year at about 10 - 12 ppt (Figure 5), which is an increase from the 8 - 10 ppt salinity used before. The increased salinity is one of the factors that has allowed steadily increased biomass per m<sup>3</sup>. The process from hatch to the market takes 30 - 35 months. Average weight of the salmon product is now close to 4 kg gutted weight (gutted and in some cases, filet fish), and the arctic char product is about 1 kg. Hitherto, the plant has been free of any kind of fish disease, which to some extent relates to the superb water quality for fish farming. So far, not a

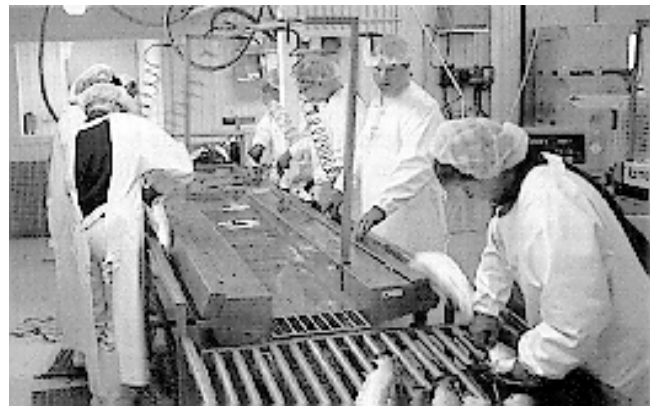


Figure 6. Slaughtering of fully grown salmon in the processing plant (photo by G. Ó. Fridlefsen).

single dose of medicine has been used. The fish is slaughtered four times a week, about 50 weeks a year (Figure 6).

Presently, the annual production is 900 - 950 tonnes or 50 - 60 kg/m<sup>3</sup>, which is a record production. Of this, salmon is about 80%. The steadily increasing production strongly relates to the stability in rearing conditions that can be held due to the geothermal energy, which the siting of the fish farm was based on. Not only the temperature control, but also the purity of the groundwater and the salinity control are of fundamental importance to that can be added successful experiments in increasing the oxygen level in the farming water. These optimal growing conditions are manifested in various ways, such as the exceptionally high yield where only 1.05 kg of fish feed are needed to produce 1.00 kg of salmon. These figures do not include the arctic char kept with the salmon (about 2% of the fish weight in the tanks).

