GEORG

GEOTHERMAL RESEARCH GROUP

FINAL REPORT

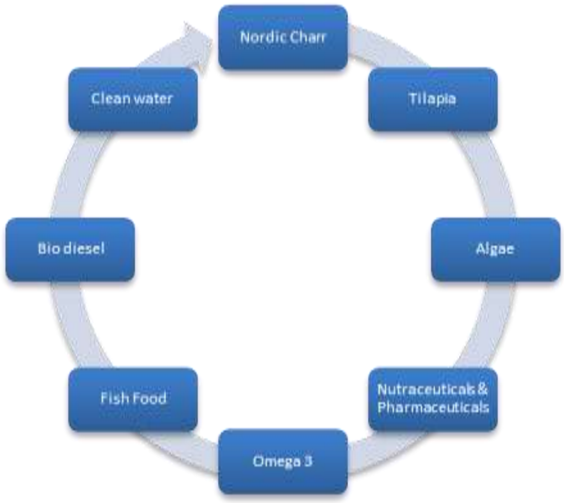
YEAR 2011-2012

GREEN GEOTHERMAL GROWTH
Use of geothermal heat for warm water ecoculture

Project ID: 10-03-004
Coordinator: Sjöfn Sigurgísladóttir
Start date: April 2011
Partners: University of Iceland, Islensk matorka ehf and Orkustofnun

1 Project summary

The main achievements are development and design of the “Green Circle Unit” where water and heat is used for future food production in Europe. The Green Circle is based on reutilization of the water between two different fish species, one warm water and one cold water, and for plants and algae originated from aquaponics. The recirculation system of the water is based on 40% - 60% re-circulation. Using this setup it is possible to increase the production with the same quantity of water and heat. The design will be used as a model for the future stations and food production in land based stations. Growing fish in different temperature and using cold water from Arctic charr for Tilapia is unique and is based on the principle that warmer water dissolves less oxygen than cold water. To use the effluent from the fish to produce herbs and/or algae for omega 3 production.



Green Circle

The selected species often live at optimum temperatures of 20-30°C and can be cultured in polyculture systems which can further be integrated into sustainable healthy ecosystems including aquaponics, fungi and single cell production. Aquaponics is defined as the polyculture of fish and plants. The word derives from a combination of aquaculture and hydroponics, which is the practice of growing plants without soil.

The implementation of sustainable polyculture aquaculture will introduce a whole new green food industry, utilizing local resources, building an ecological food park based on integrated systems with polyculture, aquaponics, tailored feed from local raw materials and added value food production with focus on healthy and safe food for export. Natural green production circles optimize the utilization of energy, water, organic waste material, land and other local resources. This will provide conditions favorable for the sustainable growth of European food production with focus on utilization of water and heat, ensuring both adequate supplies of seafood and vegetables and protection of the environment.

The first step is to focus on new warm-water species for aquaculture, initiating commercial production of Nordic tilapia in relation to Arctic charr production, designing a system for utilizing the effluent water from the fish rich in nutrients for vegetables production. Typically, an aquaponics system utilizes the nutrient-rich waste from a fish farm as fertilizer for the plants, to the benefit of both the product streams.

The objectives of this GEORG project are to find opportunities to utilize geothermal water and waste water from geothermal power plants to establish a whole new industry in warm water aquaculture producing new competitive species for mass production and export.

The implementation of sustainable warm water aquaculture in Iceland will introduce a whole new green food industry, utilizing local resources, building an ecological food park based on integrated systems with polyculture, aquaponics, tailored feed from local raw materials and added value food production with focus on healthy and safe food for export. Natural green production circles optimize the utilization of energy, water, organic waste material, land and other local resources. This will provide conditions favourable for the sustainable growth of Icelandic food production with focus on utilization of geothermal heat, ensuring both adequate supplies of seafood and vegetables and protection of the environment.

In this project focus has been on new warm-water species for aquaculture, initiating commercial production of Nordic tilapia in relation to Arctic charr production, designing a system for utilizing the effluent water from the fish rich in nutrients for hydroponic production of salad and herbs and growing the protein rich fungi, *Fusarium venenatum* on rest materials from vegetable production. Aquaponics usually involves using water as the growing medium for the plants, with fish living in that water, but there are many possible varieties of systems. Other designs use soil, pebbles or biological material for the plant growth media, and the used fish water may be pumped over the plants, filtered first, and/or chemically adjusted before being used for irrigation. Typically, an aquaponics system utilizes the nutrient-rich waste from a fish farm as fertiliser for the plants, to the benefit of both the product streams

The main achievements are development and design of the “Green Circle Unit” where water and heat is used for future food production in Iceland. The Green Circle is based on reutilization of the water between two different fish species, one warm water and one cold water, and for aquaponics. The first Green circle unit has been developed, designed and installed in Fellsmuli Iceland. This is a pilot and small industrial scale unit with two different fish species and an aquaponic unit. The recirculation system of the water is based on about 60% recirculation. Using this setup it is possible to increase the production with the same quantity of water and heat. The design will be used as a model for the future stations and food production in land based stations. Growing fish in different temperature and using cold water from Arctic charr for Tilapia is unique and is based on the principle that warmer water dissolves less oxygen than cold water. The project has been bigger effort than it was scheduled originally as it has taken some more time than planned to import new species and get license to make changes to the farm at Fellsmuli and to planning the facilities for the aquaponics. The work done so far has been successful as the green circle water system for the polyculture has been implemented and both the Arctic charr and the Nordic tilapia are well received on the market by the consumers. The design of the aquaponics pilot unit is finished and the aquaponic facilities in Fellsmuli is now up and running as the first aquaponic unit in Iceland connected to an industrial scale aquaculture station producing fish for export. The *Fusarium venenatum* fungi has been produced and it gives promising results for future feed material. In this report the main results from the project is presented.

WP1: Development and design of polyculture with minimum two warm water species

Warm water aquaculture is important for future production of food due to the rapid growth, low production cost and relatively low risk. It is the main production method behind increase in farmed fish and has been growing very fast in Asia. There is a need for increased warm water aquaculture in Europe, introducing new fish species that can grow fast to market size and also it is of importance to include species low in the food chain for increased sustainability and healthy food. There is a lot of knowledge regarding cheaper and more sustainable feed raw materials, polyculture and integrated systems that needs to be exposed and developed into business ideas. This project aims for developing profitable competitive landbased aquaculture using sustainable methods, designing aquaculture stations with integrated techniques focusing on relatively cheap solutions with raceways and optimization of breeding many species in a common system.

Integrated aquaculture has not been exposed and developed into large commercial units in Europe and this could become the breakthrough for European aquaculture.

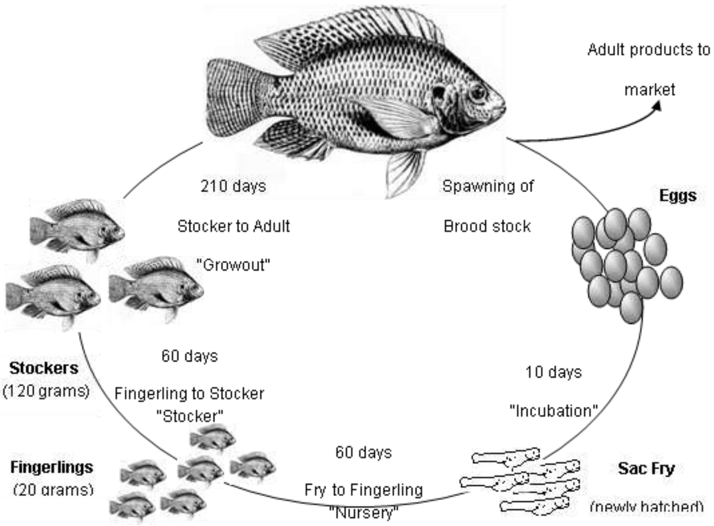
Polyculture of warm water species provide healthy ecosystems, but need careful development and design of the system, especially water management, that is how water is recirculated between different species, for optimal utilization of water, energy and nutrients, without increasing the risk of diseases and dangerous contaminations. Polyculture is providing new opportunities for aquaculture, not least land based aquaculture with new warm water species.

Utilization of geothermal energy for warm water aquaculture provides a whole new perspective for landbased aquaculture in Iceland and other places with geothermal heat. Limited development has been in Iceland during the last decade in aquaculture techniques, although the production of Arctic charr has been increasing. Most aquaculture farms are small and the total landbased production is approximately 3,000 tons annually. The implementation of novel techniques and new species focusing on the utilization of excess geothermal heat in an economically and environmentally beneficent way would increase the competitiveness of the Icelandic aquaculture industry and result in a lot of spin-offs. It is believed that the land-based warm water aquaculture could easily become 50,000 tons per year compared to the total aquaculture production in Iceland today of 5,000 tons per year. (Arctic charr 3,000 tons, salmon 800 tons and cod and other species 1,200 tons).

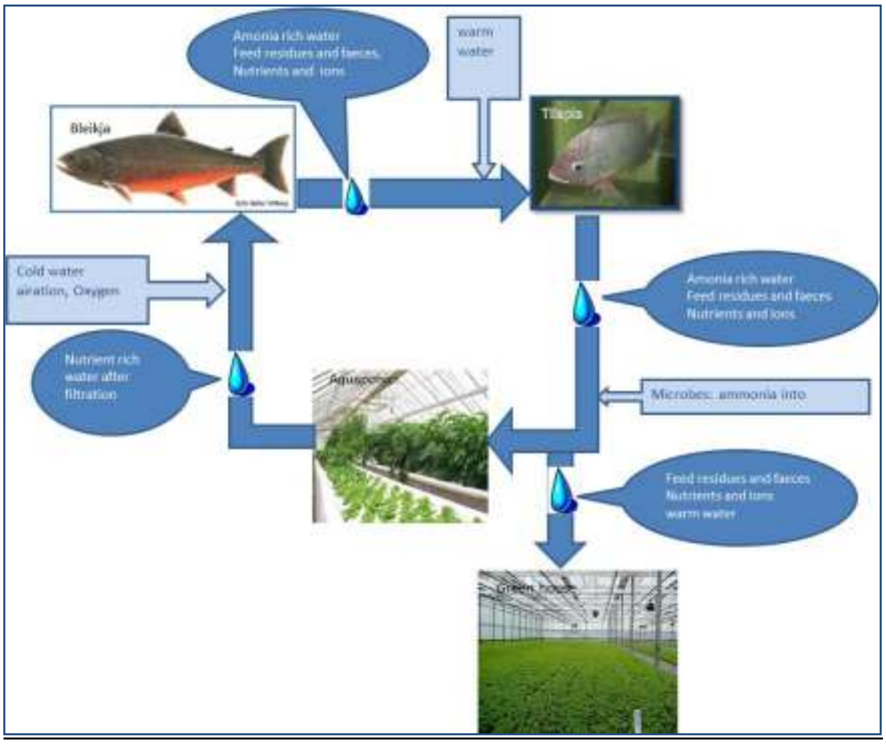
The Arctic charr aquaculture is a good business today but needs to be developed further especially regarding the water management and utilization of other natural resources. New species like the warm water species tilapia are growing to a market size within 7-9 months compared to 1,5-2 years for Arctic charr. Moreover, the warm water species can utilize residues feed and oxygen in the effluent water from the Arctic charr. The effluent water rich in nutrients from the warm water species could then be used for green house production. This creates exceptional opportunities for polyculture in Icelandic aquaculture businesses. Furthermore, the local production methods developed could be implemented in European aquaculture industry with other species, especially in places where there is abundant geothermal heat and/or waste heat from power plants or other industry.

