

Optimization of Inlet Channel to Water Filter for Fish Farming

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MASTER THESIS



Optimization of Inlet Channel to Water Filter for Fish Farming

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Abstract

This master thesis was performed in collaboration with NP Innovation. The purpose of this project was to develop a new inlet channel and two adapters for a water filter used in fish farming. Two different sizes of filters are included in the company's product portfolio. For both filters there is one inlet channel each in a corresponding size. One inlet channel consist of an adapter welded to the filter and a channel mounted on the adapter. It was established that it would be beneficial for the company if one universal channel was used instead, with the adapters made to fit different sizes of the filter. This would result in decreased production costs for the company.

The project was structured according to Ulrich & Eppinger Design Methodology. It contained planning, benchmarking, concept development and Design for Manufacturing. The project stops before production ramp-up. The concept development phase included generating ideas in CAD, and then testing them with CFD analysis. The CFD analysis was made to compare the concepts with each other, with the current inlet channel, and against the product specifications. The final concept was chosen through the concept selection phase that included concept screening, concept combination and concept scoring.

Initial simulations were made on the company's current solutions to set a benchmark for the final concept. One of the company's solutions showed severe recirculation and dead zones while another already gave an acceptable flow. During the concept development phase, it was discovered that the edge of the inlet channel causes the main separation of the flow in the inlet channel.

The deliverable to the company is a CAD model of a final concept. The final concept includes a rounded wall guiding the water into the inlet channel. The solution decreases recirculation and distributes the flow throughout the entire channel, while maintaining an acceptable velocity for the water. The manufacturing has slightly worsened in the complexity of the channel, but improvements were made in relation to only having one channel instead of two.

While solving the problem in this master thesis, it also brings further development and opportunities for the health and safety of fishes in fish-farms.

Keywords: Fish Farm, Water Filter, Inlet Channel, CFD-analysis, CAD, Flow Optimization

Sammanfattning

Detta examensarbete utfördes i samarbete med NP Innovation. Syftet med detta projekt var att utveckla en ny inloppskanal och två adapterar för ett vattenfilter som används inom fiskodling. Företagets produktportfölj omfattar bland annat två olika storlekar av filter. För båda filtren finns det en inloppskanal vardera i motsvarande storlek. En inloppskanal består av en adapter som är svetsad till filtret och en kanal som är monterad på adaptern. Det fastställdes att det skulle vara fördelaktigt för företaget om en universell kanal användes, med adapter som anpassas för att passa olika storlekar av filtret. Detta skulle resultera i minskade produktionskostnader för företaget.

Projektet strukturerades enligt Ulrich & Eppingers designmetodik. Det innefattade planering, benchmarking, konceptutveckling och konstruktion för tillverkning. Projektet avslutades före produktionsuppstart. Konceptutvecklingsfasen innefattade generering av idéer i CAD, följt av testning med CFD-analys. CFD-analysen utfördes för att jämföra koncepten med varandra, med den nuvarande inloppskanalen och mot produktspecifikationerna. Det slutliga konceptet valdes genom konceptvalsfasen som innefattade konceptscreening, konceptkombination och vikad konceptutvärdering.

Inledande simuleringar utfördes på företagets nuvarande lösningar för att sätta en benchmark för det slutliga konceptet. En av företagets lösningar visade allvarliga recirkulationer och zoner med stillastående vatten, medan en annan lösning redan gav ett acceptabelt flöde. Under konceptutvecklingsfasen upptäcktes att kanten i början på inloppskanalen orsakar den huvudsakliga separationen av flödet i inloppskanalen.

Det slutgiltiga konceptet är en CAD-modell som lämnas till företaget. Det slutgiltiga konceptet innefattar en rundad vägg som leder in vattnet i inloppskanalen. Lösningen minskar recirkulationen och fördelar flödet i hela kanalen, samtidigt som en acceptabel hastighet för vattnet upprätthålls. Tillverkningen har försämrats något i kanalens komplexitet, men förbättringar gjordes i förhållande till att endast ha en kanal istället för två.

Medan problemet i detta examensarbete löses, bidrar det också till vidareutveckling och möjligheter för fiskars hälsa och säkerhet inom fiskodling.

Nyckelord: Fiskodling, Vattenfilter, Inloppskanal, CFD-analys, CAD, Flödesoptimering

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Lund, June 2026
Mimmi Cassé
Oliver Vester Stephensen

Contents

1	Introduction	1
1.1	Background	1
1.2	Problem Description	2
1.3	Purpose	2
1.4	Delimitations	2
1.5	Approach	3
2	Method	4
2.1	Design Process	4
2.2	Product Planning	4
2.3	Product Specifications	4
2.4	Concept Generation	5
2.5	Concept Selection	5
2.5.1	Concept Screening	5
2.5.2	Concept Combination	5
2.5.3	Concept Scoring	6
2.6	Concept Testing	6
2.7	Design For Manufacturing	6
3	Initial Simulation	8
3.1	CAD	8
3.2	Pre-processing	11
3.3	Mesh	12
3.3.1	Wing Walls	13
3.3.2	Inlet Channel	16
3.3.3	Mesh Study	21
3.4	Cell Zone Conditions	22
3.4.1	Porous Media	22
3.5	Boundary Conditions	26
3.5.1	Inlet	26
3.5.2	Outlet	26
3.5.3	Walls	27
3.6	Solver Settings	28
3.7	Results	28
3.7.1	Wing Walls	29
3.7.2	Inlet Channel	30
4	Product Specifications	33
4.1	Benchmark	33

4.2	Criteria	38
4.2.1	Manufacturability	39
4.2.2	Mean Velocity	39
4.2.3	Adapter to Inlet fit	39
4.2.4	Adapter to Channel fit	40
4.2.5	Recirculations	40
5	Concept Generation	41
5.1	Concept 1	42
5.2	Concept 2	43
5.3	Concept 3	45
5.4	Concept 4	46
5.5	Concept 5	47
5.6	Concept 6	49
5.7	Concept 7	50
5.8	Concept 8	51
5.9	Concept 9	53
5.10	Concept 10	54
5.11	Concept 11	55
5.12	Concept 12	57
5.13	Concept 13	58
5.14	Concept 14	59
5.15	Concept 15	61
5.16	Concept 16	62
5.17	Concept 17	64
5.18	Concept 18	65
5.19	Concept 19	66
5.20	Concept 20	67
5.21	Concept 21	69
5.22	Concept 22	70
5.23	Concept 23	71
6	Concept Selection	73
6.1	Concept Screening	73
6.2	Concept Combination	74
6.3	Combined Concepts	74
6.3.1	Concept 24 (Combined)	75
6.3.2	Concept 25 (Combined)	76
6.4	Weighting	77
6.5	Concept Scoring	78

7	Concept Testing	79
7.1	Refinement	79
7.2	Flow	80
7.2.1	Flow size	80
7.2.2	Flow direction	80
7.2.3	Flow from the floor	81
7.2.4	Flow from the side	82
7.3	Filter A - Adapter	84
7.3.1	Flow size with Filter A	84
8	Design For Manufacturing	85
9	Final Concept	87
9.1	CAD Model	87
9.1.1	Filter A - Adapter	87
9.1.2	Filter B - Adapter	87
9.1.3	Channel	88
9.2	Channel + Filter A - Adapter	89
9.2.1	CAD Assembly	89
9.2.2	Mesh	91
9.2.3	Mesh Study	94
9.2.4	Fluid Analysis	95
9.3	Channel + Filter B - Adapter	97
9.3.1	CAD Assembly	97
9.3.2	Mesh	98
9.3.3	Mesh Study	102
9.3.4	Fluid Analysis	102
10	Discussion	105
10.1	Planning	105
10.2	Simplifications in the fluid analysis	105
10.3	Fluid analysis - Mean velocity	106
10.4	Difference in calculated velocity	107
10.5	Different volume flows	108
10.6	Different flow directions	108
10.7	Development of Filter A Adapter	108
10.8	Further Development	109
10.9	Ethics	109
10.10	Sustainability	110
10.11	Use of Generative Tools	110
10.12	Contribution	110

11 Conclusion	111
References	112
Figure References	113
Appendices	114
A Project Planning	114
B Initial Simulation Results	115
C Mesh Study for Concept Generation	127
D Final Concept - Different flows	132

1 Introduction

1.1 Background

NP Innovation is a Swedish company, working with water treatment products for land-based fish farming. The company was founded in 2012 by Nils-Åke Persson who has worked with waterpurifying technologies since 1984. NP Innovation has three main products: a disc-filter, a drum-filter and a degasser. The water filters are used to clean the water in the fish farms, and the degasser removes the carbon dioxide that the fish breathe out.

