GAIN
Green Aquaculture Intensification

SUMMER SCHOOL

FROM AUGUST 30TH TO SEPTEMBER 3RD

This project receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773330 (GAIN)

SUMMER SCHOOL

Getting the best out of aquaculture wastes

GAIN SUMMER SCHOOL

01.09.2021

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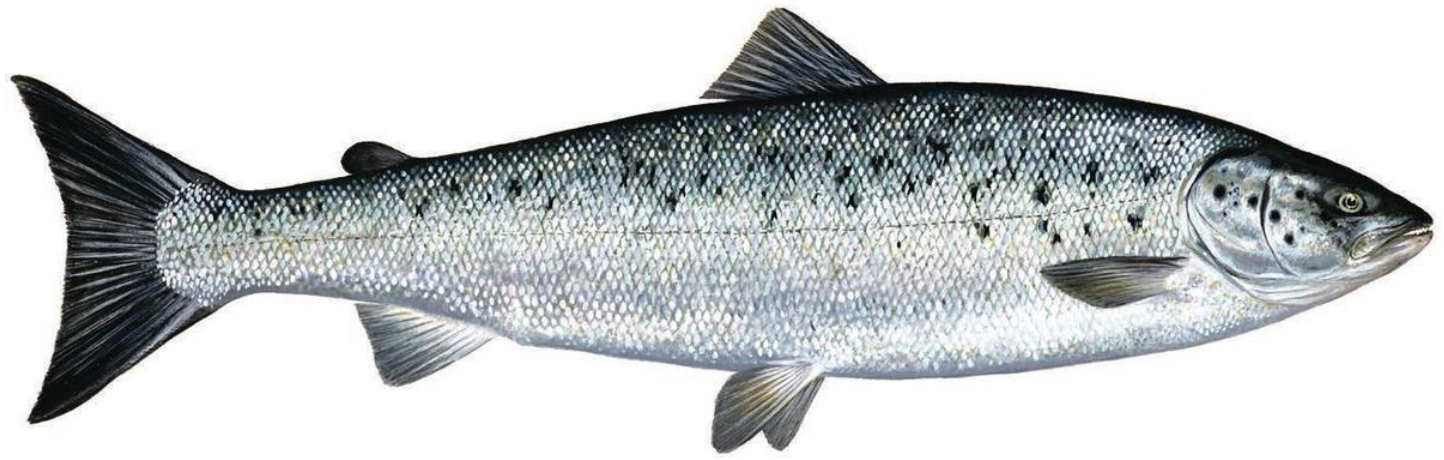
Aquaculture Mass Balance and Side-Streams

Norway is the largest salmon producer in the world. Norwegian salmon farming mass balance is shown below. Eco-intensification of aquaculture means transformation of side-streams into new raw materials in other industries to create a circular economy. GAIN has investigated innovative technologies for enhancement of these side-streams.

INPUT
Fish: 300.000.000 smolt
Feed: 1.600.000 tonnes



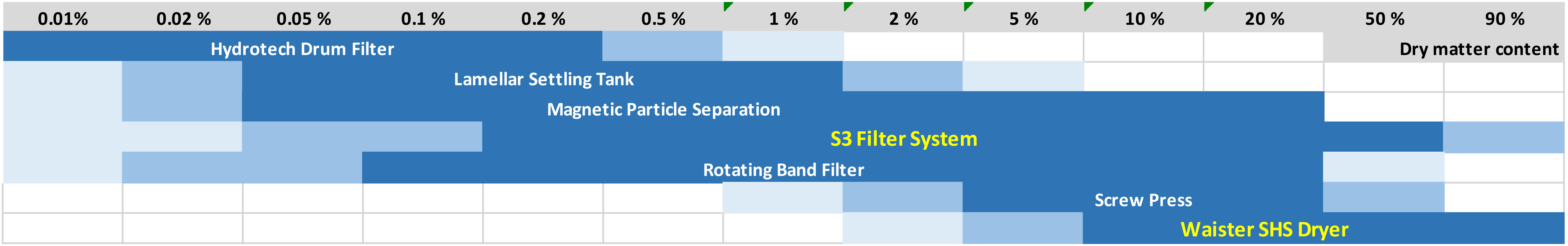
OUTPUT
Fish: 1.250.000 tonnes

SIDE-STREAMS

- **Mortalities: 60.000.000 fish (approx. 60.000 tonnes)**
- **Excess feed and faeces: 275.000 tonnes dry sludge**
- **Dissolved nutrients in wastewater**

Source: BarentsWatch (https://www.barentswatch.no/en/)

BACKGROUND – Fish Sludge in Landbased Aquafarms



The **S3 Filter System** and **Waister SHS Dryer** were chosen as innovative technologies for application on fish sludge within the GAIN project, as these technologies represented two alternatives for cost-efficient transformation of aquaculture wastewater into a dried and stable circular economy product.

- Few steps in dewatering and drying
- Robustness in DM as input to the process
- Creating best quality dried end product

Legislation-driven technology development. Removal of:

- 50-70 % of suspended solids (SS): >0,45µm
- Minimum 20 % reduction in COD/BOD (mg O_2/l)

Characteristics:

- Typical Dry Matter (SS): 0.01-0.02%
- 1 kg feed typically produces 0.15 kg dried fish sludge consisting of faeces and excess feed
- Nitrogen: 7 mg/l (95% ammonium NH4+)
- Phosphorus: 9 mg/l
- Salinity: ≈1‰ (smolt)

Wastewater from smolt production

Wastewater	Observed values	Analytical method
Suspended solids (>0.45µm) (n=8)	0.006-0.180 %	EN872
Particle size (n=6):		
- Median diameter	0.097-0.469 mm	ISO13320
- Average diameter	0.170-0.569 mm	ISO13320
Organic matter:		
- biochemical oxygen demand (BOD) (n=4)	100-200 mg l^{-1}	EN1899-1
- chemical oxygen demand (COD) (n=6)	219-2290 mg l^{-1}	ISO15705
Chloride (Cl^-) (n=3)	620 - 1960 mg l^{-1}	SM 17 udg. 4500-NH3
Conductivity (n=3)	47.6-242 mS m^{-1}	ISO7888
Total phosphorous (n=4)	6.2-9.3 mg l^{-1}	ISO6878
Orto-phosphate (n=2)	1.5 mg l^{-1}	ISO15681-2
Total nitrogen (n=3)	4.3-7.8 mg l^{-1}	ISO15682:2001
Ammonium (n=3)	1.1-6.9 mg l^{-1}	ISO11732
Total fat (n=4)	4.8-27.4 mg l^{-1}	CSN757506

Aquaculture side streams – dissolved matter

- Besides, particulate matter aquaculture wastewater contains dissolved substances as e.g. nitrogen and phosphorous compounds.
- Technologies to remove dissolved substances are based on filtration of wastewater, either supplemented with coagulants or treated with sono-electro flocculation, to precipitate dissolved matter.
- Another possibility to extract dissolved matter, particularly nitrogen and phosphorus containing compounds, is the cultivation of seaweeds in aquaculture wastewaters.