Islensk matorka bought the aquaculture stations at Fellsmuli and Galtalaekur in Landsveit in South Iceland in September 2010. Fellsmuli has access to geothermal water and indoor facilities or warm water species, juvenile production and green houses, while Galtalaekur has access to self-running cold water for the on-growing of Arctic charr. Fellsmuli and Galtalaekur farms were smolt farms producing wild salmon and trout juveniles for the rivers and lakes. The production facilities in Fellsmuli have now been changed from being a smolt farm producing juveniles for the rivers to aquaculture of Arctic charr and Nordic tilapia for the food market. The production started in 2011 together with marketing in Iceland, Europe and USA. The Arctic charr has been sold mainly to Europe with a small amount to the Icelandic market, while the Nordic tilapia has mainly been sold in Reykjavik due to the relatively small production amount in 2011. Both species have been very well welcomed on the market as high quality products produced in a sustainable way. Brochures and logos were made both in Icelandic and English.

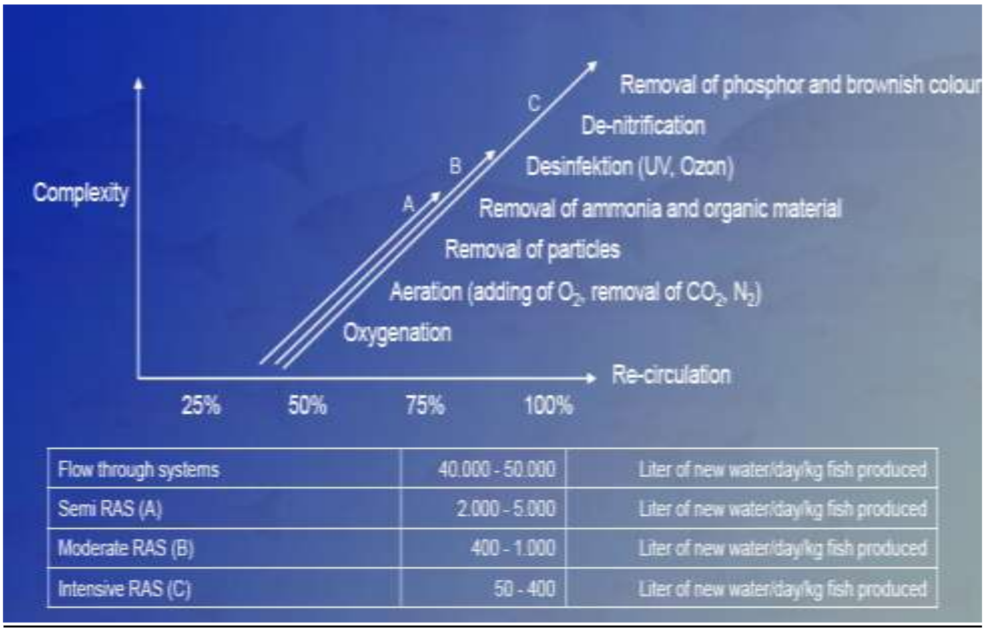
The production volume is increasing steadily and in 2012 the annual production is estimated to be approximately 100 tons of Arctic charr and 80 tons of Nordic tilapia. The tank volume for Nordic tilapia production has been increased tenfold and the recirculation of water is becoming approximately 70%, yet without using bio filters. This has been done by a new water system were the water is recirculated first in the Artcic charr tanks and then transferred through a system were the water is aerated and adjusted for the Nordic tilapia and then recirculated through the Nordic tilapia tanks. The final part of the system is composed of raceway and filtration system for the water prior to releasing as effluent to the river. The aquaculture station in Fellsmuli can today produce Arctic charr juveniles for an annual production of approximately 1,000 Tons of Arctic charr, but the company does not yet have tank capacity for the on-growing of more than around 150 Tons. With increased tank capacity and reutilization of water in Galtalaekur the production capacity of Arctic charr there could in practice become 300 Tons or even more. A change in Galtalaekur has been designed with a raceway system reusing water from the circular production tanks that are used today.



Life cycle of Nile tilapia. Fingerlings are grown to maturity and adults are sold in various forms as food fish. Adults are shown as 2.1 pounds.



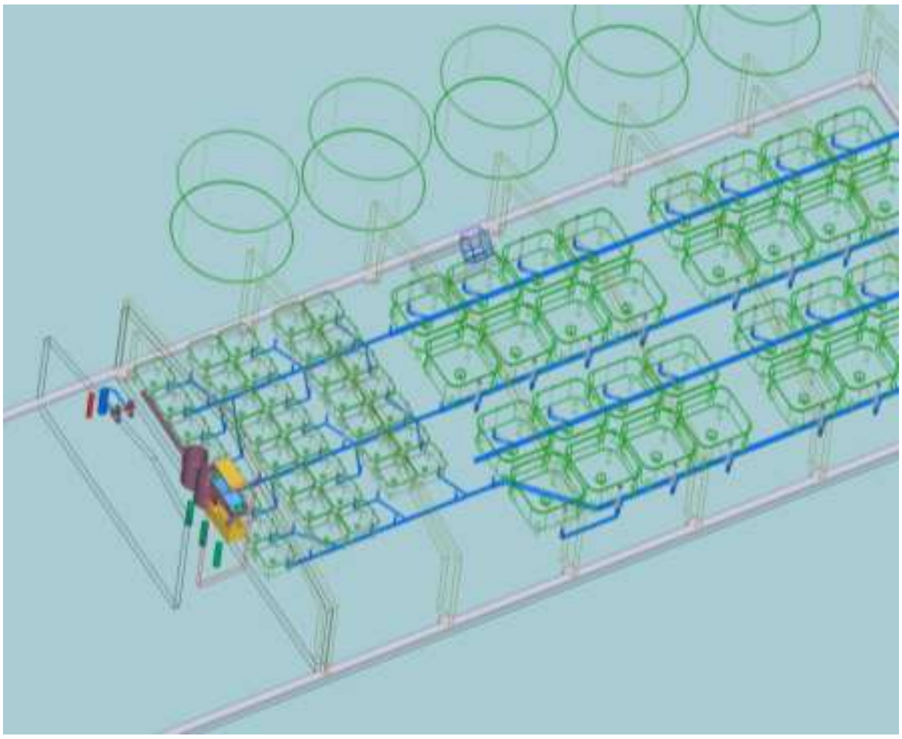
Green circle production



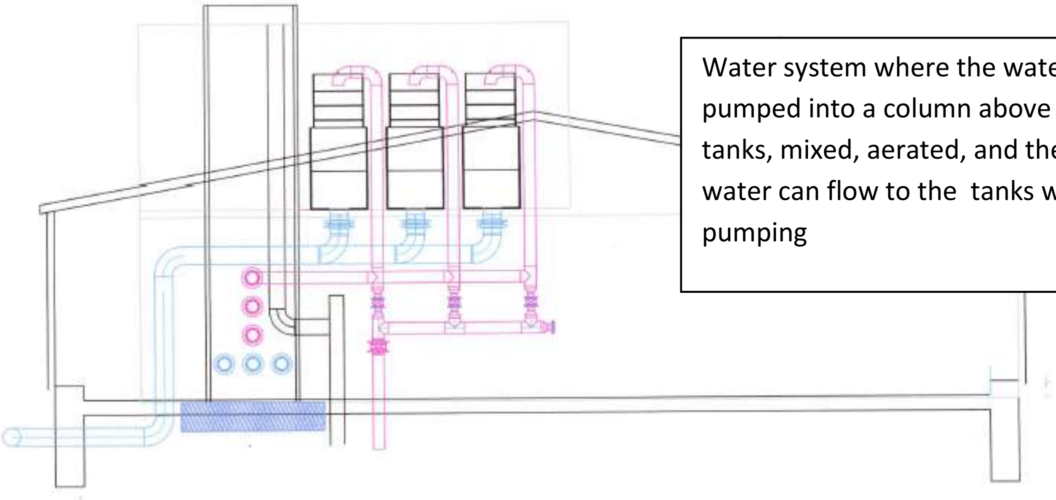
Flow through systems	40.000 - 50.000	Liter of new water/day/kg fish produced
Semi RAS (A)	2.000 - 5.000	Liter of new water/day/kg fish produced
Moderate RAS (B)	400 - 1.000	Liter of new water/day/kg fish produced
Intensive RAS (C)	50 - 400	Liter of new water/day/kg fish produced

Diagram showing the increased complexity of systems by increasing the recirculation of the system

Flow through system is the only one being used in Iceland and the system A and B has been set up in this project and is giving promising results. The aquaculture side of aquaponics operations can usually be classified into one of two different types: Recirculated Aquaculture Systems (RAS) and ‘pond’ or ‘open’ systems. Pond aquaculture is based on the simple, traditional method of fish farming, often in small natural or man-made ponds cut off from rivers, or in pens in larger lakes. In open aquaculture systems such as these, the farmer does not have much control over the water quality in the system, but there are often natural flushing mechanisms (for example, annual river flooding) which make it easier to control the amount of nutrients in the water. RAS systems, on the other hand are ‘closed’ production systems, where all the water quality parameters and characteristics are known and controlled. These systems are land-based, and usually fresh water. Managers control the feed inputs, water chemistry and temperature, but they must also provide the filtration system and waste treatment, something which would be taken care of by an open, self-flushing system. Another aquaponics technique which is usually carried out in marine waters is known as Integrated Multi-trophic Aquaculture (IMTA). This is normally an open type of system but could also describe some of the land based, fresh-water systems, such as a polyculture aquaponics operation with a closed nutrient cycle. The three aquaponics models will be explored in more detail below.