Water filters are the most commonly used product in these land-based fish farms for cleaning the water. It is essential for the farmers that the filters can handle a certain amount of flow in order to keep a healthy environment for the fish. The filters take in the dirty water through an inlet channel or a wing-wall solution. The inlet channel consists of an adapter welded to the filter and a channel mounted on the adapter. Wing walls are two walls guiding the water into the filter. The filter types in NP Innovation's portfolio are the drum filter and the disc filter. A drum filter has the filter cloth on the outside of the drum. A disc filter has small discs in the drum that handles the filtering. The difference is that you get more cleaning area with a disc filter compared to a drum filter. A drum filter and a disc filter with wing walls can be seen in Figure 1.¹



(a): Drum filter with wing walls, approximately two meters in diameter



(b): Disc filter with wing walls, approximately two meters in diameter

Figure 1: Illustration of filters from NP Innovation

¹NP Innovation, "*NP Drumfilter*" 2026 <https://www.npinnovation.se/drumfilter> (Retrieved: 2026-02-27) NP Innovation, "*NP Discfilter*" 2026 <https://www.npinnovation.se/discfilter> (Retrieved: 2026-02-27)

1.2 Problem Description

Increasing scale in the farming facilities increases the expected performance on the filters. When installing the filters, it is common to build large pools out of concrete. When these pools are built, it is very expensive to try and increase the size or change to a larger filter. This means it is essential to find different solutions to increase the flow of water that is cleaned in the filter. One of the areas that can be improved is the inlet channel for the filters. The current inlet channel consists of an adapter, made for attaching the channel to the filter wall, and the channel. The design of the current inlet channel leads to recirculation and dead zones in which dirty water accumulates, thereby worsening the water flow into the filter. Another problem is that different sizes of channels are used for different sizes of filters. This increases the costs for the channels since manufacturing is divided into more parts.

1.3 Purpose

The purpose of this thesis project is to develop a concept of an improved inlet channel in sheet metal to a disc-filter, with two additional adapters. The current solution includes high fluid velocity with an inlet that is very similar to a bottle-neck. This results in turbulent flow going into the filter. The task is to develop one universal inlet channel, with two adapters made to fit two different sizes of filters. The goal is to reduce the manufacturing costs by only having one channel instead of a separately fitted channel for each size of the filter. Furthermore, the goal is to improve and optimize the inlet to create a more efficient and laminar flow, for the inlet channel of the filter.

1.4 Delimitations

Constant flow is assumed to enter the filter. A pressure loss from outside of the filter, going into the filter, is the main driving force of the flow. As a result of constant incoming flow, the water level is assumed to remain constantly at maximum water level of the filter.

Although multiple sizes with varying lengths and diameters of the filter exists in the company's portfolio, a limited selection is chosen to be analyzed. The company's smaller filter will be called "Filter A". It will be analyzed separately for the wing walls and the inlet channel. The same analysis will be conducted for the company's larger filter which will be called "Filter B".

1.5 Approach

The project will commence by analyzing the current product at the company. The analysis will contain field studies of the product in use, study visits to customers and computational fluid dynamics (CFD) analysis of the current inlet channel. The data will be used as a benchmark going forward. In the concept generation phase, distinct concepts will be analyzed through CFD analysis in order to evaluate the output data against the benchmark. This will be an iterative process, since each concept will have weaknesses and strengths, that can be used for further development. The final concept will be chosen through concept scoring, after performing a concept screening and concept combination. The product will be designed for manufacturing and it will be presented as a computer-aided design (CAD) model. The concept itself will be validated through CFD and evaluated against the benchmark.

2 Method

2.1 Design Process

The design process used in this project is shaped according to the Ulrich-Eppinger methodology. This methodology was used since it is suitable applied within industrial environments. The method is very structured and includes activities to go from establishing product specifications, to manufacturing a final concept. A graphic representation of the design process can be seen in Figure 2.

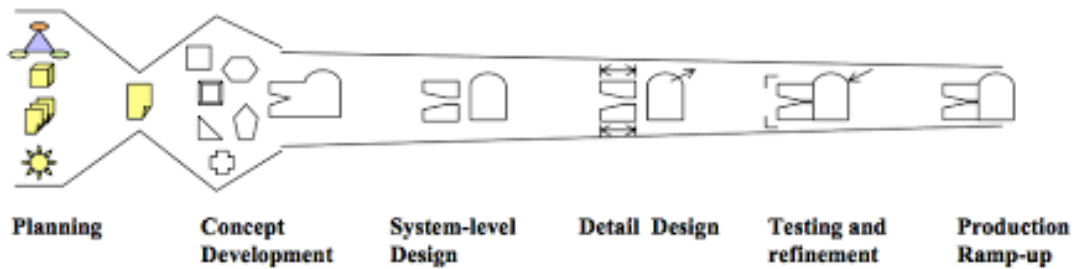


Figure 2: Illustration of the Design Process described by Ulrich & Eppinger

This project will only include the activities from Planning, to Testing and Refinement. Production Ramp-Up is not included in this project.

2.2 Product Planning

The planning phase started by setting up a time frame for the entire project. It is based on a Gantt chart, but with more specifications as to what each day should contain.

The product planning also included analyzing what the company already has, so that when a result has been reached, the results could be compared. Discussions were also held with the company, in order to establish what filters and lengths of channels that were to be developed, in addition to the company's own criteria for the product.

2.3 Product Specifications

The product specification phase started with a market analysis, in order to establish what the competitors had. This phase included analyzing the closest competitors, but also other areas where water filters are used. A benchmark was then

made from the market analysis. The company's requirements in combination with the market analysis, lead to the criteria our product needed to reach.

2.4 Concept Generation

The concept generation phase was mostly performed in CAD. The concept generation phase is supposed to be inexpensive and effective. Expected to lead to a lot of different and distinct concepts, that align with one or more criteria from the product specifications. Each concept was analyzed through CFD analysis, in order to get results that could be evaluated against the product specifications. The process was iterative, since the CFD analysis of each concept lead to new ideas and areas to improve. Without performing concept combination, some concepts were changed marginally between the simulations to observe how small changes would affect the different output parameters.

2.5 Concept Selection

The concept selection phase was divided into three different steps. The process involved eliminating concepts that were worse than what the company currently has, combining different elements from the concepts that advanced, and finally choosing the concept that best fulfilled the product specifications. A more thorough explanation of the different steps is presented below.

2.5.1 Concept Screening

The concept screening matrix was set up, according to Ulrich and Eppinger.² The concept screening is used to effectively eliminate the concepts that are worse than the reference. Each concept is evaluated against the product specifications and the reference. If it is better than the reference within the criteria it receives a "+", if same a "0" and if worse a "-". The sums are then added up, and if the concept received more minuses than pluses, it was eliminated, since this means it was worse than what the company currently has.