Aquaculture side streams – dissolved matter

Coagulants and polymers
‘Magnetic particle separation’
P removal >96%
N removal >30%
SS removal >95%

Highly effective and cannot clog up, but renders the phosphorus unavailable for plants

Aquaculture side streams – dissolved matter

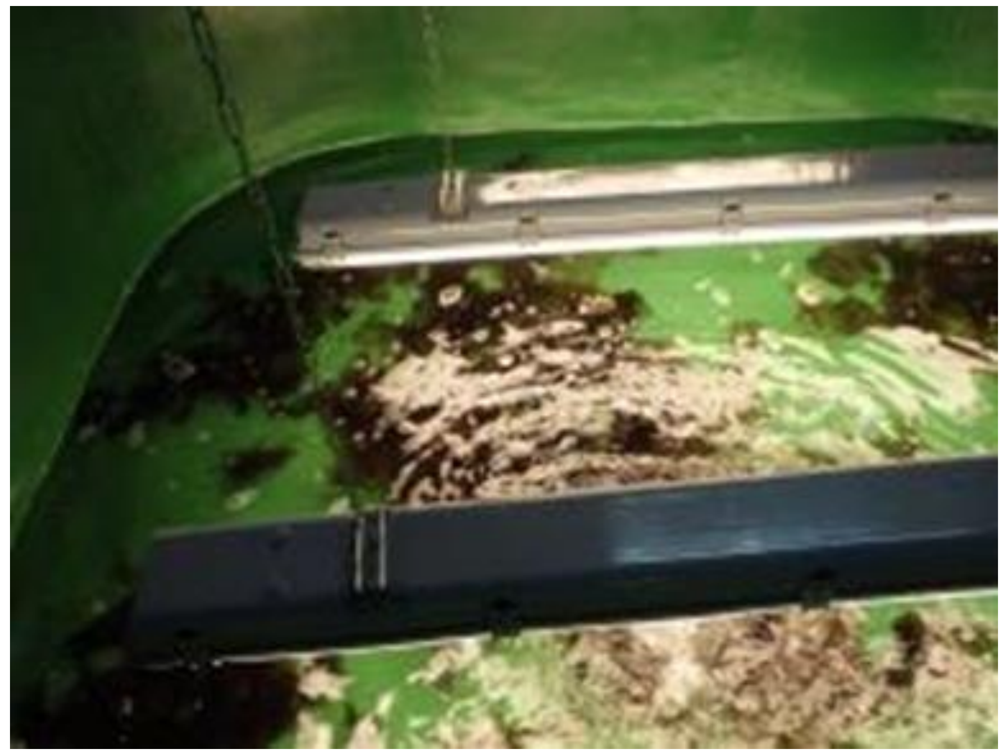
Sono-electro flocculation
P removal >99%
N removal >80%
SS removal >99%

Strong electric field and ultrasound gives a very efficient water treatment

Aquaculture side streams – dissolved matter

Seaweed cultivation in aquaculture waste water may be used to remove dissolved nitrogen and phosphorous compounds from aquaculture wastewater.

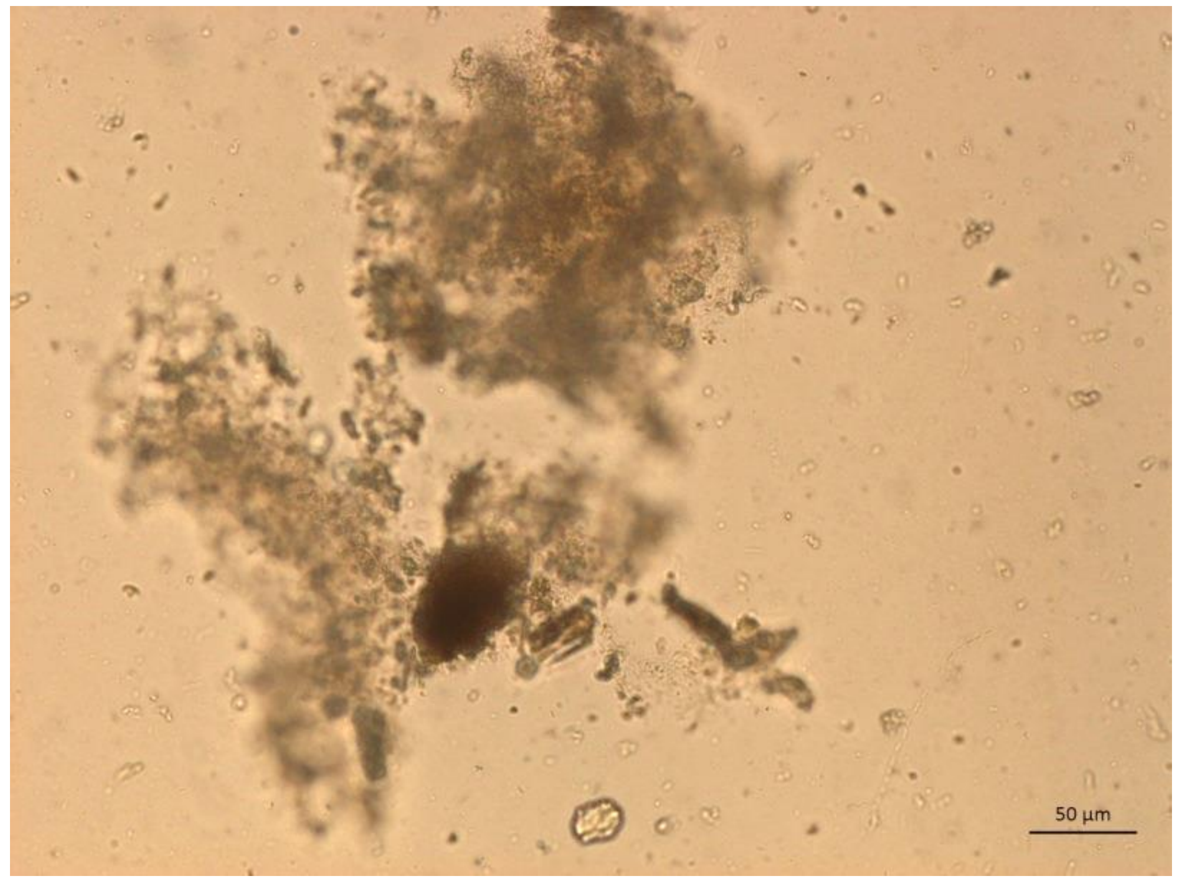
- Small, fast growing seaweeds with a certain freshwater tolerance (red-/greenalgae) are well suited aquaponics candidates.
- Together with the Thuenen institute, Germany, results from *Ulva lactuca* aquaponics pilot scale experiments were used to estimate bioremediation efficiency and economic viability of *U. lactuca* production in a downstream production system of a smolt RAS system (1300 t annual salmon production) in Nordland, Norway. Such an aquaponic system, using a mix of smolt waste water (30%) and seawater (70%) as growth medium, consists of a total area of 15.6 ha, including 9.9 ha tanks, ordered in rows of 10 tanks each (33m length, 1.5m width, 0.2 m depth) and 5.7 ha concrete paths/manoeuvring area.
- Given the light conditions in Northern Norway we expect the production plant to be in full productivity for 6 months per year (0.39 – 0.41 t (DW) d^{-1}), whereas 4 months have 30 % productivity (0.12 t (DW) d^{-1}) and 2 months are unproductive. The yearly productivity is therefore assumed to be 85 – 89 tons dry weight.
- This corresponds to a yearly nitrogen uptake of 2.7 – 2.8 tons and a phosphorous uptake of 0.16 – 0.17 tons. Given the waste water characteristics of the smolt producer Helgeland smolt Sundsfjord, 45 – 71 % of the nitrogen emissions and 3 – 6 % of the phosphorous emissions can be neutralised. Combined with the S3 filter nitrogen can be even neutralised completely, as well as 4 – 12 % of the phosphorous.