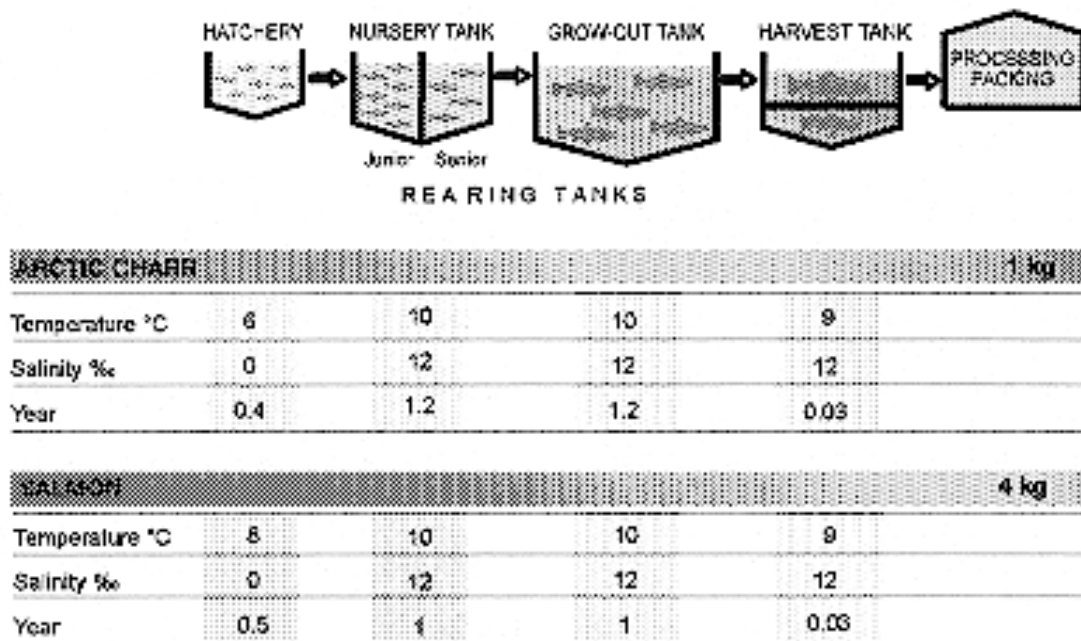


Figure 5. A schematic layout of conditions and fish growth at Silfurstjarnan Ltd.

Marketing is done by the company itself. About 90% of the product is exported, mainly as a fresh fish product; but, some is marketed smoked. Most of the customers make use of the fish farm's capability of delivering the same size of fish in similar quantity throughout the year. Despite fierce competition, this has resulted in fairly high prices for the product, which in turn directly relates to the use of geothermal water.

The transport of fresh fish to the markets in America and Europe needs to be quick, and therefore, most of the product is exported by air. From slaughtering in this remote fish farm in NE-Iceland to the markets, the iced and packed product is driven about 700 km by trucks overnight to Keflavik airport in SW-Iceland, to be air-freighted to the markets the same day. The whole process only requiring about 1.5 days, up to 3 days at the most.

## FUTURE DEVELOPMENT

Products from the Silfurstjarnan fish farm have many advantages for its customers. The biggest salmon producers today are the Norwegians where fish farming is based on pen-rearing. The ever increasing competition has led to prices being at a minimum to be able to pay off investment costs. Construction is now underway on additional fish tanks with a capacity of about 6,000 m<sup>3</sup>. With their completion in July 1997, the annual production is scheduled to increase to 1,200 -1,300 tn. In these new tanks, the water from the older tanks will be reused. Results of experiments show that by filtering food particles from the water, full production capacity can be kept by mixing it with some new water. The amount of re-used water needs to be kept below 80%, else the growth rate can only be kept up with addition of chemicals which would be against the principles of the Silfurstjarnan fish farm. The increased production will definitely help the Silfurstjarnan fish farm towards economical stability as it is to a large extent based on existing investment.

The Silfurstjarnan Ltd. has always been ready to participate in development of new methods for fish farming. One of these projects, in cooperation with several partners, was an experiment with CO<sub>2</sub> exhaust system with the purpose of increasing the live mass per m<sup>3</sup>. This is of fundamental importance, as each ton of live mass at each time results in 2 tons production at each time. The results were not up to expectations. However, they provided vital information that led to the ongoing plans for the expansion of the fish farm.

Experiments on growing rainbow trout (*Salmo Gairdneri*) are now done at the hired Arlax hatchery in the South-Öxarfjörður region. This hatchery uses local 12 - 14°C warm groundwater for breeding. Breeding of arctic charr there did not prove economical due to high content of protozoan ectoparasites in these relatively warm waters, resulting in slow growth. However, the first results of the new breeding programme indicate that this water is good for breeding of rainbow trout, at low costs.

Further experiments are on the drawing table. One of them is the development of an advanced control equipment for oxygen. The oxygen use of the fish is quite variable, and to some extent, associated with the feeding. The idea is that by precise monitoring of the outlet water from the tanks, the

oxygen injection into the inlet water can be optimized, which is very feasible economically.

Another experiment involves adding sea bass (*Dicentrarchus Labrax*) into the breeding programme. The sea bass requires about 23 - 24°C water. It is adaptable to very variable salinity though about 50% of seawater salinity is preferred. It will be located at the start of the breeding programme, using mainly the brackish warm water, before it is used for the salmon and arctic charr. At optimal conditions, the growth rate of the sea bass is about double that of salmon and the current prices are about 70 - 80% higher. Experiments on this will start in 1997. Thus, rainbow trout and sea bass may become important products of the Silfurstjarnan Ltd. in the future.

## ACKNOWLEDGEMENTS

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