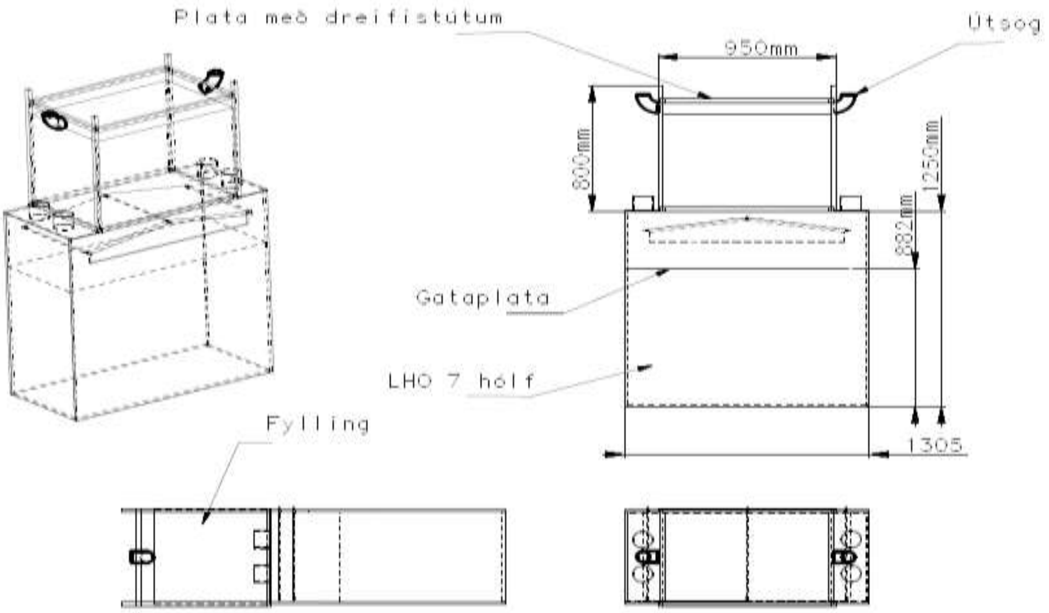


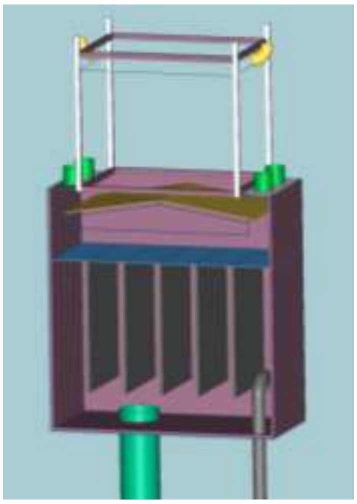
Schematic diagram, description of the setup of the water grading system



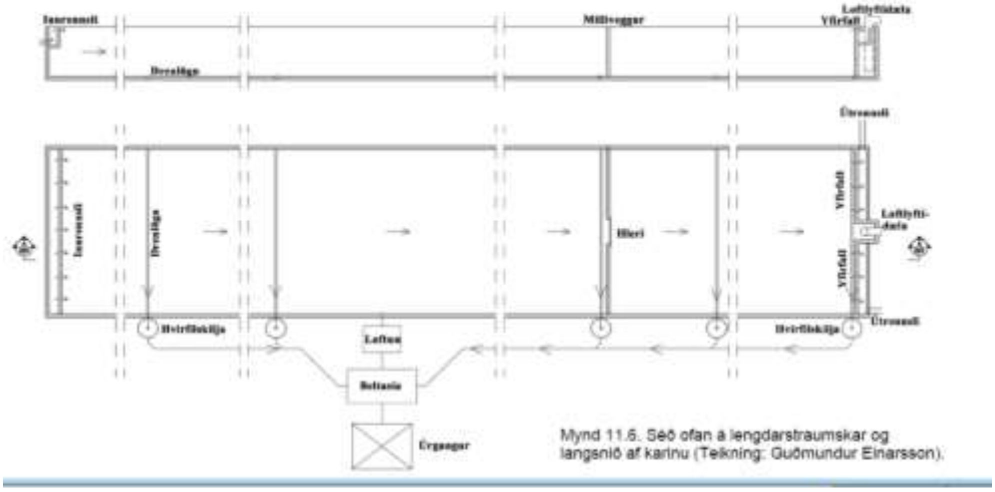
Water system where the water is pumped into a column above the tanks, mixed, aerated, and then the water can flow to the tanks without pumping

Water system was located in the containers

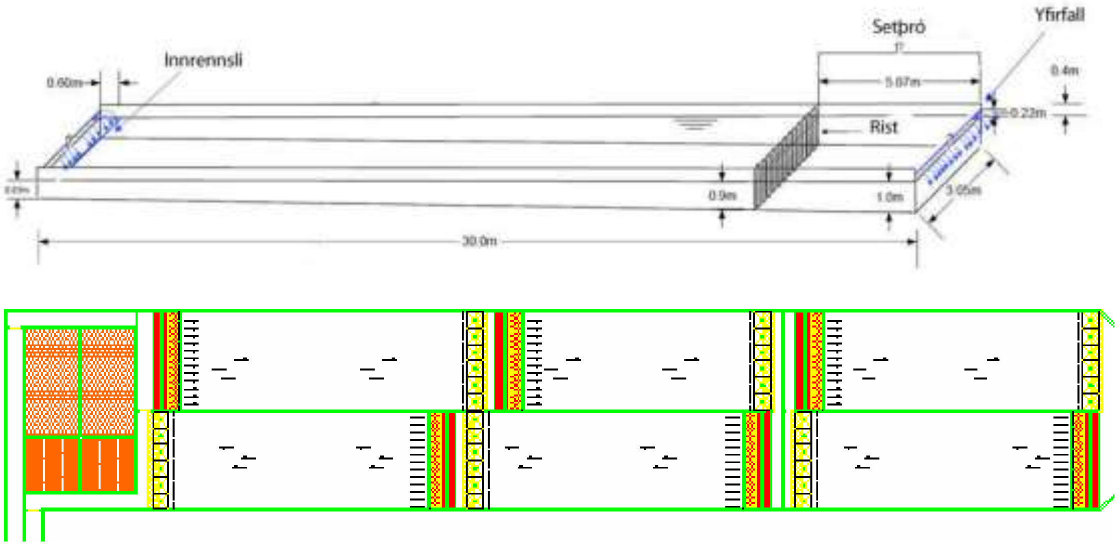




Airation system set up – low head generator



Mynd 11.6. Séð ofan á lengdarstraumskar og langsnið af karinu (Teikning: Guðmundur Einarsson).



Schematic diagram of the raise way showing the flow of water and recirculation of water through the raise way and how water is lifted by air

Planning of the station and buildings in Fellsmuli

ARCTIC CHARR NORDIC TILAPIA

The labels for charr and tilapia from Íslensk matorka

With increased recirculation in aquaponics systems the production of Nordic tilapia could be increased substantially, and this would also include an enormous production of vegetables and/or fruit in green houses. Arctic charr brood stock has been bought from Holar University College and Stofnfiskur and Tilapia brood stock has been imported from Canada. Import licenses from Icelandic authorities have also been given for the import of tilapia brood stock from Fishgen / Stirling University in UK. The plan is to import two different types, a silver type and a red type. The third species planned in the system is still being discussed but big shrimps such as Tiger shrimps are known to grow well together with the plants in the aquaponics system. Other species discussed are Vannamei and Rosenbergii shrimps. Shrimp farm in Australia has been contacted and they have sent information that is under evaluation for import of shrimp to Iceland. Also some salt water species have been evaluated and will be further evaluated if it is reasonable to import those to Iceland.

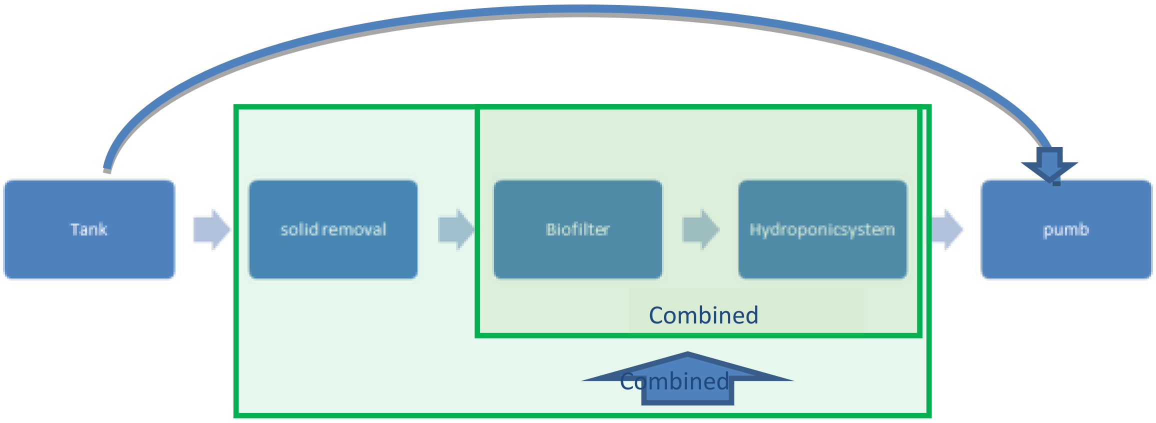
New system

Construction of the raceway and the new water system in Fellsmuli

WP2: Integration of aquaponics

The utilization of effluents from aquaculture to hydroponic production is called aquaponics. This is not a new idea, and has been used for example in Asia, Australia, USA and Central- America. The interest is increasing rapidly in Europe as this could become one of the future production methods for local food. The interest is mainly focused on urban production with small units for homes and restaurants, but in this project we are mainly focusing on larger production units by utilizing the geothermal heat and land space.

In aquaponics systems the effluents from one system become valuable raw materials for another system. The effluent water from the aquaculture is rich in nutrients for the plants and the plants clean the water that can then be recirculated to the fish. This is like a natural circle and thus it minimizes the environmental impact of the production. Therefore, if this is successful and economically beneficent, aquaponics systems could become a breakthrough for land based aquaculture stations as the bottleneck for the production capacity of land based units are most often the environmental impact of the effluent water. Moreover, this provides opportunities for more local food production that means less transport, increased food security and food safety, in summary increased sustainability.