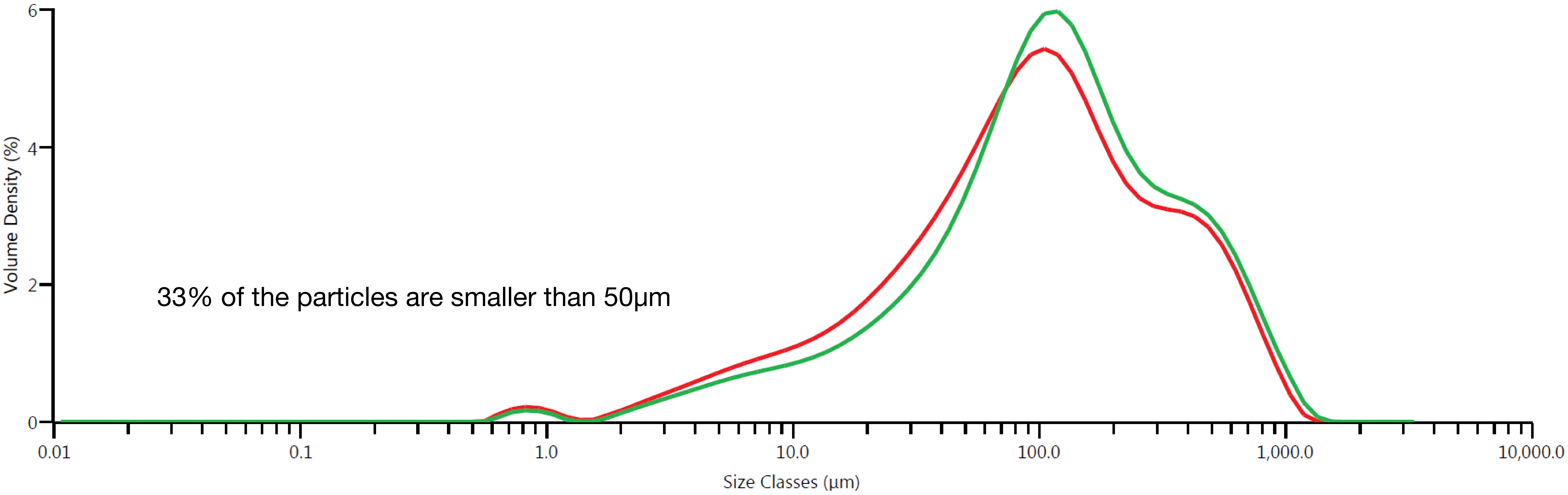
Aquaculture emissions and regulations in Europe with specific examples from Norway

- Aquaculture emissions are regulated differently in European countries, even at a municipal administrative level.
- In Denmark, an EU country, land based fish production requires a permit to discharge waste water into the sea. Such a permit is related to the capacity of the facility and may involve requirements to clean the waste water besides other obligations.
- Other factors assessed in such a permit are e.g. maximum levels of wastewater, levels of specific chemicals in the waste water, maximum allowed feed usage, contents of nitrogen and phosphorus in the feed as well as maximum emission of nitrogen and phosphorus. The farms granted permits are obliged to carry out self-monitoring
- In Norway, an EU associated country, regional regulations apply for land based aquaculture. Nordland fylkeskommune, the County municipality for Nordland (a regional authority), demands the following procedures for smolt production: (I) The concession for producing smolt is given for a defined tonnage fish produced yearly. (II) The producers need to plan the feed-use for this production and send the plan to the authorities. (III) The producers need to calculate the respective emissions and send the calculations to the authorities. (IV) The emissions need to be monitored by the producer and may be checked by the authorities.
- Removal of dissolved or particulate matter is not mandatory in general, but all new farming licenses awarded for land-based aquaculture need to reduce the particulate matter/suspended solids (SS; defined as particles larger than 0.45 µm) by, at least, 50 % and the organic content by, at least, 20 % (measured as chemical or biochemical oxygen demand; COD or BOD; mg O_2 l^{-1}). Recirculation aquaculture systems (RAS) are therefore popular, since, due to their much lower water flow-through, less effort is required for complying with the above limits.