2.5.2 Concept Combination

From the concepts that advanced in the concept screening, a concept combination was performed. Concept combination is a way to systematically combine fragments of different concepts, and it is performed in a concept combination table.

²K.T. Ulrich & S.D. Eppinger, *Product Design and Development*, 6th Edition, (McGraw-Hill Education, 2016) page 152

The columns in a concept combination table corresponds to the different subproblems in the product. Each entry in the column is a solution to that subproblem, derived from one of the concepts.³ With this method, it is possible to combine different solutions from different concepts and reach a concept that solves all the subproblems.

2.5.3 Concept Scoring

After the concept combination, a concept scoring was performed on the newly created concepts, in combination with the concepts that advanced from the concept screening. The concept scoring is used to better differentiate the competing concepts by scoring them between 1 and 5. In this step, each criteria was weighted based on the importance of the criteria. The weight of all the criteria add up to 1, making each criteria contribute with a percentage to the final score.

After the weight was determined, a reference needed to be established within each criteria. The reference concept is included in the concept scoring matrix, however, that does not mean that it is a reference within the criteria. This is one of the main differences between concept scoring and concept screening.⁴ The reference within each criteria is given the score 3, and is marked bold in a table. This is the reference point for all of the concepts, independent of what concept it is. Each concept may receive the score 3, within the criteria, but only one concept is the reference within the criteria. After the references were established, each concept was scored 1-5. The score was then multiplied with the weight, resulting in the weighted score. The weighted scores were then added up, and the concept received a final weighted score. From this, the final concept was chosen as the concept that received the highest weighted score.

2.6 Concept Testing

Concept testing is performed to ensure the concept's performance with the predetermined criteria.⁵ The tests were performed to investigate how the final concept would behave with different flows, and different water inlet directions. The tests were based on the different setups of the filters used by the company's clients.

2.7 Design For Manufacturing

Manufacturing is considered throughout the whole design process. Component integration is applied as described by Ulrich & Eppinger, meaning that each section

³Ibid, page 134

⁴Ibid, page 156

⁵Ibid, page 17

within the architecture consists of a minimal amount of parts.⁶ After the final concept was chosen, it was refined, for more feasible manufacturing. This included reducing the number of parts and changing the geometry for less complexity and reduced costs. A sheet-metal manufacturer was also contacted to further validate that the final concept was manufacturable and cost-effective.

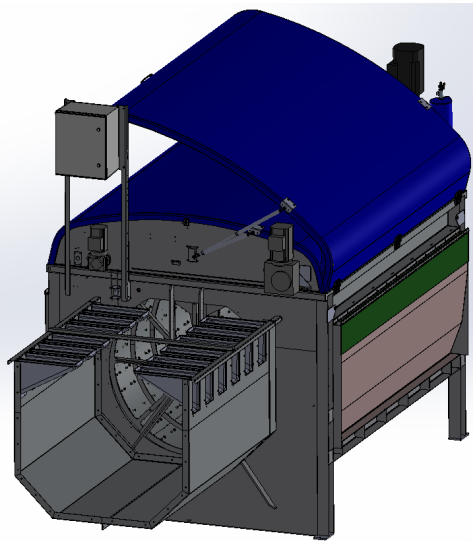
⁶Ibid, page 192

3 Initial Simulation

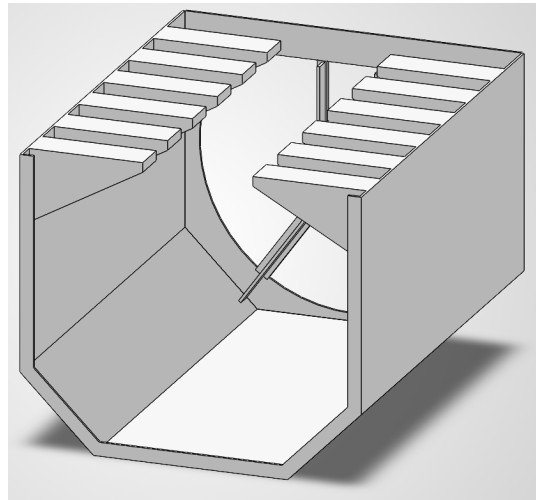
Initial simulations are made as a benchmark of the company's current products. The benchmark focuses on the company's two main options for directing the flow prior to the inlet of the filter, i.e wing walls and inlet channel. Three different flows are to be tested, given from the company. This benchmark will be compared to our own designed geometry to ensure improvements are made.

3.1 CAD

Starting with the company's digital model of the filter, it was decided what details needed to be included in the CFD analysis. The company's CAD-model was therefore analyzed, and simplified to reduce the total number of elements in the mesh, which significantly decreases simulation time. However, careful considerations were made on the different components that were simplified, since the simplifications shouldn't affect the overall results of the simulations. The digital model for the channel is around 1400 mm wide and 1200 mm high. The digital model for the wing walls is around 1200 mm in width and 1700 mm high. The simplification of the inlet channel can be seen in Figure 3, and for the wing walls in Figure 4.