Optimum arrangement of aquaponic system components – not to scale

For maximum growth, plants in aquaponic systems require 16 essential nutrients. These are listed below in the order of their concentrations in plant tissue, with carbon and oxygen being the highest. The essential elements are arbitrarily divided into macronutrients, those required in relatively large quantities, and micronutrients, those required in considerably smaller amounts. Three of the macronutrients—carbon (C), oxygen (O) and hydrogen (H)—are supplied by water (H2O) and carbon dioxide gas (CO2). The remaining nutrients are absorbed from the culture water. Other macronutrients include nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P) and sulfur (S). The seven micronutrients include chlorine (Cl), iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu) and molybdenum (Mo). These nutrients must be balanced for optimum plant growth. High levels of one nutrient can influence the bioavailability of others. For example, excessive amounts of potassium may interfere with the uptake of magnesium or calcium, while excessive amounts of either of the latter nutrients may interfere with the uptake of the other two nutrients. Enriching the air in an unventilated greenhouse with CO2 has dramatically increased crop yields in northern latitudes. Doubling atmospheric CO2 increases agricultural yields by an average of 30 percent. However, the high cost of energy to generate CO2 has discouraged its use. An aquaponic system in a tightly enclosed greenhouse is ideal because CO2 is constantly vented from the culture water. There is a growing body of evidence that healthy plant development relies on a wide range of organic compounds in the root environment.

It is necessary to use a bio filter in aquaponics systems. These are microorganisms that change ammonium from the fish to nitrite and then nitrite to nitrate. Without an effective biofilter the system would not work as ammonium and nitrite are poisonous for the fish and the plants need nitrogen mainly in the nitrate form. It normally takes approximately 2-4 weeks for the biofilter to get established and well-functioning in the system. In the project special focus has been on using natural substance as biofilter and Icelandic pumice has been tested and will is now used for the production.

There are three main aquaponics production methods, nutrient film technique, floating rafts and growbeds.

Nutrient film technique

In nutrient film technique systems a thin layer of water is flowing in plastic pipes, approximately 10-15 cm in diameter. The plants are grown in pots that are placed in holes made in the plastic pipes so they can reach the water and nutrients. The system is very simple and therefore relatively cheap and easy to handle. The system is suitable for salad, herbs and other small plants.

Floating rafts

The floating raft system is based on large and long tanks. The plants are grown in pots that are placed in holes on plastic plates (often polystyrene foam) floating on the water, similar to the nutrient film technique. The system is excellent for salad and other vegetables.

Growbeds

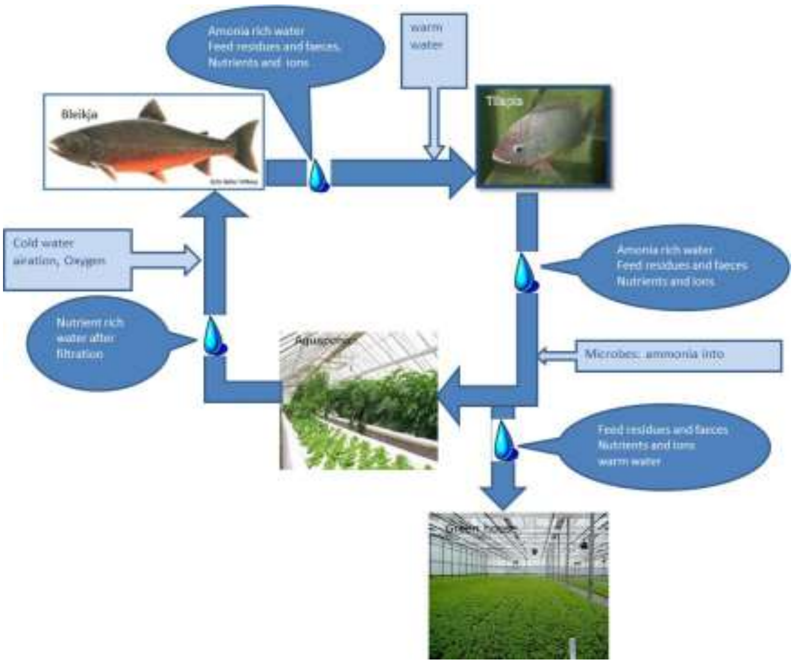
In growbeds systems some kind of gravel or sand is used to stabilize the plants. It also works as an aeration system. This provides better stability for higher plants, but in practice all plants can be grown in this system.

Three different plants, salad and herbs were tested. Trials at the institute's greenhouses showed that nitrogen, phosphorus, and other nutrients in aquaculture effluent can be effectively removed by plants grown in NFT hydroponics or constructed wetland systems. Tilapia is raised as a warm-water fish species. Hydroponic crops include basil, lettuce, and wetland plants.

Most big landbased farms in Europe use recirculating systems because they do not have enough water and have to comply with environmental restrictions. Fish farms with a recirculation of 95-99% have higher investment and operation costs. The electricity cost in Europe is in general 3-5 times higher than in Iceland. Warm-water stations in Europe often have to rely on weather conditions to be competitive. A few places in Europe have geothermal heat and some may use surplus heat from industry or power plants.

In Asia the aquaculture production is dependent on seasonal weather conditions and the products are sold frozen to the market. Aquaculture production cost in China is lowest in the south where the temperature is highest. The variation in the climate has a major impact on the production capacity. The temperature in the summertime is often too high and too low in the winter. A visit by Matorka to China gave a fairly good picture of the situation in Asia. Several problems associated with environmental conditions make these areas difficult for both the winter production and the hottest periods in the summer. Most warm water species do not tolerate a very high temperature variation, which is if the water goes much below 15°C or well above 30°C. Temperature in southern China is often down to 10°C in January and in northern China down to minus 10-15°C. The temperature in summer can then go well over 30°C throughout these areas. Changes in temperature and sea-water are 15-20°C between winter and summer, which has a great impact on the aquaculture because it is desirable to maintain stability in water temperature.

In Iceland, an aquaponic pilot plant has been designed and constructed based on results from the project. A pilot plant based on an NFT system and production of basil has been designed and been adapted to Icelandic situation.



Green circle production

To be able to start to build these greenhouses for the aquaponics all necessary permits needs to be in house. Therefore, it was decided to build a pilot unit that does not need new permission additionally with what Íslensk Matorka has today in Fellsmuli. The aquaponics is up and running. The water system from the fish tanks is being recirculated for aquaponic unit as the new system in Fellsmuli is the ideal setup for this aquaponic system. The plants grown in the new aquaponics system are lettuce, basil and mint. One of the most important elements of the aquaponics system is the healthy community of nitrifying bacteria that is required to transform ammonia from fish waste into nitrite, which is less toxic than ammonia, and then nitrate, which plants can use for growth. If ammonia is not converted by the bacteria, it builds up in the water and becomes toxic to the fish. This conversion process is natural, occurring in all ecosystems; the natural process can be harnessed for a RAS by using a ‘biological filter’, or bio filter. A bio filter is a unit containing a porous media that is well aerated, with the correct temperature, pH and DO levels, and importantly, plenty of surface area for the bacteria to grow on. Most small aquaponics systems do not require a separate biofilter because the media or the rafts and other parts of the system act as a biofilter, however systems using NFT to grow the plants do require biofilters since there is not usually enough surface area for adequate bacteria colonization. The process of nitrification occurs in two steps, with the help of two different autotrophic bacteria. The first is the conversion of ammonia to nitrite by Nitrosomonas bacteria, and the second is the conversion of nitrite to nitrate by Nitrobacter. Nitrifying bacteria work best when pH is around 7.0, which is also approximately the midway point between the ideal pH levels of the fish and the plants. Since the nitrification process also generates H+ ions (see equations above), the pH is being lowered all the time (the rate at which this occurs depends on the alkalinity, buffering capacity and temperature of the water being used), and research has shown that nitrification slows as the pH drops and will stop at below 6.0. As a result, most aquaponics growers add CaOH and/or KOH, which both raises the pH and provides supplemental calcium and potassium for healthy plant growth. If the biofilter malfunctions, or in an aquaponics system where there is no biofilter, levels of nitrite or nitrate could build up and become toxic to the fish. Nitrite poisoning in freshwater fish causes a condition known as 'brown blood disease' caused by the nitrite reacting with haemaglobin in the blood, preventing it from carrying oxygen. The New Zealand seafood industry has published safe limits of nitrite and nitrate for aquaculture species commonly grown there.

Nitrate and Nitrite Guidelines for New Zealand species

Species	Lifestage	Nitrite limits (mg/L)	Nitrate limits (mg/L)
Chinook Salmon	All	Freshwater <0.01	<400
Grass Carp	All	Ideally <0.03	No guideline
Paua	All	<0.1; no data available – estimate only (levels of 0.5 have been shown to affect growth	No guideline, generally not a concern
Pacific Oyster	All	Very tolerant to high levels	Not a concern. Used by phytoplankton who remove them from the water, as a source of nutrients
Red Rock Lobster	All	<1.0	<100 mg/L for short term exposure and <50 mg/L for long term exposure

Because aquaponics is a combination of different production systems, compromises sometimes have to be made with the optimal conditions. Most fish prefer a pH level at 7.5-8.0, most plants prefer pH of 6.0-6.5 and the nitrifying bacteria in the filter tank do best at 7.0-8.0. This means that the most commonly used pH level is 7.0. As discussed above, the nitrification process occurs less efficiently in lower pH conditions and low nitrifications occur in the biofilters at pH 5.5.

Most plants can grow well in *hydroponic* systems. Though there are some plants that can not tolerate to have the roots in water. The different hydroponic systems are fit differently for different plants. Root-vegetables are fits for *aquaponics* kerfi in rafts were heavy plants are not good in *floating rafts* system where the units cannot hold the weight. Main nutrients necessary for the plants are *macronutrients* carbon (C), oxygen (O), hydrogen (H), nitrogen (N), kalíum (K), calcium (Ca), magnesium (Mg), phosphor (P), and sulfur (S). Carbon, oxygen and water get the plants from the water and CO2 but the others are dissolved in the water. There needs to be equilibrium between the compounds. High content of one compound affects the absorption of another. High content of kalium prevents absorption of magnesium.