Aquaculture wastewater



50 µm

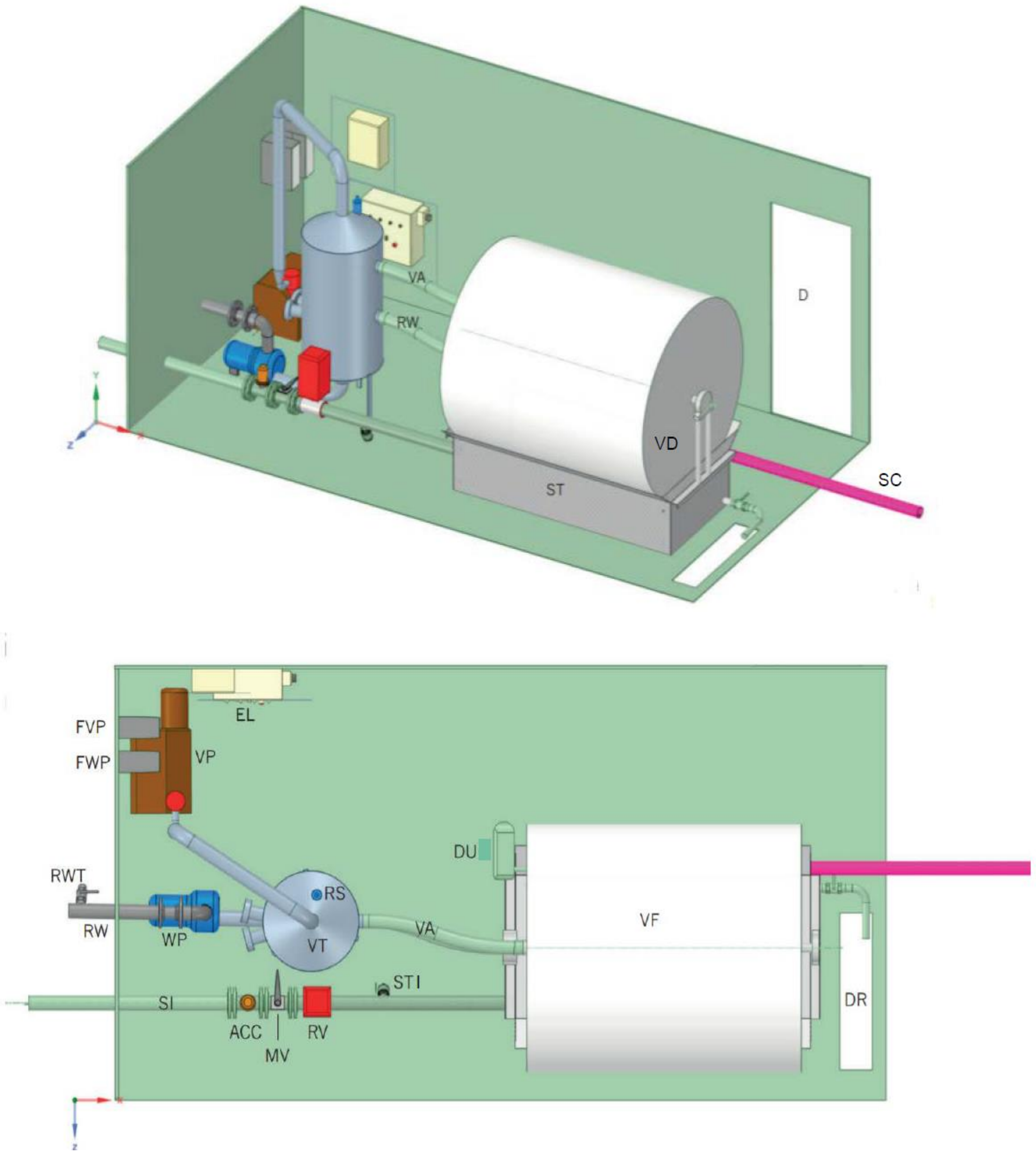


33% of the particles are smaller than 50µm

Fish sludge consists of small particles and are relatively sticky compared to other sludge's

Particulate matter in aquaculture side-streams

- Aquaculture wastewater has a very low dry matter content (Helgeland smolt, Sundsfjord: 0.006 – 0.02 %), posing the challenge of a high water flow-through and a small particle load.
- Existing technologies to treat these waters are therefore generally regarded as too costly and inefficient. However, drum filters (commonly with pore-sizes in the range of 20-80 μm) are the most cost-efficient technology for initial dewatering and concentration of particulate matter in aquaculture wastewater from both RAS and flow-through systems.
- Filtration efficiency is often increased by the addition of coagulants as e.g. polymers or magnetic particles.
- A filter-dryer developed by a Swedish company, LS Optics AB (www.lsosweden.com), was identified as the most promising technology to separate particles using a fine filter (mesh size 6 μm).
- Under current Norwegian regulation, this filter system meets the obligatory demand for wastewater purification as a standalone unit, without the use of coagulants. By using vacuum to draw wastewater through the filter material, high flow rates can be achieved, in spite of the fine filter mesh size. An infrared based heating element surrounds the filter membrane, evaporating most moisture already during the filtration process, resulting in a dry sludge product (DM content 93+2 %).



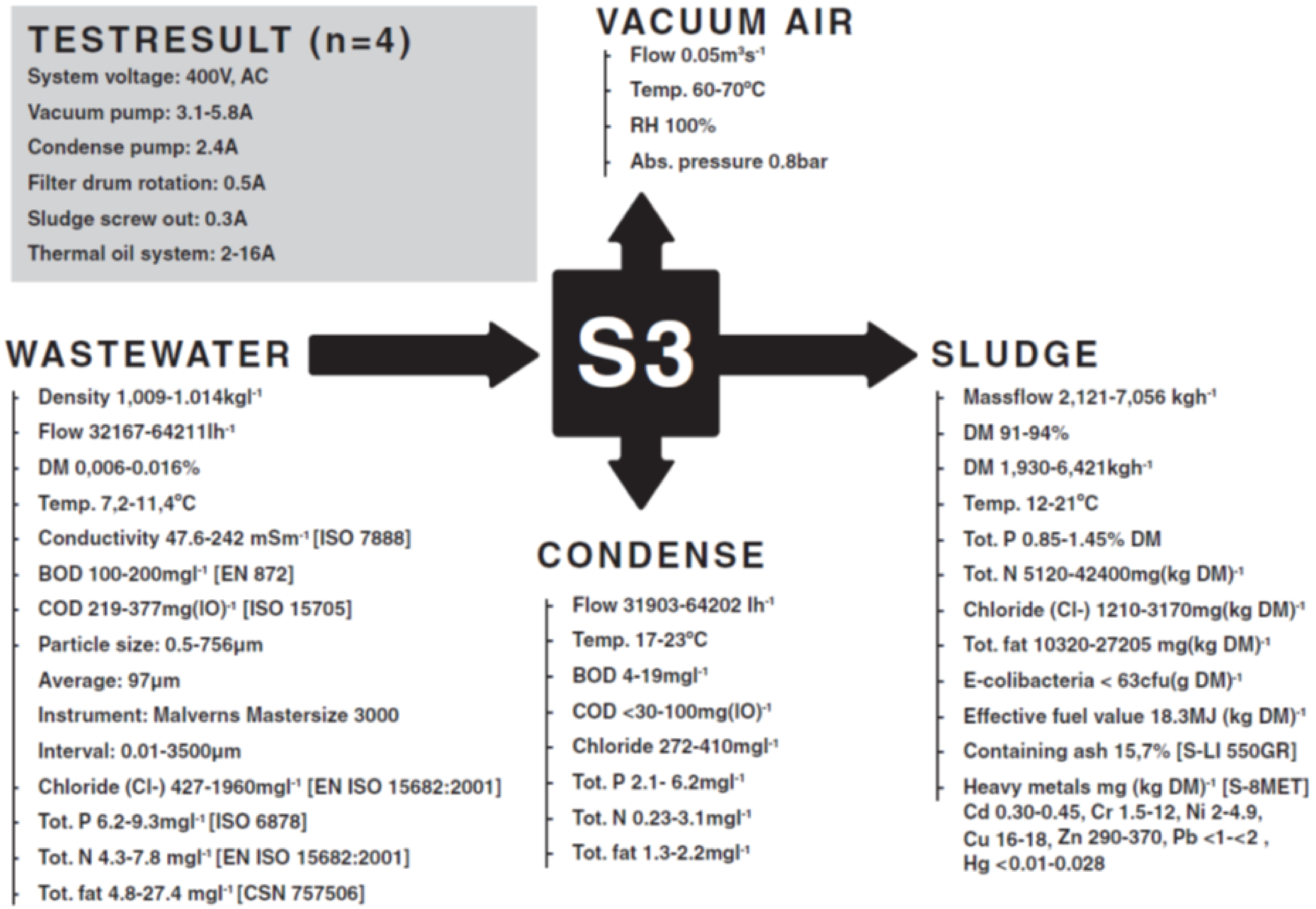
Aquaculture side streams – particulate matter removal

Overview over the most important components of the S3 filter system. Please see the text below for a detailed description. ACC = Activator; BF = Buffer tank; D = Door; DR = Drain; DU = Drive unit; EL = Electrical cabinet; FL = Floor; FVP = Frequence generator vacuum pump; FWP = Frequency generator water pump; KI = Wall; IP = Inlet pipe buffer tank; MV = Manual valve; OF = Overflow pipe; OWV = One-way valve; PP = Pressure clock; PT = Pressure transmitter; RC = Radar sensor; RS = Radar sensor; RV = Regulating valve; RW = Reject water; RWT = Reject water out; SC = Screw conveyor; SI = Sludge in; ST = Sludge tank; STI = Sludge test in; VA = Vacuum air; VB = Vacuum box; VD = Vacuum drum; VF = Vacuum filter; VP = Vacuum pump; VT = Vacuum tank; VV = Vacuum Valve; WP = Water pump;