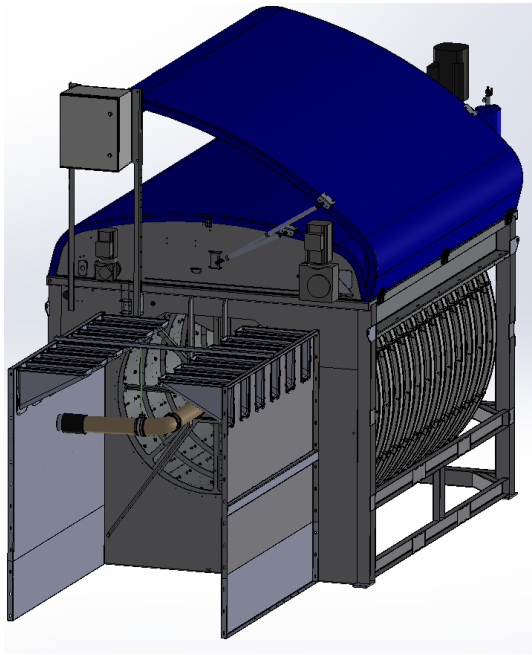


(a): Original digital model of the filter with inlet channel

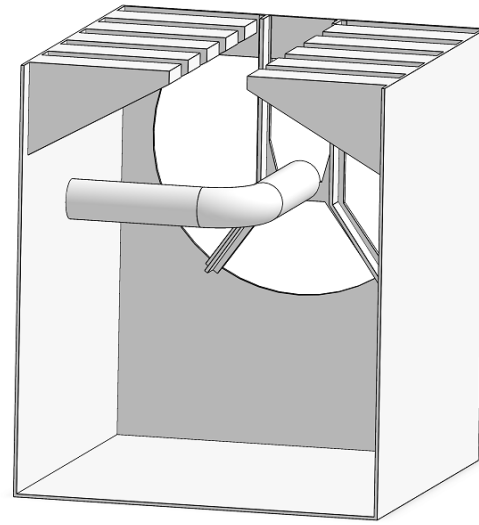


(b): Modified digital model of inlet channel used for CFD analysis

Figure 3: The original model and the simplified model of the inlet channel



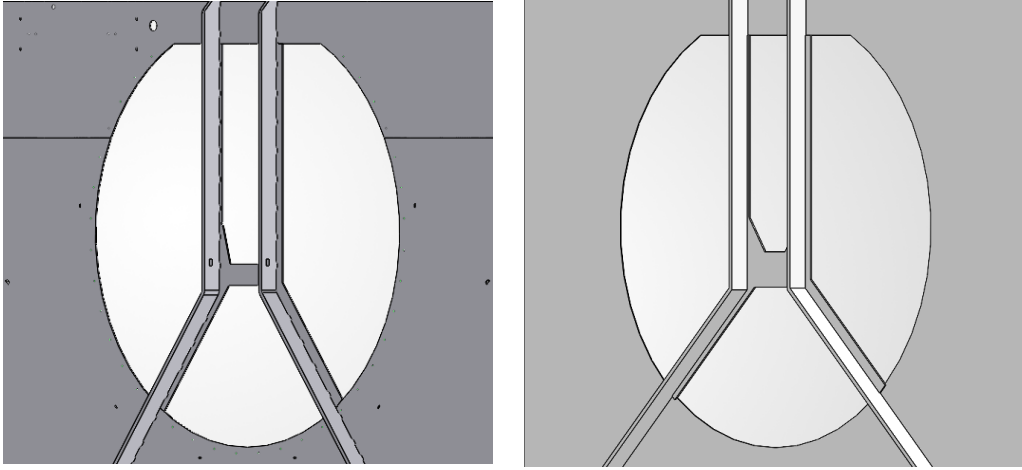
(a): Original digital model of the filter with wing walls



(b): Modified digital model of wing walls used for CFD analysis

Figure 4: The original model and the simplified model of the wing walls

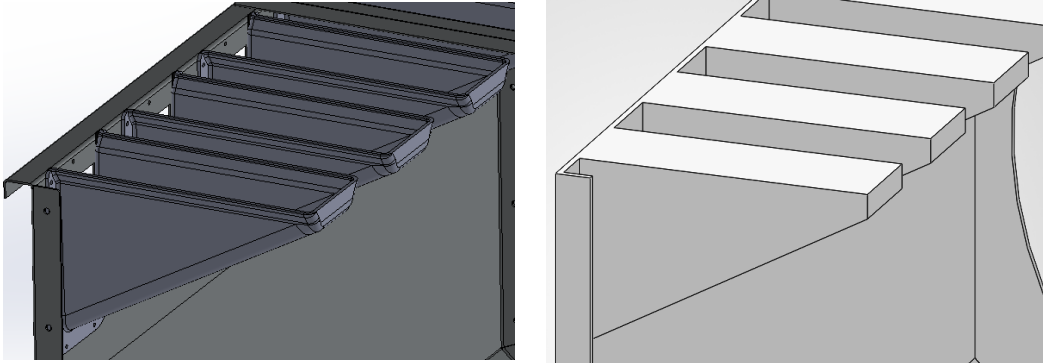
The goal of rebuilding the digital model was to make the necessary changes and prepare the model for CFD analysis. This includes having an intact model without unnecessary gaps and holes. The model was reconstructed from an assembly of multiple parts, to one single part in order for the CFD program to process the geometry correctly. Complicated geometry past the inlet channel was removed since it wasn't within the scope of this project. Rounded edges were assumed to be sharp corners to avoid loading the computational analysis with unnecessary cells. These areas can be seen in Figure 5 and Figure 6. The geometry over the water level was also excluded as a simplification, to reduce the number of elements.



(a): Original geometry

(b): Simplified geometry

Figure 5: Details not facing the flow was neglected



(a): Original geometry

(b): Simplified geometry

Figure 6: Rounded edges was simplified as sharp corners

Only simulating the flow through the inlet channel or the wing walls would result in the boundary conditions being too close to the observation point. This would potentially exclude important behavior of the flow close to the boundaries. To avoid such uncertainty, the geometry was extended prior and post inlet channel or wing walls. Prior to the inlet channel, an arbitrary pool was made to represent the water going from a larger geometry, into the channel. This is a concept observed at several customer's facilities. After the inlet channel, the water enters the filter. The filter consists of a drum that can be filled with water, creating a pressure resistance for the water to enter the drum from the inlet channel. This transition is simulated

with a porous media with the same geometry as the inside of the drum. A top surface is made to limit the water level according to the recommended maximum height for the filter. The final geometry to be used in the simulations including a pool, the inlet channel, and the porous media, can be seen in Figure 7.

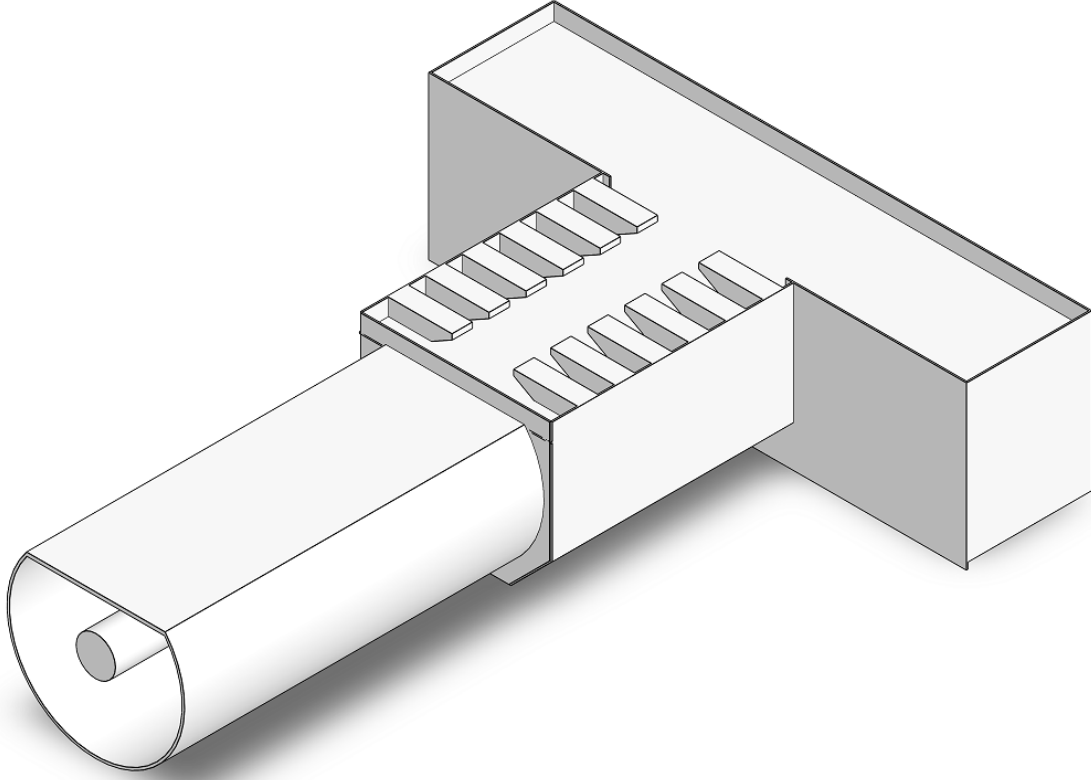


Figure 7: Inlet channel with arbitrary pool prior to the inlet channel and geometry of the drum post inlet channel

3.2 Pre-processing

The model is currently hollow and made of one solid walls, however, in order to perform a simulation, it is crucial to remove the walls and create a solid volume. This step was done in ANSYS Design Modeler. The first step was to enclose the volume. This was done by creating surfaces openings in the model. The fill operation was then used to create a volume inside of the CAD-model. The CAD-model was then suppressed, leaving only the volume of the fluid. Before meshing could be performed, the porous media needed to be created. This was done by slicing the model with a geometry plane, where the drum starts. Two

different cell zones exists, and the porous region could be designed in Fluent. The prepared model of the fluid domain can be seen in Figure 8, with the brown section representing the porous media and green represent liquid water.