Appropriate concentration of nutrients in water for plants

Nutrition	**Min (ppm)**	**max (ppm)**
Nitrate	70	300
Ammonia	0	31
Kalíum	200	400
Phosphor	30	90
Calcium	150	400
Sulphur	60	330
Magnesíum	25	75
Iron	0.5	5
Bor	0.1	1
Mangan	0.1	1
Zink	0.02	0.2
Molybdenum	0.01	0.1
Copper	0.02	0.2

These are only reference as plants have different needs. Often there is lack of kalíum (K) and calcium (Ca) in aquaponics system and therefor these compounds needs to be added to the system. Aquaponics system is based on reutilization of water and provide system that decreases the water usage compared to aquaculture and green houses and releases less organic nutrients. Content of nutrients in water from tilapia RAS system was as seen in the following table.

Content of nutrient in fish water

Nutrient	**amount (g)**
Nitrate	26.7
Phospate	1.7
Sulfphate	2.6
Kalíum	57.8
Calcium	14.2
Magnesíum	2

Content of nutritional components of effluent from aquaculture after filtration through 10 m^2 *hydroponic* system.

Nutrient	**amount (g)**
Nítrat	22
Phosate	0.9
Sulfphate	2.1
Kalíum	55.4
Calcium	12.3
Magnesíum	1.8

Hydroponic is based on growing plants without using soil. In the nature the soil has the role to store salts, water and other compounds that the plant might need later. By using water with dissolved nutrients and contains all the necessary nutrients for growing makes it is possible to grow plants without soil.

Based on the Matorka situation the *NFT* system was selected as the best system for and what could be typical for Icelandic NFT syste*m.* NFT is being used in green houses in Icelandic with good experience in hydroponic situation. *The pilot* unit was designed and implemented. The NFT is likely to work for the Matorka system as it is not fully recirculated aquaculture system. Some of the water is re-used by the tilapia after it has been used by the arctic char, but it is then released into the environment (after the solids have been settled out of it). For this reason, many of the aquaponics system designs are not completely relevant. For example, much of the community aquaponics advice and design specifics concentrate on making sure the filtration system is working correctly so that the health of the fish is not compromised. In the Matorka system, there is no such requirement that the water be very clean or oxygenated after the plants have used it, since the fish are not going to be exposed to that water.

The design of the Matorka aquaponic system, and especially the initial development is focused on a number of issues:

- Treating the wastewater so that there are lower nutrient levels in the water that is released back into the environment. The cost of this effluent treatment would be subsidized by the sale of the vegetable crops, and Matorka would also benefit by being (one of?) the first land-based commercial scale fish farm companies in Iceland to treat their waste water in this novel and cost-effective way.

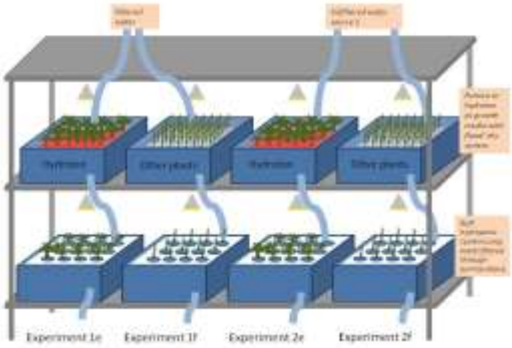
- Ensuring that the nutrients produced by the fish are bioavailable to the plants. This issue is related to the nitrification by bacteria, discussed above.
- Ensuring that the plants grown are either commercially viable, or the lessons learnt from the experiments will be able to be applied to other plants for which there is a market.
- Considering the future of fish farming in Iceland (and globally). There is a growing public awareness of some serious environmental concerns regarding fish farming. The use of wild caught fish as an ingredient in fish feeds is a big problem, and Matorka is already experimenting with alternative feed sources. The possibility of aquaponics being used as part of the fish food production loop in the future should be considered. Similarly, the production of biodiesel from algae, the use of a renewable energy source (such as hydropower) for the lighting, and development of similar plant or algae-based nutrient removal systems for saltwater fish farms could all be considered for future research.

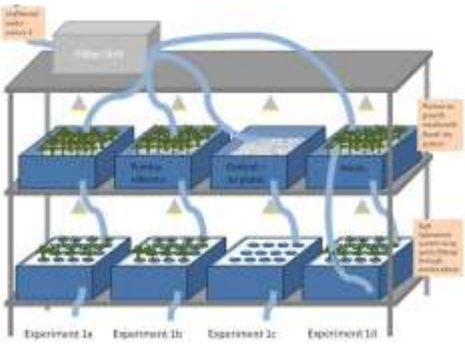
  Now the aquaponics has been designed, established and implemented in Matorka aquaculture station. In the implantation the system was tested for following parameters:

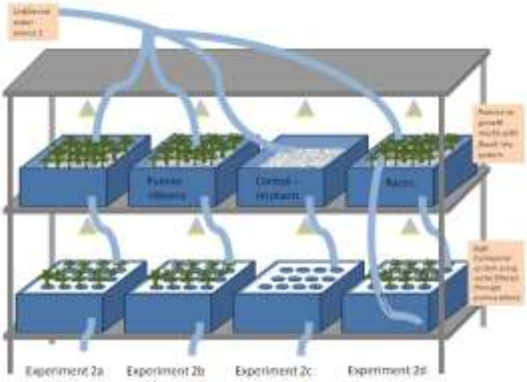
1. To characterise the water at various points in the Matorka production process and determine the best water source(s) to use for hydroponic plant growth.
2. To test various hydroponic systems and compare the productivity.
3. To test the efficacy of the different hydroponic systems as a means of removing nutrients.
4. To calculate the optimal amount of plant biomass that should be planned to utilise the nutrients in the Matorka waste-water stream.
5. Icelandic pumice as a bio-filter and develop it.

The new aquaponics system several parameters are still being tested and new innovation will be continued. The focus is on to optimize the usage of the water from the aquaculture station and the nutrient from the fish as well as the growth media for the aquaponics were the focus is on the Icelandic material such as pumice. The pumice is giving promising results as a biofilter for the plants.

The following diagram shows the design and setup and the aquaponics developments made:

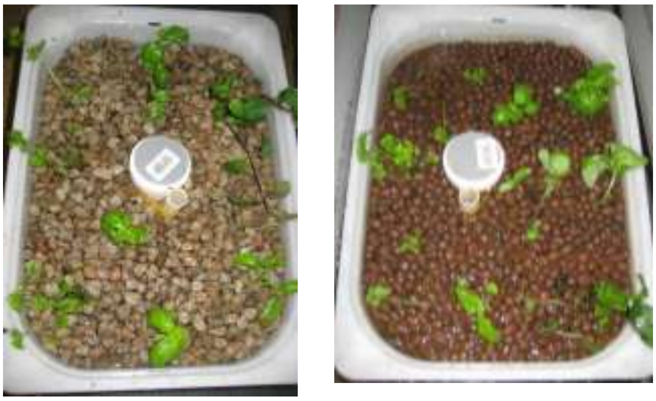






Description of experiment elements

Experiment	Water Source	Plant	Grow system	Water system
1a	Filtered	Plant type 1	L1- Pumice F/D L2 – Raft DWC	Flow through
1b	Filtered	Plant type 1	L1- Pumice F/D + Worms L2 – Raft DWC	Flow through
1c	Filtered	No plants	L1- Pumice F/D L2 – Raft DWC	Flow through
1d	Filtered	Plant type 1	L1- Pumice F/D L2 – Raft DWC	Recirculated
1e	Filtered	Plant type 1	L1- Hydroton F/D L2 – Raft DWC	Flow through
1f	Filtered	Plant type 2	L1- Pumice F/D L2 – Raft DWC	Flow through
1g	Filtered	Algae	TBD - Bucket with aeration?	
2a	Un-filtered	Plant type 1	L1- Pumice F/D L2 – Raft DWC	Flow through
2b	Un-filtered	Plant type 1	L1- Pumice F/D + Worms L2 – Raft DWC	Flow through
2c	Un-filtered	No plants	L1- Pumice F/D L2 – Raft DWC	Flow through
2d	Un-filtered	Plant type 1	L1- Pumice F/D L2 – Raft DWC	Recirculated
2e	Un-filtered	Plant type 1	L1- Hydroton F/D L2 – Raft DWC	Flow through
2f	Un-filtered	Plant type 2	L1- Pumice F/D L2 – Raft DWC	Flow through
2g	Un-filtered	Algae	TBD - Bucket with aeration?	



Pumice hydroton

Aquaponics setup in Fellsmuli with both Pumice as a biofilter and hydroton as biofilter.

The various elements studied was the water source focusing on the temperature, pH, suspended solids quantification, total N, total P, ammonia, nitrite, nitrate.

The results of the characterization is used to select the most appropriate water source for the plant growing experiments. The water from the end of the aquaculture station, which is has the highest amount of organic matter, and has also had the most opportunity for bacteria cultures in films on the various surfaces to have started the process of converting ammonia into nitrate. The other half of the experiments (2a-g) unfiltered water was used. Using unfiltered water could cause problems with organic matter build up, and it is possible that it will be necessary to modify it. However, it might be advantageous because the fact that Íslensk Matorka does not have RAS but 50-70 % reutilization of water means that the nutrients might be in much lower concentrations than in the published aquaponics system designs. Therefore the suspended solids in the water may be a valuable contribution to the plants' health.