Particulate matter removal by the S3 filter-dryer system

- The wastewater enriched in particles by a 0.45 µm drum filter is collected in a big reservoir called the buffer tank. This tank of large capacity is holding the liquid waste before it enters the filtering system.
- The wastewater flows towards the sludge tank, which is a smaller steel tank including an immerged rotary drum.
- An agitator homogenizes the wastewater to prevent the solids from settling too rapidly.
- The filter drum, also termed vacuum drum, is covered by a filter cloth with a mesh size of 6 µm, appropriate for collecting sludge from aquaculture.
- A vacuum tank connected to a vacuum pump is located next to the drum to separate air and liquid discharge from the filter. The whole system is therefore exposed to the same underpressure, which is used to suck the wastewater through the filter cloth of the immerged filter drum. The vacuum sucks both liquid and solids onto the surface of the filter cloth. The liquid penetrates through the mesh of the cloth while the solids are retained on the drum surface.
- A drive wheel is used to rotate the drum slowly, which allows the solids to form a filter cake on the drum surface which dries while not in contact with the wastewater.
- The resulting dry sludge is finally scraped off the drum by a knife located on the side of the drum. This “cleaned” part of the filter cloth then re-enters the wastewater and undergoes a new cycle of filter cake build-up/drying/discharge.
- By using vacuum to draw wastewater through the filter cloth, high flow rates can be achieved, in spite of the fine filter mesh size. Further, the filter material has exceptional heat transferability properties, with heat energy recovery rates around 95 % (without considering the energy in the condensate), making very energy-efficient. ‘
- For keeping a constant vacuum, the filter cake on the filter cloth needs to be air tight and to act as a seal, while the vacuum sucks the moisture off the filter cake. The remaining moisture in the dried sludge is actually 6 % – 9 % when it gets discharged from the cloth, depending on wastewater characteristics.
- The resulting sludge product is carried away by a screw conveyor for further processing.
- Water and air are passing the filter cloth flow through internal pipes towards the vacuum tank, where the purified water is discharged.
- The different components are monitored by sensors and controllers ensuring highest grade of smooth and consistent automated operation. Liquid levels are measured by radar level sensor in the buffer tank, sludge tank and vacuum tank. The respective data are transmitted to a controller unit, which adjust liquid levels within the pre-set of desired ranges. The sensor in the buffer tank interacts additionally with the vacuum pump controller, which vice versa adjusts the intensity of the vacuum to optimize the water flow through the filter cloth. The sensor in the sludge tank interacts with a regulating valve situated at the inlet side of the sludge tank. The opening of the valve is adjusted according to the liquid level in the sludge tank. The sensor in the vacuum tank interacts with the water pump controller, regulating the water pump to adjust the water flow and to keep a constant level in the vacuum tank. Additionally a pressure sensor in the vacuum tank is used as a controlling device to monitor the underpressure inside the vacuum tank.

Particulate matter removal by the S3 filter-dryer system



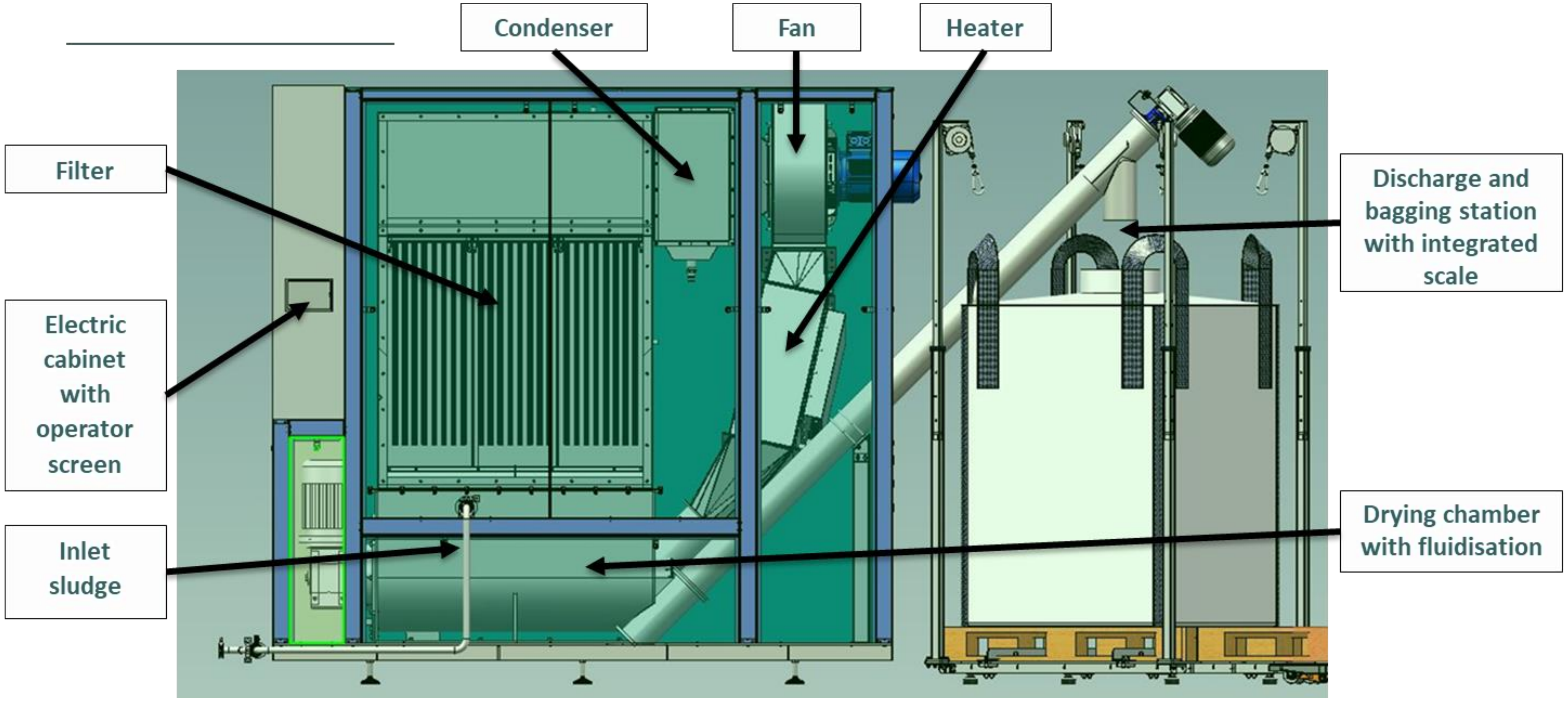
Summary of the main achievements and technical characteristics of the S3 filter system.
Wastewater = smolt production wastewater enriched in particles by a 45µm drum filter; Abs = Absolute; AC = Alternating current; BOD = Biochemical oxygen demand; COD = Chemical oxygen demand; Condense = Purified wastewater; DM (I) = Dry matter content; DM (II) = production rate of dried sludge; RH = Relative humidity; sludge = Accumulate particles removed from wastewater; Temp = Temperature; Tot. = Total;