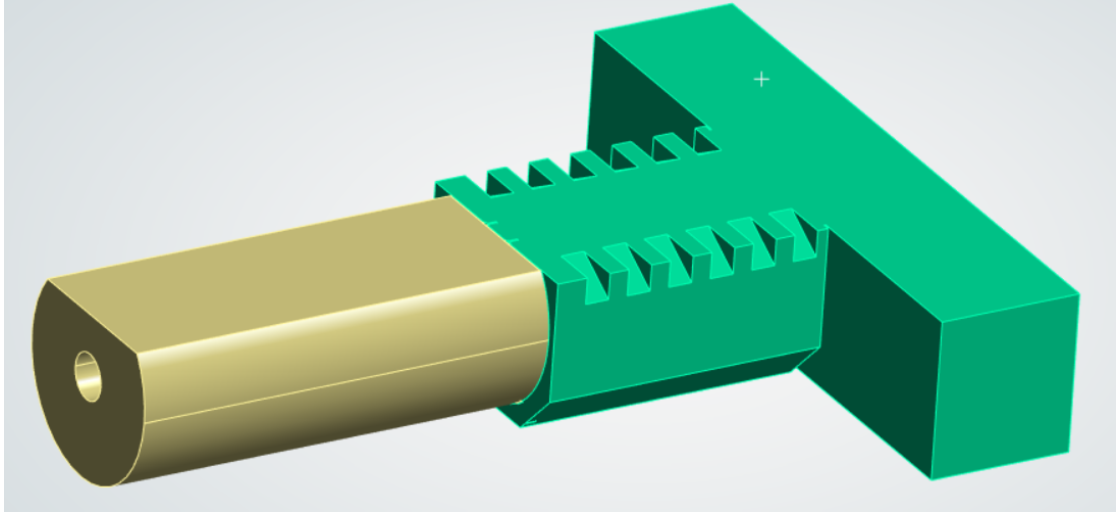


Figure 8: The fluid domain with the water domain in green and porous domain in brown

3.3 Mesh

The same method for meshing was used for the four variations of leading the water into the filter; Filter A wing walls, Filter B wing walls, Filter A inlet channel and Filter B inlet channel. Using a symmetry plane was decided against due to the asymmetry of the wing walls. Some differentiations are made to ensure compliance with the geometry. The mesh mainly consists of body sizing, refined sizing and inflation. Body sizing mesh was added to both bodies of fluid domain. Face sizing and edge sizing was included in more detailed areas and areas subjected to high pressure from the water. Inflation was also added in areas where water put a higher pressure on the walls.

To determine if the mesh is satisfactory, the element quality and the element skewness will be analyzed. The element quality is a general evaluation of how good each element is, based on several factors. Some of the factors are element length, angles and stretching. The goal is that each element has a value as close to one as possible. The element skewness is a value of how skewed the elements are. The goal with the element skewness is to have a value that is as close to zero as possible, since this means the element has a low skewness.

3.3.1 Wing Walls

The meshing for the wing walls is divided into different sections. Firstly, there is a body sizing on the whole body. The size of these elements are the ones that are changed between each iteration in the mesh study. The volume of the body sizing can be seen in Figure 9

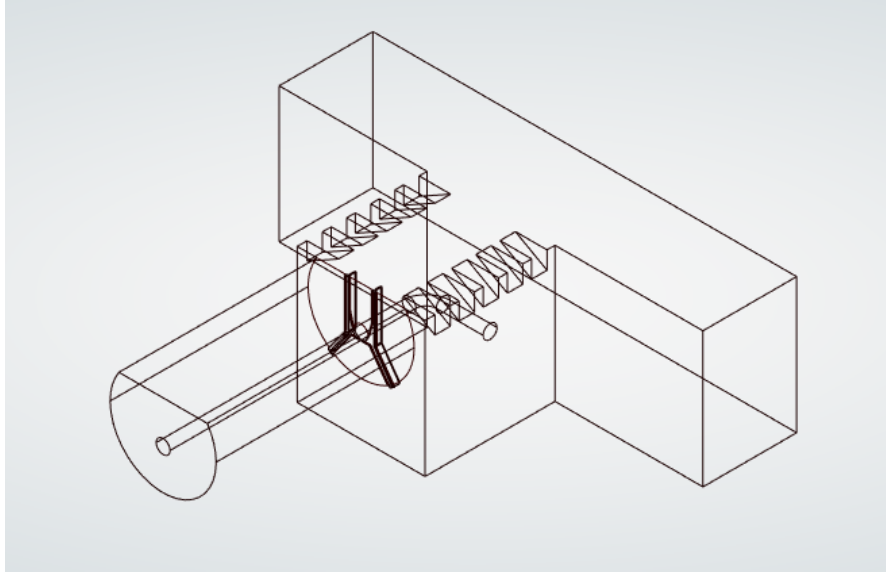


Figure 9: Wing wall mesh volume for the body sizing

For the more critical areas, it is essential that the areas are well refined. All critical areas have a 40 mm element size. For the walls that are perpendicular to the flow, the high velocity fluid is experiencing a sudden obstacle. It is very important that these sections are fine enough to handle the high velocities and turbulence. To deal with this, two inflations are inserted using smooth transition with maximum of 12 layers and 1.1 growth rate. Inflation layers are thin layers that increase in size, moving away from the wall. By inserting these, it enables finer elements closer to the wall, with a smooth transition to the surrounding elements. The inflations were modified by reviewing the element quality until the elements in the inflation region were acceptable. The two inflations can be seen in Figure 10 and Figure 11.

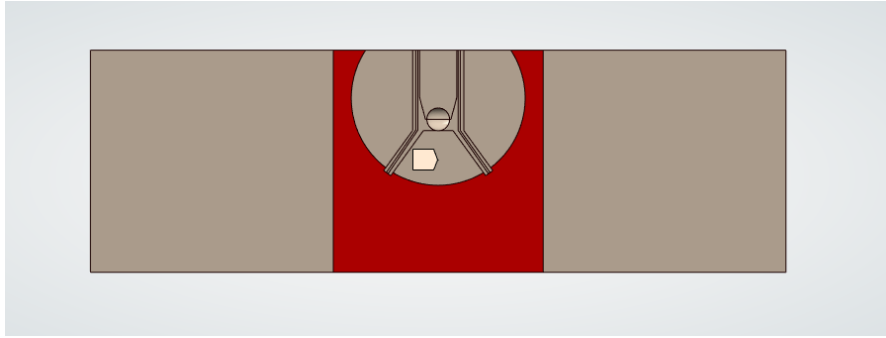


Figure 10: Inflation on the boundary between the wing walls and the filter

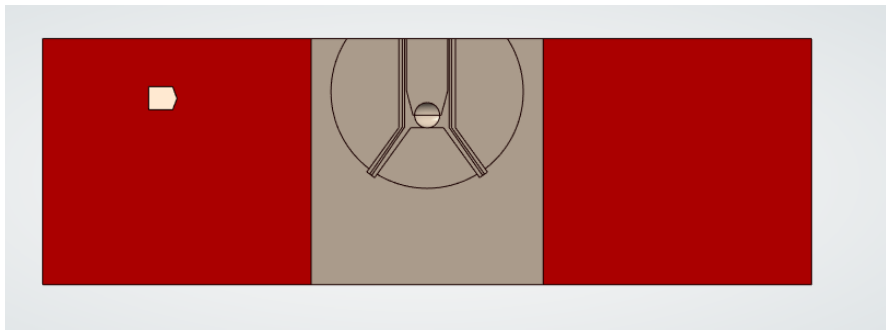


Figure 11: Inflation on the pool wall, going into the wing walls

Another critical area is the boundary between the filter and the wing walls. A face sizing is therefore applied to the water volume, and a face sizing is applied to the structure in the boundary. For reference, the circular hole is around 1200 mm in diameter. This can be seen in Figure 12 and Figure 13.