Nutrient analysis of the aquaculture station and aquaponics system (Flett,I, Master thesis, 2012)

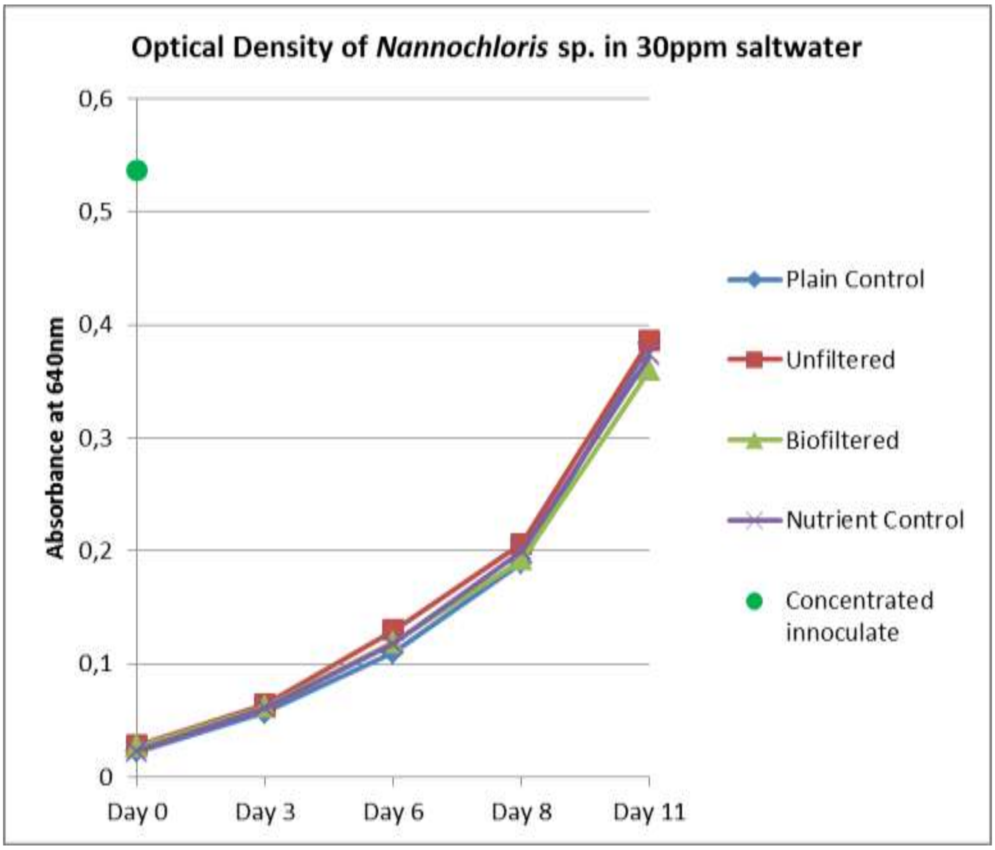
Water Source	Nitrate (mg/L)	**Nitrite (mg/L)**	**TAN (mg/L)**	**pH**	**Total Suspended Solids (mg/L)**
Cold Spring Water	0.122*	0.000*		7.98	0.00
Hot Ground Water	6.906*	0.015*			0.00
25 Degree tap mix	0.246*	0.000*		9.50	0.00
After charr tanks	1.139*	0.011*		8.01	0.30
Outside, before raceway	1.650*	0.039*		8.89	1.80
After raceway (trial water)	1.289*	0.038*		8.28	4.50
Experiment - Unfiltered inlet water	0.432*	0.092*		8.26	560.00
Experiment - Water at end of biofilter	0.261*	0.057*		8.05	0.00
Experiment - Tap water + pumice box	0.079	0.001		9.58	0.83
Experiment - Tap water + hydroton box	0.074	0.001		9.58	0.80
Experiment - Tap water + raft box	0.092	0.001		9.59	0.13
Experiment - Biofilter + pumice box	0.499	0.067		8.08	1.20
Experiment - Biofilter + hydroton box	0.525	0.084		8.09	1.50
Experiment - Biofilter + raft box	0.423	0.084		8.15	1.00
Experiment - Unfiltered + pumice box	0.334	0.059		8.26	3.57
Experiment - Unfiltered + hydroton box	0.348	0.066		8.20	2.97
Experiment - Unfiltered + raft box	0.281	0.059		8.29	1.07

**Data based on only one sample so far; final results may change*

The three experiment boxes receiving bio-filtered water show consistently higher nitrite and nitrate concentrations than those receiving ‘unfiltered’ water, as well as lower pH (highlighted). This indicates that the ammonia in the fish waste is being transformed into nitrite and then nitrate in the biofilter, which means that the nitrifying bacteria in the biofilter are efficient.

Optical Density - Absorbance Measured at 640nm

	Day 0	Day 3	Day 6	Day 8	Day 11
Concentrated inoculate	0.536				
Plain Control	0.022	0.057	0.11	0.189	0.384
Unfiltered Water	0.028	0.064	0.13	0.206	0.386
Biofiltered Water	0.027	0.062	0.119	0.192	0.36
Nutrient Control	0.023	0.061	0.118	0.2	0.373



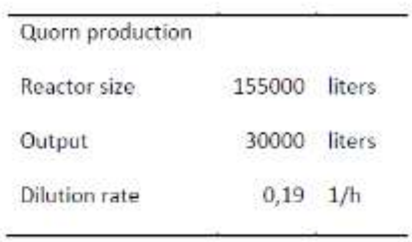
The aquaponic system is working according to the design and is a base for future development of aquaponics in Iceland.

WP3: Production of mycoprotein

Fusarium venenatum is a microfungus of the genus *Fusarium* that has a high protein content. One of its strains is used commercially for the production of the single cell high quality protein mycoprotein. It is a valuable food supply for human consumption, not least for vegetarians, best known as the Quorn products.

It could also be used for aquaculture feed, if economically feasible and thus making a difference for the economy and sustainability of aquaculture in general. Mycoprotein is produced by fermentation. The products are similar to meat as the hyphae of the fungi are similar in length and width to animal muscle fibres. Quorn production is at enormous scale, operating largest airlift reactors known today, with volume of 155m3, 50 meters tall, weighing 250 tons with an output of liquid volume 30 tons per hour.

The following table shows productivity of a one reactor at Quorn for mycoprotein production.



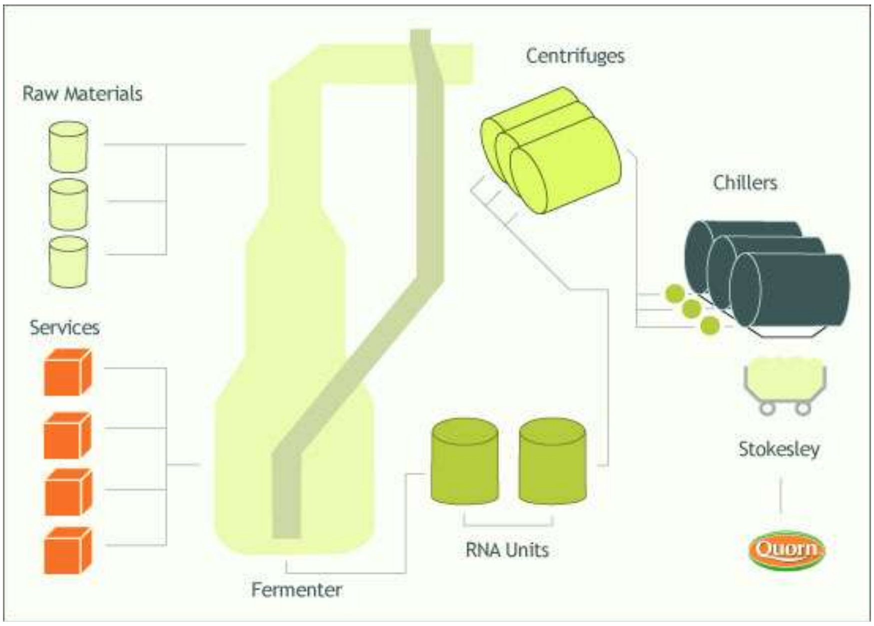
Quorn production		
Reactor size	155000	liters
Output	30000	liters
Dilution rate	0,19	1/h

Mycoprotein is the generic name given to the ribonucleic acid-reduced biomass comprising the hyphae (cells) of *F. venenatum*, initially identified as *F. graminearum*. Production of mycoprotein was introduced in the UK in 1985 under the brand name "Quorn" and was used as a meat substitute in foods. The Food and Drug Administration (FDA) approved the use of mycoprotein as a food ingredient in 1998. Mycoprotein is produced by continuous aerobic fermentation of food-grade carbohydrate substrates by *F. venenatum*. The nucleic acid content of fungi may be as high as Fungi may comprise 6% to 11%. In humans, the purine bases in the nucleic acids are metabolized to insoluble uric acid. This can lead to the formation of kidney and gall stones.

Mycoprotein has high all-round nutritive value, no animal fat and little overall fat, no cholesterol, high content of protein (nutritive value as high as that of skimmed milk protein), high dietary fibre content, contains useful amounts of trace elements and B vitamins. The fiber component of mycoprotein may function as a prebiotic in the lower gut.

Nutritional analysis of freshly-harvested mycoprotein:

Constituent	***Mass (g per 100g)***
Protein	*11.8*
Dietary fibre	*4.8*
Fat	*3.5*
Carbohydrate	*2.0*
Sodium	*0.24*
Cholesterol	*0.0*
Water	*75.0*



Schematic diagram of showing operation of mycoprotein production

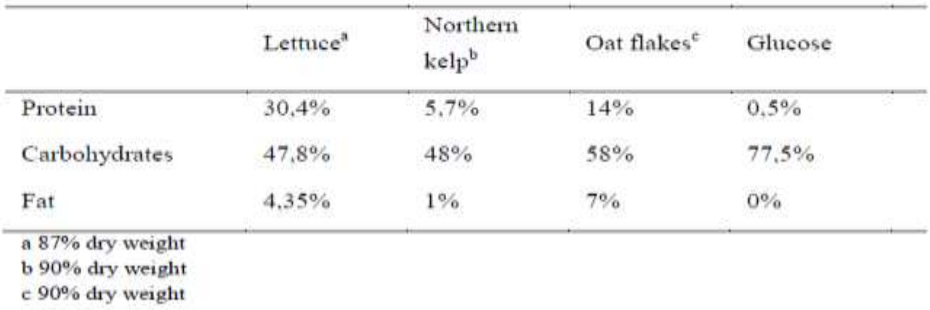
Islensk matorka and Matis ohf imported the *Fusiventarum venenatum*. This fungi (DSM 21739) was chosen on account of its suitable organoleptic and nutritional properties. The fungi was prepared initially on oat flakes at temperature of 22°C as recommended by supplier and after approximately 5 days it had grown to be later applied in experiments. It was withdrawn and stored in a cooler for later use. Fermentation tests have been ongoing growing the fungi on different media. Fermentation with iceberg salad, northern kelp and oat flakes has been done. Main theories within bioprocessing consist of pretreatment, bioreaction and downstream processing; Cellulosic materials are hard to breakdown, and therefore not accessible for microbes. Therefore cellulosic raw materials need the appropriate pretreatment in order to increase its digestibility for the fermentation process where microbes utilize the material as a carbon source to grow. Various methods are available but have to be considered from the raw material properties. The heart of the bioprocess is the bioreaction, where microbes are intended to grow in favorable conditions. Most common fermentation method is continuous culturing, where a constant flow though fermentation vessel takes place. Microbes are dependent on temperature, pH values, substrates that are supplied to them in form of raw materials, oxygen and other growth factors included. Downstream processing is the final stage where cells are removed from the reactor and separated and purified for further treatment.