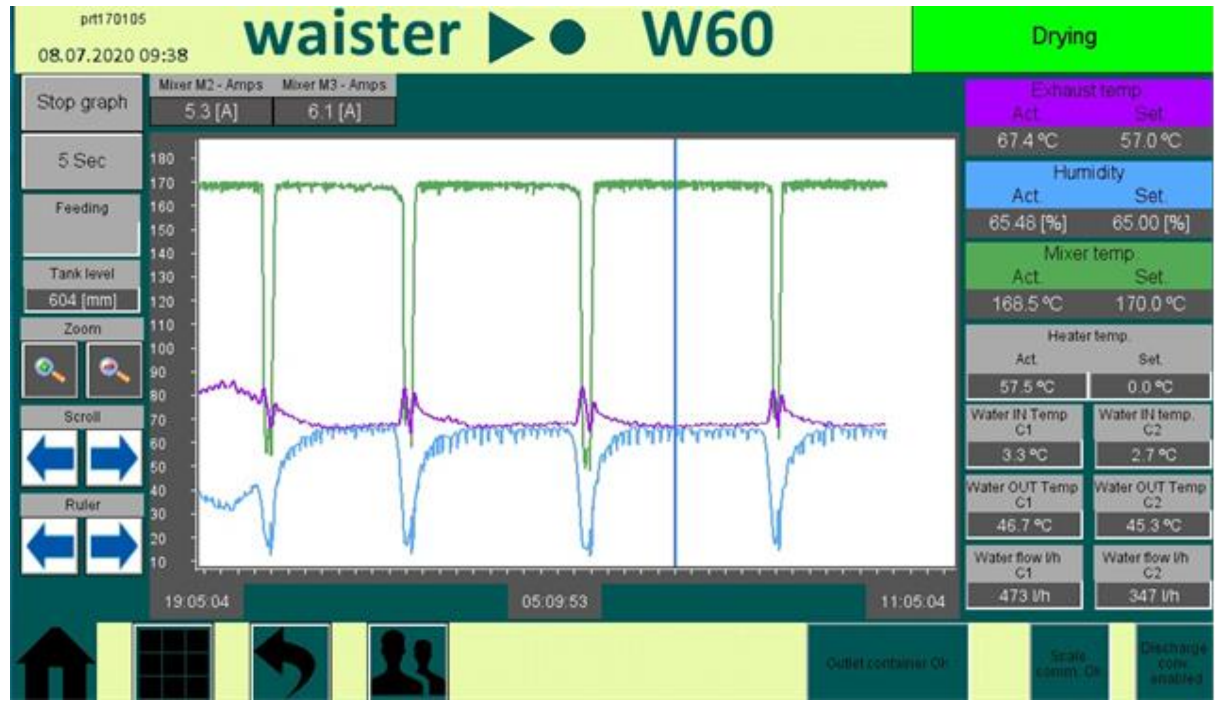
Particulate matter removal by the S3 filter-dryer system

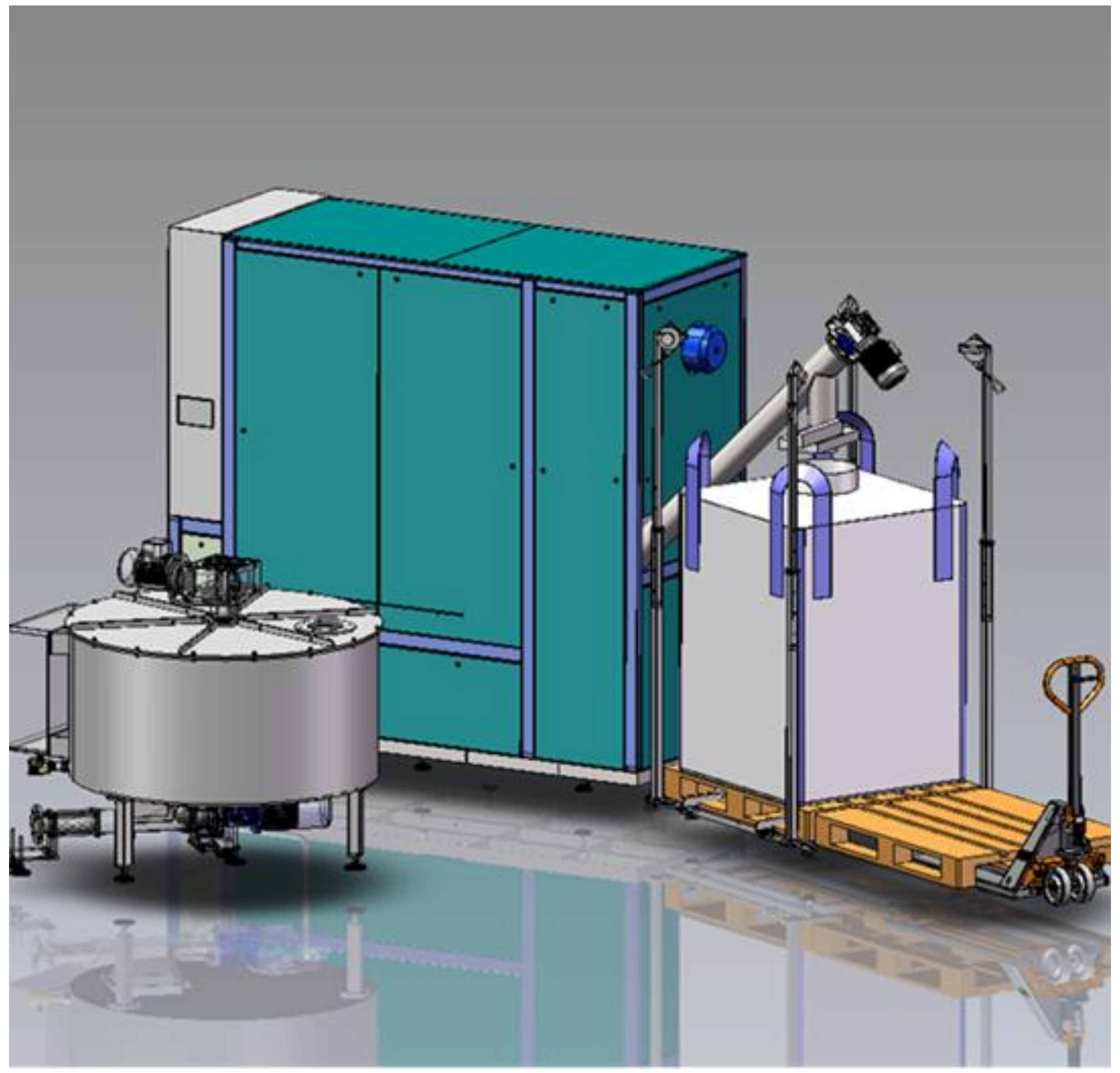
- DM content of the sludge produced by the S3 system ranges between 91 % and 94 %, depending on wastewater characteristics.
- This exceeds by far the DM content achieved by classical 45 µm drum filter systems, producing sludge with typical DM contents between 0.1 % and 5 %.
- The S3 system can be applied as a standalone unit not only to filter aquaculture wastewater efficiently, but to produce in parallel a dry and sanitized, stable sludge product.

S3 filterdryer demonstration unit as produced by Salten Havbrukspark/LS Optics AB. Right frame show the details of the filter during change of filter cloth.