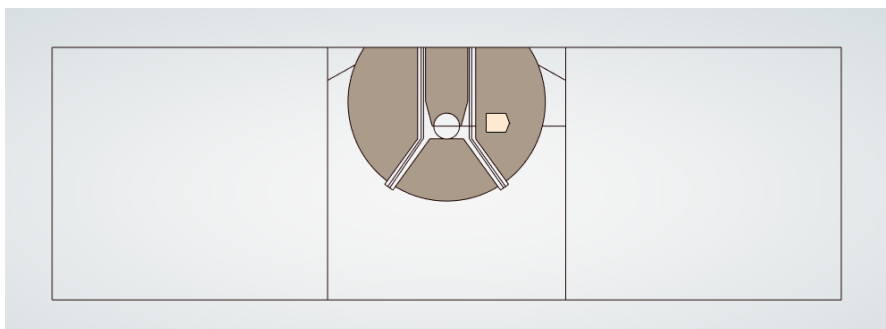


Figure 12: Mesh of the water face in the boundary

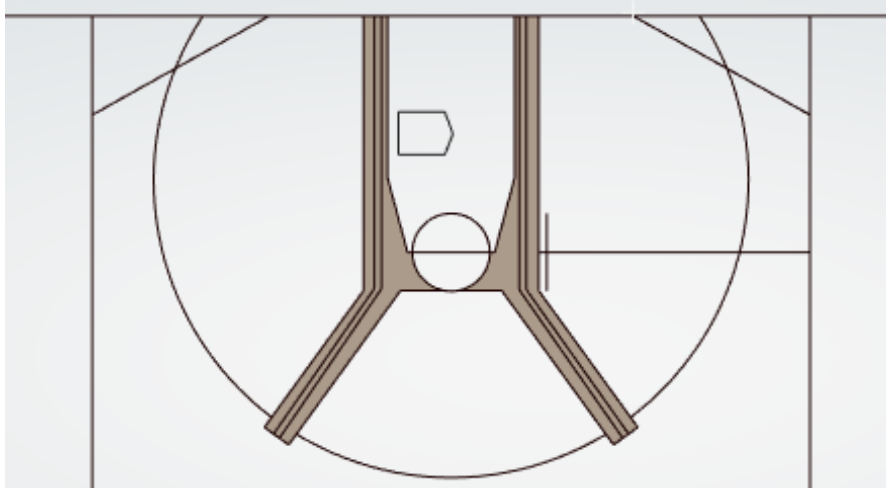


Figure 13: Mesh area of the structure in the boundary between wing walls and filter

The last area to be refined is the edge between the face seen in Figure 12, and the wall. A smooth transition is needed in this area since this area is experiencing high fluid velocities. This mesh area can be seen in Figure 14.

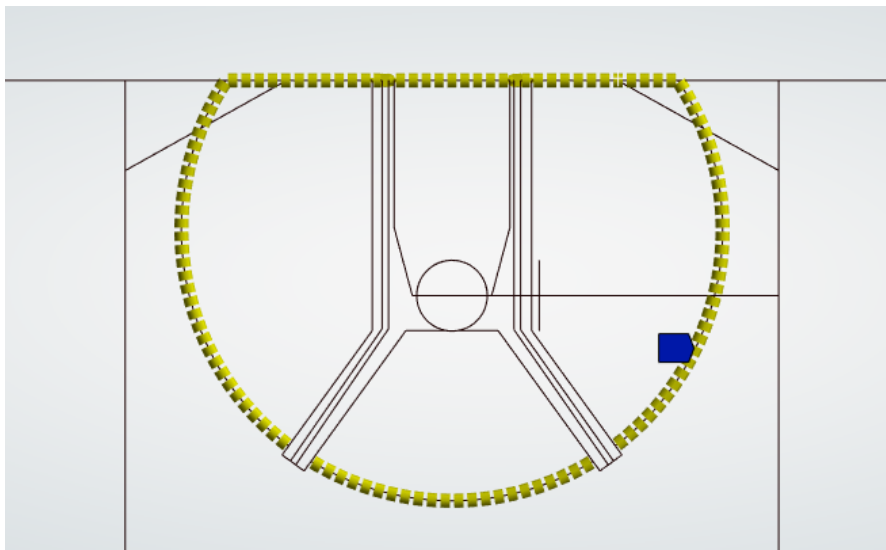


Figure 14: Mesh area of the edge in the boundary between face and wall

The mesh evaluation of the element quality showed the majority of the element scored 0.75 or higher where 1.0 is ideal. The y-axis translates to the amount of

elements, and the x-axis translates to the element quality between 0 and 1, with 1 being the best. The element quality for the wing walls can be seen in Figure 15.

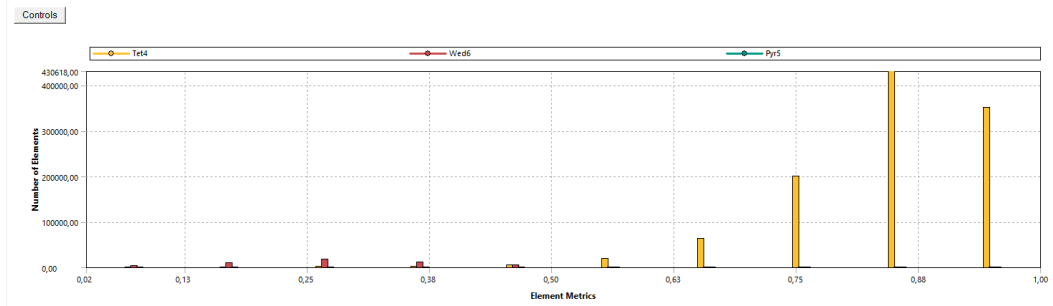


Figure 15: Element quality for the meshing of the wing walls

The majority of the element had a metric of 0.23 or lower where the ideal is 0.0. The element skewness can be seen in Figure 16.

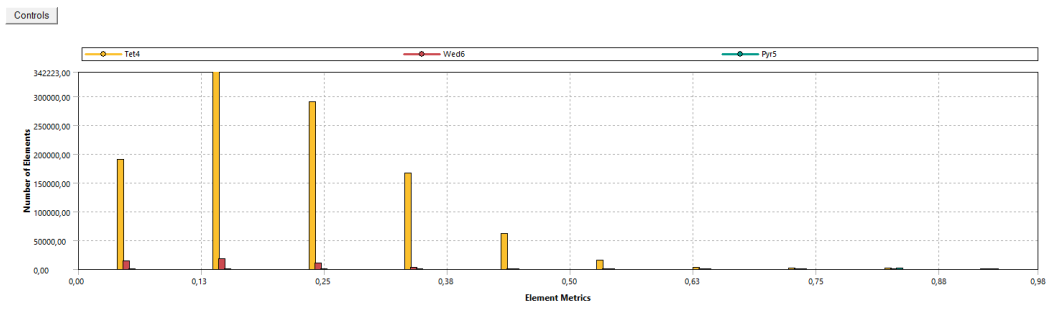


Figure 16: Element skewness for the meshing of the wing walls

3.3.2 Inlet Channel

The meshing for the inlet channel is also divided into different sections. Firstly, there is a body sizing on the whole body. The size of these elements are the ones that are changed between each iteration in the mesh study. The volume of the body sizing can be seen in Figure 17.