Four main substrates were selected for comparison:

- oat flakes (as in the inoculum buildup),
- glucose (Lyles Golden Syrup), as an ideal substrate,
- lettuce (lettuce sativa) and
- northern kelp (Laminaria hyperborean).

Oat flake medium was added to the lettuce and kelp medium to observe if the oat flakes any growth variations would occur. These four materials were selected as medium based on the objective to compare two ideal mediums with the cellulosic medium, which was assumed to be less effective, but most interesting as available byproduct in Iceland which is discarded. The cellulosic substrates, lettuce and the northern kelp were pretreated by air drying; the lettuce was dried to an 87% of dry matter content and the kelp to a 90%. Then followed by grounding to a particle size of 250 µm conducted with a corresponding sieve.

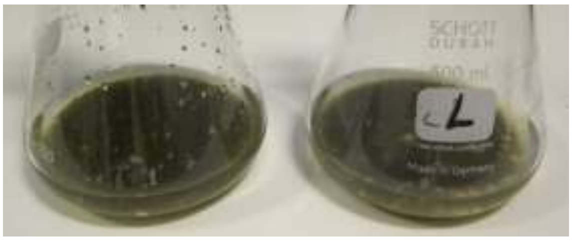
Subtrate nutrient values as g/100g



	Lettuce[a]	Northern kelp[b]	Oat flakes[c]	Glucose
Protein	30,4%	5,7%	14%	0,5%
Carbohydrates	47,8%	48%	58%	77,5%
Fat	4,35%	1%	7%	0%

a 87% dry weight
b 90% dry weight
c 90% dry weight

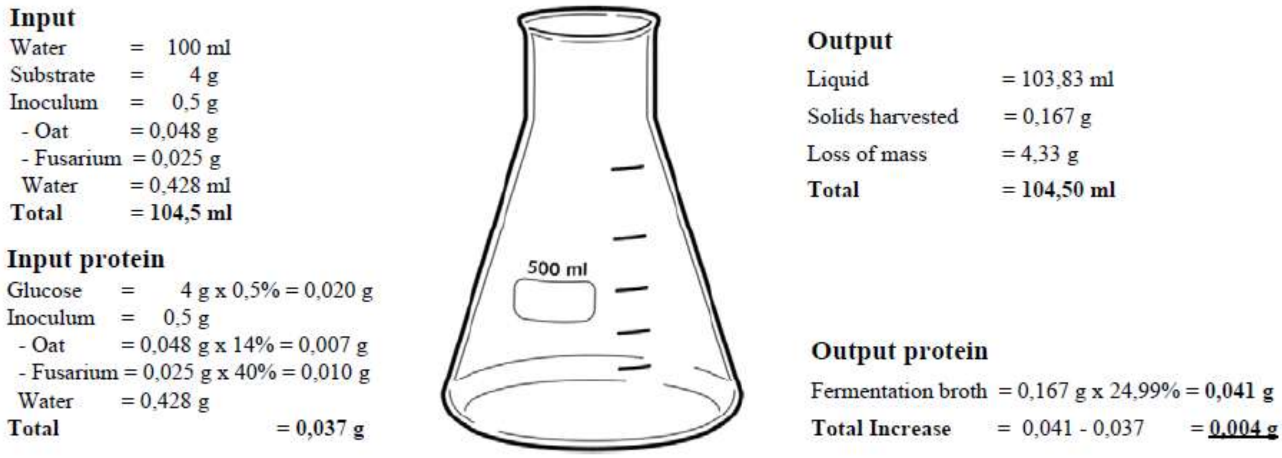
F. venenatum on day three grown on oat flakes at room temperature (Stefán Freyr Björnsson 2012, Master thesis in engineering)



F. venenatum on day three grown on oat flakes at room temperature. (Stefán Freyr Björnsson 2012, Master thesis in engineering)

Mycoprotein from lettuce, kelp and oat (Stefán Freyr Björnsson March 2012, Master thesis in engineering) The crude protein content of each culture on a dry weight basis (Stefán Freyr Björnsson 2012, Master thesis in engineering)

Substrate (30°C)	Crude Protein (%)	**Substrate (21°C)**	Crude Protein (%)
1. Lettuce	10,4	7. Lettuce	37,52
2. Lettuce + oat flakes	21,72	8. Oat flakes	31,04
3. Northern kelp	4,29	9. Northern kelp	5,94
4. Northern kelp + oat flakes	2,39		
5. Glucose	24,99		
6. Oat flakes	26,33		



Input

Water	= 100 ml
Substrate	= 4 g
Inoculum	= 0,5 g
- Oat	= 0,048 g
- Fusarium	= 0,025 g
Water	= 0,428 ml
Total	**= 104,5 ml**

Input protein

Glucose	= 4 g x 0,5% = 0,020 g
Inoculum	= 0,5 g
- Oat	= 0,048 g x 14% = 0,007 g
- Fusarium	= 0,025 g x 40% = 0,010 g
Water	= 0,428 g
Total	**= 0,037 g**

Output

Liquid	= 103,83 ml
Solids harvested	= 0,167 g
Loss of mass	= 4,33 g
Total	**= 104,50 ml**

Output protein

Fermentation broth	= 0,167 g x 24,99% = **0,041 g**	
Total Increase	= 0,041 - 0,037	= **0,004 g**

Raw material and protein flow for the glucose culture at 30°C. (Stefán Freyr Björnsson, 2012, Master thesis in engineering)

The filter cake obtained from kelp and lettuce cultures contained the highest proportions of solids, but clearly those cellulosic materials had not been enriched with mycelia protein. The lettuce was least promising as a substrate for bioconversion, resulting in no apparent growth and protein increase. The microscopic examination of the cellulosic cultures confirmed small amount of fungi present, confirming the results.

Nine trials of four different raw materials at two different temperatures were carried out. The two cellulosic materials lettuce and kelp went through a physical pretreatment. The other two materials involved were oat flake medium and glucose as favorable substrates. The experiment was set out to compare cellulosic materials as substrate for a fermentation process. The most protein increase in the fungal fermentation from the experiment came from a glucose medium.

These results agreed with theories as sugar based mediums are ideal source for microbial fermentation. Cellulose utilization is considered economically viable above 1 gram per liter an hour. The mass balance flow was based on relative research premises. If cellulosic bioconversion process to mycoprotein is to be economically viable then cellulose utilization and conversion rate have to be 35% and 45% respectively. From this premise a production yield of 0,164 gram per liter per hour of output from the fermentation process is considered to be on the average of economical viability.

Mycoprotein value was evaluated in terms of cost and nutrients. Soybean meal was the basis for mycoprotein price estimation and resulted with a $395 per ton. Mycoprotein theoretical nutrient value was utilized to optimize general aquafeed formulation. From the results mycoprotein was replaced with fish meal/oil about 4,5% share of the aquafeed mix and is considered a decent raw material ingredient for aquafeed formulation. Assuming that an industrial scale process capacity of cellulosic waste has to be at least 6,5 tons to break even, a mycoprotein production would require at least 10.000 liter bioreactor. Establishment of the production plant must take into consideration proximity to resources of raw materials availability to sustain the process at lower substrate cost. (Stefán Freyr Björnsson, Master thesis in engineering)

Operation design

Raw material as substrate: Following operation phases to turn cellulosic material into reactive substrate for fungal fermentation followed by downstream processing.

Alkaline pretreatment: Alkaline pretreatment acquires only ambient conditions, therefore usually less severe than other pretreatments. But the tradeoff is a short processing time than for other pretreatments which however requires higher temperature. The raw material is obtained fresh and put in an alkali solution, with the objective to release lignin from the cellulose by making it more digestible. Using 1,5% sodium hydroxide (NaOH) for wheat straw for 144 hours at 20°C, results in 60% release of lignin and 80% release of hemicelluloses making cellulose more accessible. The solution is reused after each batch of raw material. After the treatment the material is washed with hot water to remove substantial amount of alkali metals. A buffer tank needs to be installed due to the long period of alkali treatment, so material is not lacking for feeding the reactor.

Drying: The material is dried until 90% of dry matter content is reached, in order to achieve sufficient grinding process after the alkali treatment. Drying is uncertain and depends on material properties and drying time depends on water content for each specific substrate. Rotary drum driers are applicable for continuous systems; the drier will be reused later in the process. Drying is the most energy consuming phase in the process and minimizing resident times of material is crucial.

Grinding: The aim is size reduction of the cellulosic residue to increase surface area. The material will be put through a hammer-mill, with 0,05 mm screen and wet disintegrated. The particle size is determined of common procedure with typically ≤50 µm particle size. The energy requirements for physical pretreatments are dependent on the final particle size and reduction in crystallinity of the ligno cellulosic material. Thus, large particle sizes can greatly reduce the costs of the overall process.

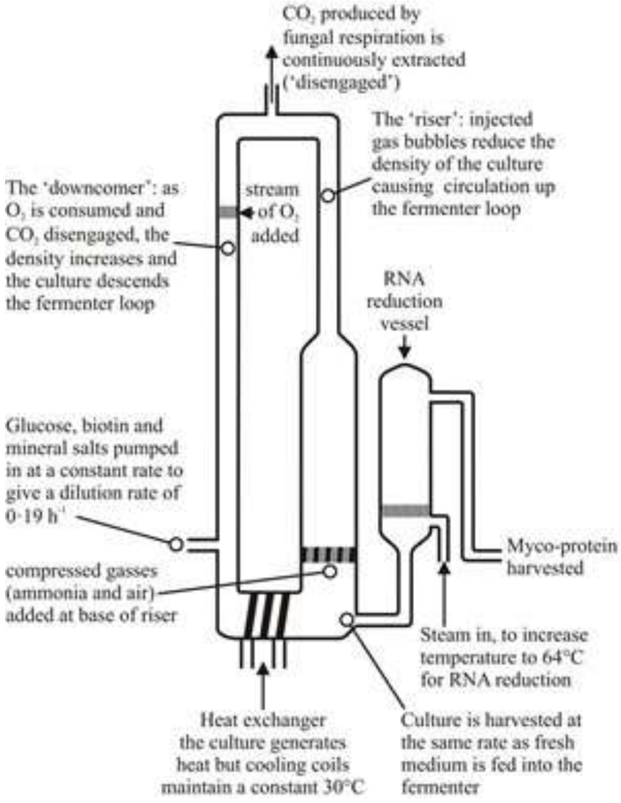
Medium formulation: The substrate is treated before fermentation by adding water, nitrogen, minerals and other growth factors to the solution. The nitrogen sources are derived from ammonia or ammonium salts and phosphorus added as salt which are required with naturally sources of cellulose. The medium is recommended from a cellulose fermentation.