Waister innovative superheated steam drying technology







- Based on dewatered sludge at typically 10 – 35 % DM
- Low temperature – 140 °C atmospheric pressure superheated steam → high level of N in dried product
- Low level of oxidation
- Proven concept: Delivered to three fish farms

Valorisation of fish sludge

Black soldier fly larvae fed with aquaculture sludge

Dried fish sludge in big bag

Dry matter: 93–96 %
Energy: ≈20 MJ/kg
Fat content: ≈3.5 %

Fish sludge may contain flocculants (polymers) for agglomeration of sludge particles. These are used to increase cleaning efficiency.

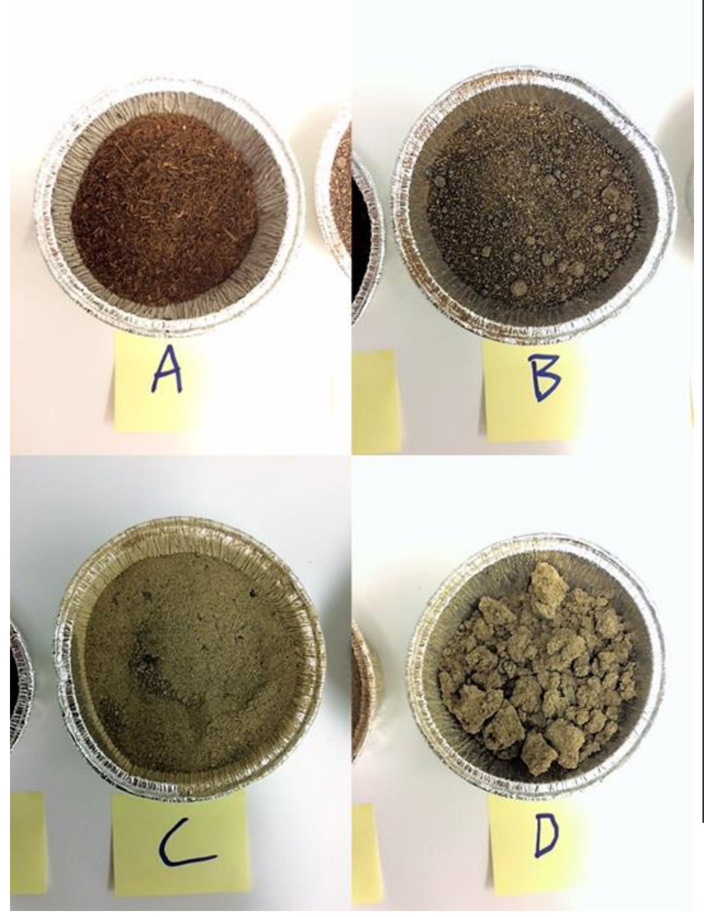
	Applications
Potential value	**Insect feed**: Presently, commercial application is not compliant in the EU / EES. Legislation needs adaptation to meet the ambition of the circular economy.
High value	**Bio-fertiliser:** Very potent as bio-fertiliser product, rich in N and P - low content of K, high level of Zn
Low value	**Bioenergy**: Biogas substrate. Rich in N and low in C, means mixing with other substrates for stable anaerobic digestion process. Direct incineration in industrial process (i.e. cement factory replacing fossil fuels).
Potential value	**Pyrolysis**: Conversion into biochar.

Fish sludge as bio-fertiliser product

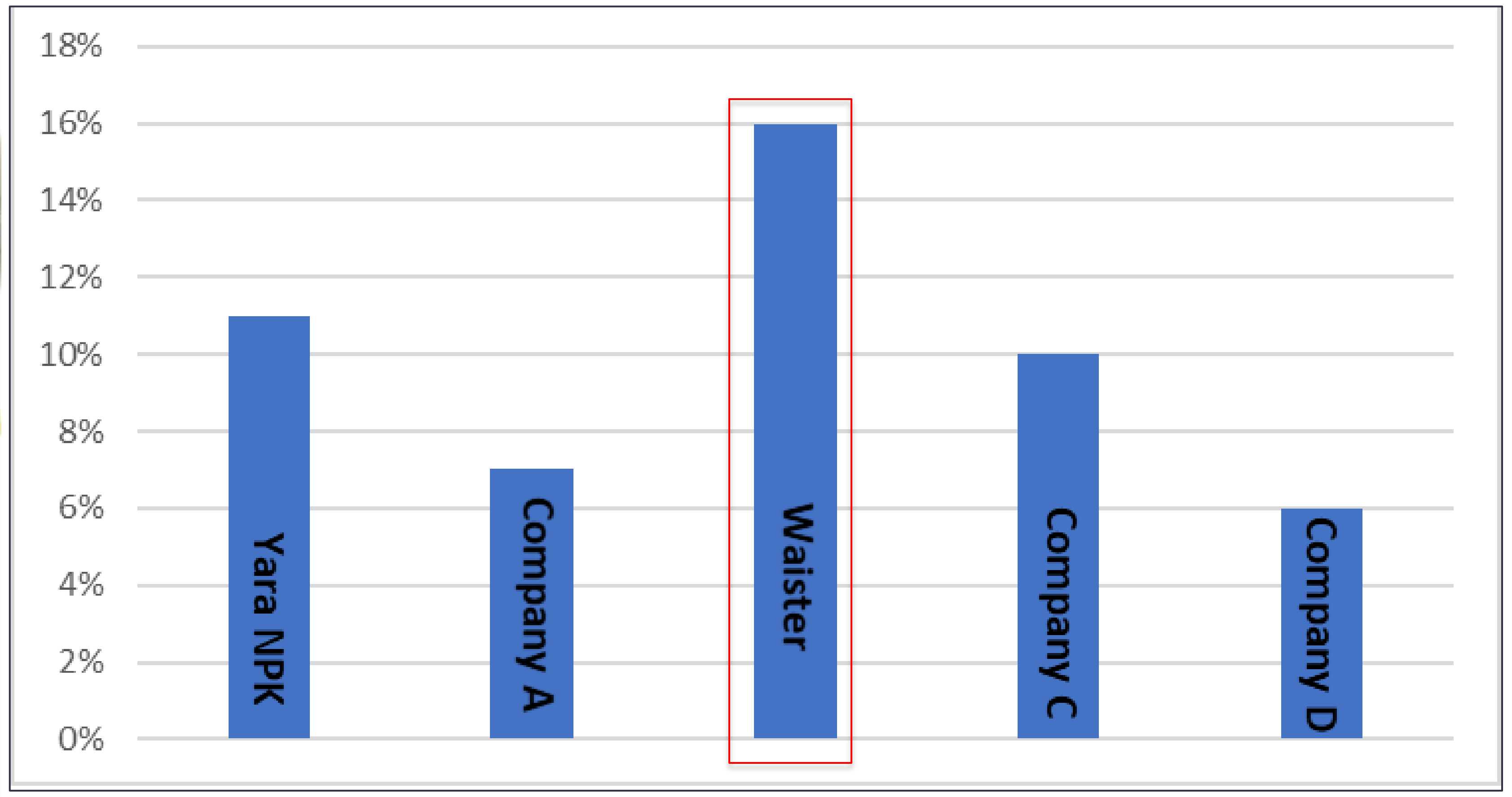
N = 7.0 %
P = 3.4 %
K = 0.2 %

Spread ≤ 4 000 kg per acre in a period of 10 years

NIBIO
NORWEGIAN INSTITUTE OF BIOECONOMY RESEARCH



Barley yield using fish sludge from different providers, in comparison with an inorganic commercial fertiliser.