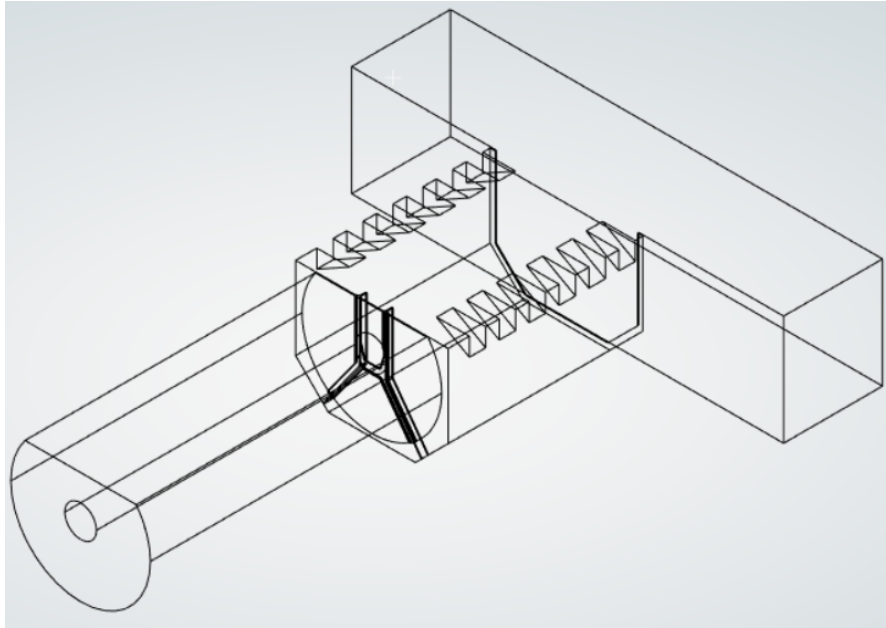


Figure 17: Inlet channel mesh volume for the body sizing

For the more critical areas, it is essential that the areas are well refined. All critical areas have a 20 mm element size. For the walls that are perpendicular to the flow, the high velocity fluid is experiencing a sudden obstacle. It is very important that these sections are fine enough to handle the high velocities and turbulence. To deal with this, two inflations are inserted using smooth transition with a maximum of 12 layers and 1.1 growth rate. Inflation layers are thin layers that increase in size, moving away from the wall. By inserting these, it enables finer elements closer to the wall, with a smooth transition to the surrounding elements. The two inflations can be seen in Figure 18 and Figure 19.

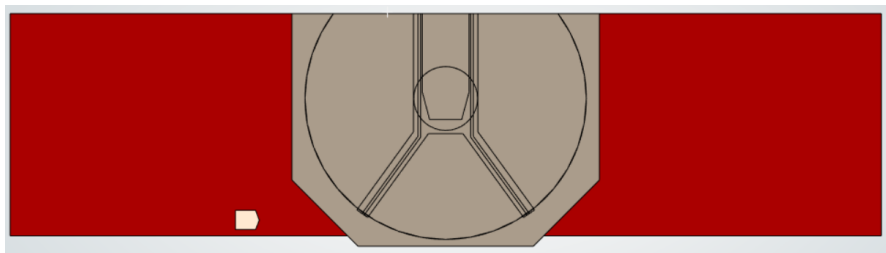


Figure 18: Inflation on the boundary between the inlet channel and the filter

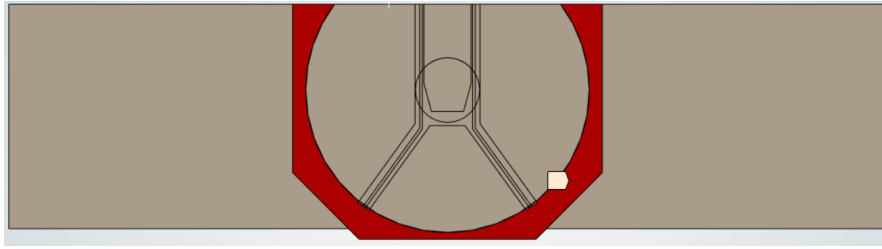


Figure 19: Inflation on the pool wall, going into the inlet channel

Another critical area is the boundary between the filter and the inlet channel. A face sizing is therefore applied to the water volume, and a face sizing is applied to the structure in the boundary. For reference, the circular hole is about 1200 mm in diameter. This can be seen in Figure 20 and Figure 21.

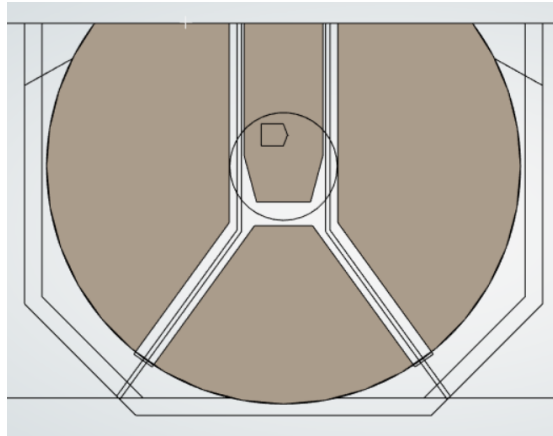


Figure 20: Mesh of the water face in the boundary

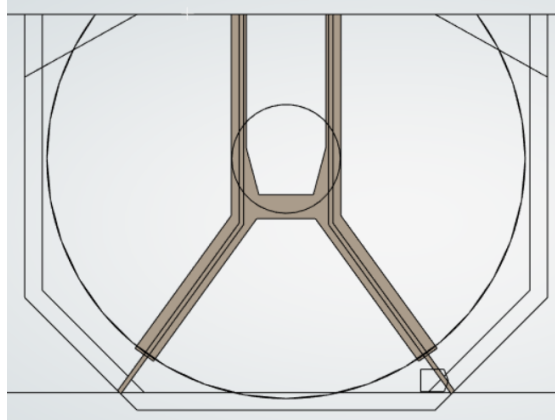


Figure 21: Mesh area of the structure in the boundary between inlet channel and filter

The last area to be refined is the edge between the face seen in Figure 20, and the wall. A smooth transition is needed in this area since this area is experiencing high fluid velocities. This mesh area can be seen in Figure 22.

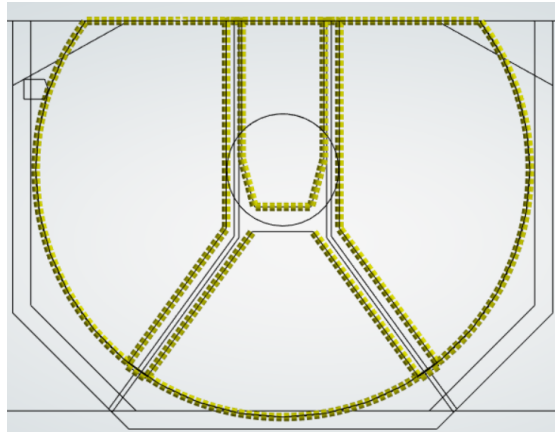


Figure 22: Mesh area of the edge in the boundary between face and wall

The majority of the element scored 0.74 or higher where 1.0 is ideal. The element quality can be seen in Figure 23.

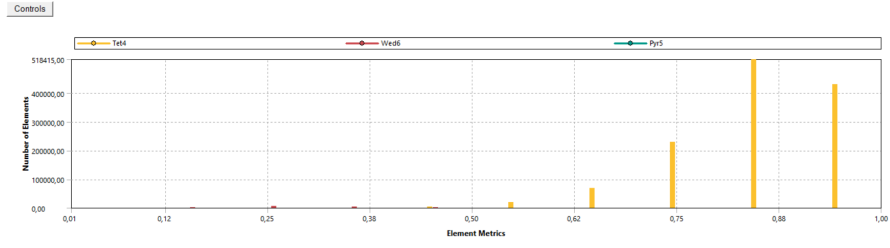


Figure 23: Element quality for the meshing of the inlet channel

The majority of the element had a metric of 0.22 or lower where the ideal is 0.0. The element skewness can be seen in Figure 24.