Sterilization/autoclaving: In order for the substrate and fermentation to be effective, sterilization is vital to eliminate other contaminants. The medium is sterilized in an autoclave at 121°C for 20 min as standard procedure for substrates and then aseptically transferred to a bioreactor after being cooled to ambient temperature. The bioreactor is sterilized before fermentation. Sterilizing a large laboratory vessels (e.g., 20 liters) containing cellulosic substrates impose complications, because longer sterilization periods are often needed in order to hinder convection of cellulose in slurries.

The fermenters currently being used to manufacture mycoprotein are 40m high. The fermenters run continuously for six weeks, after which there is a two week period for cleaning and preparing the fermenter for the next run. During the six week run, there is a steady input of nutrients and a corresponding output of medium containing the product. Apart from oxygen, a source of carbon is required; this is provided as a syrup, containing approximately 95% glucose, derived from enzymic and/or acid hydrolysis of maize starch. Nitrogen is also needed; this is supplied as ammonia. Other mineral ions, including potassium, magnesium and phosphate, are also supplied, as well as trace elements.

Stringent precautions are taken to avoid contamination with unwanted organisms which would ruin the product and compete with *Fusarium* for the substrate. These include the initial sterilization of the fermenter, using steam. The incoming nutrients are heat sterilized and a filtered air supply is used. Conditions within the fermenter are monitored by means of probes. Adjustments to pH, temperature, nutrient concentration and oxygen supply can be made as required to secure the optimum growth rate. After emerging from the fermenter, the mycoprotein is subjected to a temperature of 65°C, a treatment which triggers the breakdown of most of the fungal nucleic acid, the level of which would otherwise exceed health and safety limits. The material is then dried in huge centrifuges. It emerges from the dryer looking rather like pastry and has a slight mushroom-like smell.

In order to achieve the highest production yield, cultivation parameters including temperature, agitation speed, carbon and nitrogen sources is optimized. The optimum conditions obtained for mycoprotein production were: 25°C, 150 rpm, 5 g of glucose per liter and 3.4 g of ammonium dihydrogen phosphate per liter which resulted in the product containing 42% (w/w) crude protein.



The nitrogen supply for growth (which is ammonia) is fed into the fermenter with the sterile compressed air, at the base of the riser. The rate of supply of ammonia to the culture is regulated by a pH monitor set to give a culture pH of 6.0. The nutrient solution is fed to the culture to give a dilution rate in the range 0.17 to 0.20 h^{-1}, and is operated as a glucose-stat, that is, glucose is always in excess and the fungus always grows at μ_{max} at a biomass concentration of 10 to 15 g l^{-1}. The fermenter is can be a 24-h basis.

In this process, the temperature of the biomass is raised to 68°C for 20 to 30 min to stop growth, disrupt ribosomes and activate endogenous RNAases which break down cellular RNA to nucleotides which diffuse through the hyphal wall into the culture broth. Importantly, RNAases are more heat resistant than proteases, so protein loss is minimized. This method is carried out in the culture broth with no other adjustments, since a pH of 5 to 6 is optimal for RNAase activity. RNA reduction has a substantial economic penalty attached to it, since as well as removing RNA, other cell constituents are inevitably lost during this process, including perhaps up to 30% of the biomass dry weight and a significant amount of protein, but it is essential to reduce the RNA content. After this treatment, the mycoprotein contains only 1% (w/w) RNA, similar to that present in animal liver and well within the 2% (w/w) upper limit recommended by WHO.

One of the advantages of using a filamentous fungus rather than a bacterium or yeast for SCP is the comparative ease with which mycelia can be harvested. After RNA reduction, fungal biomass is harvested by centrifugation to give a product which contains about 30% (w/w) total solids.

Continuous operation: The medium is introduced to the reactor and the fermentation broth is removed continuously after a few hours when cell growth is reaching its maximum and reaching steady state ($dX/dt = 0$). Feed stream is added continuously corresponding to extraction of effluent when the system is stabilized. Oxygen is supplied through sparging in the reactor with gas consisting of approximately 21% of total air volume, and dissolved oxygen ranges between 17-20% of the air saturation value. pH value is adjusted with 0,1 M solution acetate

Centrifugation: buffer and kept within range of pH 6,0 - 6,5 and the temperature is kept within range of 25-30°C. Salts of potassium, manganese, cobalt, calcium, magnesium, iron, copper and biotin recommended as nutrients to enhance culture growth. Appropriate reactor would be an airlift bubble column reactor where no stirring occurs, to prevent damage to the mycelia tissue. Care must be taken to ensure the substrate is evenly suspended in the feed reservoir, for delivery of constant feed sample as the reservoir empties Substrates invested have to correspond to an even distribution throughout the chemo stat in order to monitor accurate data as non-uniform distribution of particles complicates interpretation of data Suspension of the substrate in the fermenter is also important, and consistency of substrate concentration in the fermenter and the effluent leaving the reactor. Two streams are identified when the biomass is harvested from the reactor; the biomass and the rest product. The rest product is the slurry which is separated from the biomass in a centrifuge and might be used as a byproduct or disposed. Molds are relatively easy to harvest due to their filamentous nature, but in this case when solids are present, filtration is not sufficient if the fungal mass is to be obtained as a single substance. Therefore, centrifugation is an adequate method when separating the fungal mass from the broth. The biomass harvested from yeast culture through continuous centrifugation has resulted with biomass concentrations of about 30% (w/v)

Drying: Before finalizing the product by a grinding process, drying is conducted by a rotary drum drier, with optimal temperature of 75°C. Heating beyond that temperature might cause decrease in nutritional value due to alteration in the lysine. Therefore drying temperature within range of 30-50°C is considered adequate. Heat treatment for RNA reduction is disregarded. Heat treatment is normally conducted by heat shock at 64-65°C for 20-30 minutes. The fungal mass has 75% moisture content and 90% of water content is removed in the process. The drying process yields stabilized product with shelf life for few years.

Grinding : The dried filter cake is then grinded to mycoprotein meal in and prepared for further processing for fish feed formulations as the final step. The process is simplified with inputs of cellulosic waste and water, while the outputs are biomass and wastewater.

Mass flow: Solid substrates continuous cultures are similar to the ones grown on soluble substrates with respect to concepts of balanced metabolism and substrate limitation. In a steady state extracellular variables (e.g., substrate, cell, and product concentrations) over time, can be referred to in a chemostat a “balanced metabolism” where no significant change occurs of intracellular metabolites. Substrate limitation often desirable in a chemostat, corresponds to when an increase in certain a substrate would also increase the rate of growth whereas increase in other substrates would have no or little effect on growth. The inputs are cellulosic waste, inoculum and water while the outputs are biomass and wastewater. A mass balance calculation for each step in the process has been illustrated. Development of large scale production of mycoprotein will require refinement of already proven systems, scaling them up or down. The development and production of mycoprotein in the project is based on batch production and the design and calculation for the continuous production in a bioreactor is based on that.

Nevertheless simple batch cultivation scheme using fermentation flasks is adequate to some extent to realize growth and performance of microbes. Theoretical profiles on nutrients of *F. venenatum* fungus will be elaborated on and applied in optimization of ingredients for a standard aquafeed mix. Assessment is made on potentials in Icelandic aquaculture industry. By assessing potentials for Iceland to improve the domestic feed production in terms of resources of raw materials availability for integration to aquafeed. The issue in converting cellulosic waste to protein rich aquafeed, intended as replacement ingredient of fish meal in the aquafeed formulation (Stefán Freyr Björnsson, Master thesis in engineering). The development of the process has been implemented and the operation is established to produce products for experiments for testing in feed and will we developed further for full industrial scale using selected raw material as substrate based on the result from the project.

The green circle is to increase the sustainable production of high quality food for export by utilizing the abundant resources in Iceland, not least the geothermal resources, other renewable energy resources, clean water, land space and natural image. That is to make use of natural processes in the production of healthy food.

2 Project Management

1. Development and design of polyculture with minimum three warm water species

The project has been completed according to schedule. The design of the polyculture is now ready for three species and has been implemented for two species and will be implemented for the third species as soon as the company get the import accepted. The import is taken more time than initially planned.

2. Integration of aquaponics.

The integration of the aquaponics was more time consuming than expected but has now been implemented as part of the green circle.

3. Production of mycoprotein

The production has been carried out and been implemented for different substrates.

The project management has been carried out as planned. Nordic project has been established both in development of aquaponics and feed. This is a network of the leading groups in the Nordic countries in implementation of aquaponic.

3 Student involvement

- The engineering master students Tryggvi Sigurðsson and Daníel Másson have been working on the aquaculture part in WP1.
- The engineering student Elma Dögg Steingrímsdóttir and the biology student Hildur Gyða Grétarsdóttir have worked on the aquaponics part in WP2 in their summer studies 2011.
- The master student Stefán Freyr Björnsson from Aarhus University – Institute of Businessand Technology, has been working on the *Fusarium venenatum* part in WP3 as part of his master thesis.
- The Master student Iona Flett Masters in Coastal and Marine Management, University Centre of the Westfjords, Ísafjörður, Iceland has been working on the aquaponics system in WP2 as part of her master thesis.

4 Publications and disseminations

Aukin Framleiðslugeta Bleikjueldisstöðva, MSc project, Daníel Másson and Tryggvi Sigurðsson, februar 2012

Aquaponics kerfi, Nýting frárennslis frá fiskeldi til gróðurræktunar, Elma Dögg Steingrímsdóttir og Hildur Gyða Grétarsdóttir, Nýsköpunarsjóður námsmanna, September 2011

Green geothermal growth, Use of geothermal heat for warm water ecoculture, 6 months status report October 20th 2011, GEORG seminar, Reykjavik University, Ragnheidur Inga Thorarinsdottir

Green circle innovation. Lecture at Seafood industry conference 8-9 november 2012.

5 Cost statements

The project cost is according to original plan. Salaries for staff and students was 4,1 million Is kr for the second year and totally 14,1 million Is kr for the project. The operational cost is composed of technical support and engineering support and transfer of knowledge and necessary material for polyculture , aquaponic and mycoprotein. The total operational cost was 8,27 million Is kr for the total project. The travel expenses is knowledge transfer from Canada and Europe to Iceland totally 2,06 million Is kr for the whole project.