Product type:	Dried biological fish sludge
Composition:	100 % fish fertilizer from salmon smolt containing faeces and feed residue
Content:	Product of varying particle size (≤ 3 mm) supplied in big bags as bulk product with weight as indicated on each bag. Typical weight approx. 1 500 kg
Dry matter:	≥ 90 %
Fertilizer quality class:	I
Application:	Growing grains, vegetables, and other crops
Maximum spread:	4 000 kg per acre in 10 years (agriculture, private gardens, and parks)
	5 cm layer mixed in soil at place (green areas)
Process:	Dried with Waister drying technology based upon mechanical fluidization and overheated steam
pH:	5,6 ± 0,5

Chemical and physical properties:

Substance	Content	Variation
N – total	7.0 %	± 20 %
Nitrate-N	< 0.4 %	
Ammonium-N	0.17 %	
P – total	3.4 %	± 20 %
P – plant available	2.1 %	± 20 %
K – plant available	0.22 %	± 50 %
Ca – plant available	2.0 %	± 15 %
Zn	0.035 %	± 15 %
Organic content	85 %	± 15 %

Content of elements:

Substance	Content	Variation	Limit value quality class I
Cd	0.22 mg/kg	± 50 %	0.8 mg/kg
Pb	1.0 mg/kg	± 50 %	60 mg/kg
Hg	< 0.2 mg/kg		0.6 mg/kg
Ni	< 5 mg/kg		30 mg/kg
Zn	350 mg/kg	± 15 %	400 mg/kg
Cu	24 mg/kg	± 15 %	150 mg/kg
Cr	3.0 mg/kg	± 75 %	60 mg/kg

Product declaration updated 09.12.2020

BACKGROUND – Mortalities and Discarded Fish

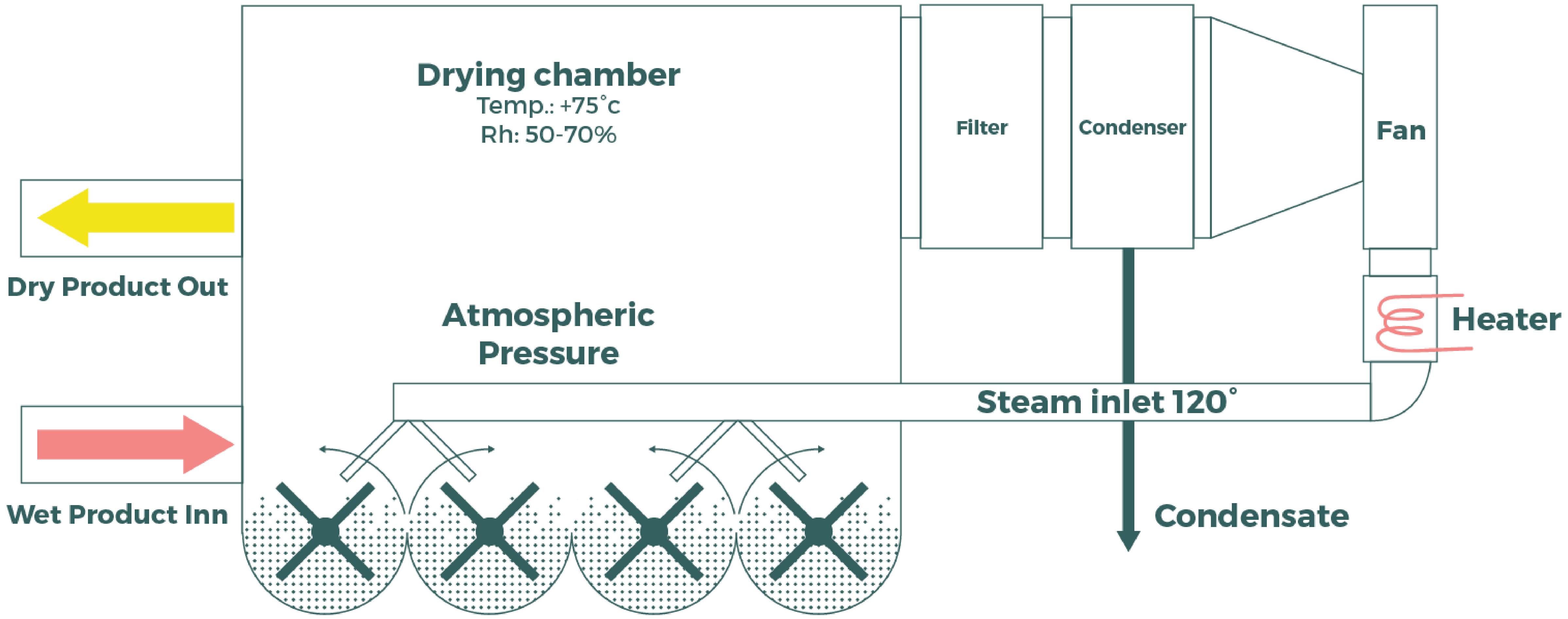
- Typical loss in sea cages: 15 – 20 % of the fish, equalling 6 – 9 % of the biomass.
- This represents about 53 million fish and an annual value loss of ≈100 M€ in Norway alone.
- Additional loss in land based aquaculture: 59 million (mortalities) + 52 million (discarded fish)

- Current method for mortality disposal faces challenges regarding Health, Safety and Environment (HSE), due to ensilage with formic acid.
- Ensilage injuries in Norwegian aquaculture per decade: 2 fatalities + 62 serious + many minor incidents!

Sources:
https://www.barentswatch.no/en/havbruk/fish-mortality-and-loss-in-production
https://www.ey.com/Publication/vwLUAssets/EY_-_The_Norwegian_Aquaculture_Analysis_2017/$FILE/EY-Norwegian-Aquaculture-Analysis-2017.pdf

Valorisation of mortalities

- ➢ Validation of mortalities drying at the fish farm, ensuring safe transport and handling without formic acid, as a preferred method of mortality disposal.
- ➢ Mortalities and discarded fish is usually treated in the same process at fish farms.
- ➢ Fat fish like salmon or trout needs an additive to ensure good fluidization in the drying inside chamber.
- ➢ No presence of enterobacteriaceae, sulphite reducing bacteria or salmonella



Applications (according to EC Regulation No 1774/2002 (animal by-products not intended for human consumption)	
Potential value	**Pet food**: Presently, commercial application as pet food for cats and dogs is not compliant in the EU / EES. Legislation needs adaptation to meet the ambition of the circular economy.
Potential value	**Bio-fertiliser:** May be applied, need approval from food safety government organisation
Zero to some value	**Bioenergy**: Biogas substrate. Mortalties as ensilage is already received by biogas plants. Direct incineration in industrial process (i.e. cement factory replacing fossil fuels). Technical applications
Around zero value	**Animal feed**: Fur animals, zoo and circus animals, other non-food-producing animals

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Getting the best out of aquaculture wastes, 01.09.2021

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