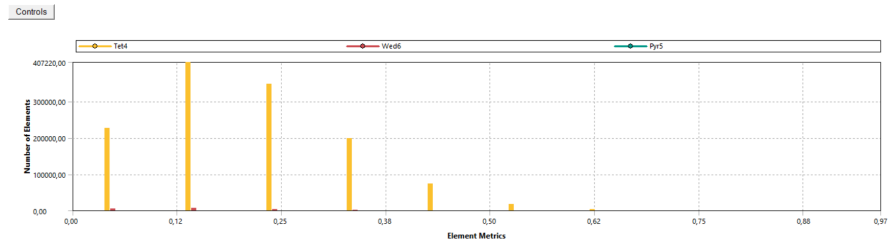


Figure 24: Element skewness for the meshing of the inlet channel

3.3.3 Mesh Study

Mesh study was performed to study mesh convergence and ensure the results were independent of the cell size. Maximum velocity in the boundary layer between the inlet channel and the porous media was measured as a benchmark point for the mesh study, due to it's critical importance of the water velocity going into the filter.⁷ The area where the maximum velocity is calculated can be seen in Figure 25.

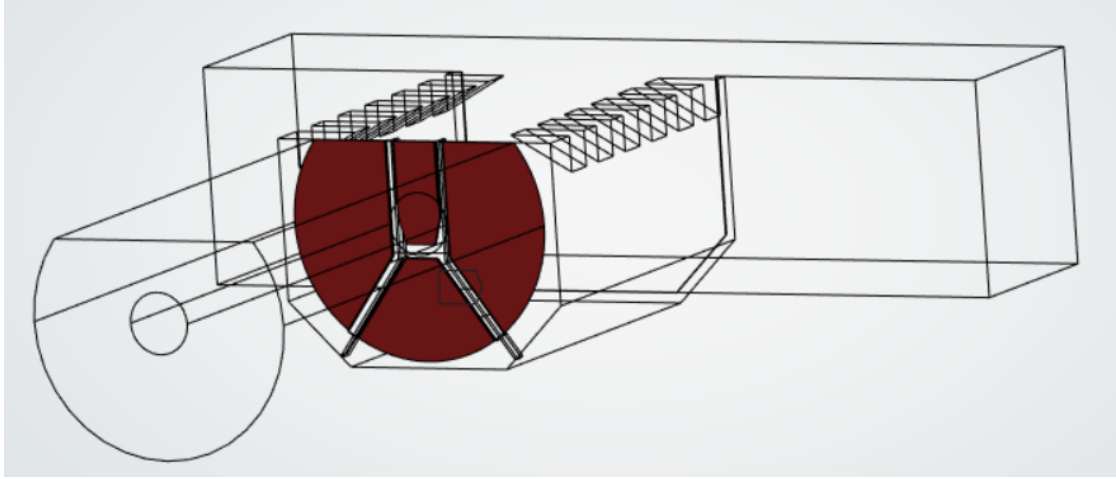


Figure 25: Boundary layer where the maximum velocity was calculated

According to general standards in the industry, less than 5% difference between iterations is considered acceptable.⁸ The mesh study focuses on decreasing the body sizing while the refinement of critical areas are already refined at a satisfied level. The three last iterations from the mesh study are displayed in Table 1 - 4 where the third is the last iteration.

⁷Nafems, 'The Importance of Mesh Convergence', <https://www.nafems.org/publications/knowledge-base/the-importance-of-mesh-convergence-part-1/?srsltid=AfmB0oo0Crg8EmjF18GgvhEJgWQNqDS6PmsEg9Y2Uj7C-Y6KkHh9NQ7g>, (Retrieved: 2026-05-07)

⁸Innovationspace ANSYS, Inc, 'Tips and Tricks for Meshing', https://innovationspace.ansys.com/courses/wp-content/uploads/sites/5/2024/01/1_Tips-and-Tricks-for-Meshing.pdf (Retrieved: 2026-03-16)

Table 1: Mesh study on Filter A wing walls

	Iteration 1	Iteration 2	Iteration 3
Body sizing [mm]	160	80	40
Element [#]	233 615	318 352	1 111 4328
Max velocity [m/s]	1.34	1.24	1.22
Difference [%]		8.50	-1.28

Table 2: Mesh study on Filter B wing walls

	Iteration 1	Iteration 2	Iteration 3
Body sizing [mm]	160	80	40
Element [#]	408 308	543 407	1 878 831
Max velocity [m/s]	1.24	1.33	1.36
Difference [%]		6.41	0.612

Table 3: Mesh study on Filter A inlet channel

	Iteration 1	Iteration 2	Iteration 3
Body sizing [mm]	160	80	40
Element [#]	147 449	202 462	730 053
Max velocity [m/s]	1.30	1.28	1.31
Difference [%]		1.57	-2.39

Table 4: Mesh study on Filter B inlet channel

	Iteration 1	Iteration 2	Iteration 3
Body sizing [mm]	160	80	40
Element [#]	227 742	326 509	1 295 082
Max velocity [m/s]	1.35	1.37	1.36
Difference [%]		-1.70	0.806

3.4 Cell Zone Conditions

3.4.1 Porous Media

Firstly, the cell zones were set to water in both fluid domains due to the one-phase analysis. In the flow-path, there are different points where there is a head loss. A head loss means the waters is losing pressure, and thereby also energy. To make the simulations as realistic as possible, we need to design a region downstream from the channel. The company has measured a height difference in the water from outside the filter going into the filter. Designing this height difference in

CAD would not represent a realistic setup. Therefore, a porous media will be used instead. A porous media is a region where the inertia and viscosity can be changed, in order to represent the real setup. Given values to be used in the calculations can be seen for Filter A in Table 5, and for Filter B in Table 6.

Table 5: Known values for the Porous Media in Filter A

Parameter	Value
Gravity, g [m/s^2]	9.82
Head loss, Δh [mm]	50
Length of Porous Media, L [m]	1860

Table 6: Known values for the Porous Media in Filter B

Parameter	Value
Gravity, g [m/s^2]	9.82
Head loss, Δh [mm]	94
Length of Porous Media, L [m]	2668

When designing the porous media the calculations were made through the Darcy-Forchheimer equation for simple homogenous porous media, which can be seen in Equation 1.⁹

$$S_i = -(\frac{\mu}{\alpha}v_i + C_2\frac{1}{2}\rho|v|v_i) \quad (1)$$

The source term, S_i , can be rewritten according to Equation 2:

$$S_i = \frac{\Delta P}{Lv} \quad (2)$$

The first term, in Equation 1, is called the Darcy-term. It is the viscous term, and it is dominant at low fluid velocities. μ is the dynamic viscosity, α is the

⁹ANSYS, '7.2.3 Porous Media Conditions', <https://www.afs.enea.it/project/neptunius/docs/fluent/html/ug/node233.htm>, (Retrieved: 2026-03-03)(Published: 2009-01-29)

permeability, and v_i is the magnitude of the velocity. The second term is called the Forchheimer-term. This is the inertial term, and it is dominant at higher velocities. C_2 is the inertial resistance factor, ρ is the density of the fluid, and v_i is again the magnitude of the velocity.

The Reynolds number will be used to determine whether the problem is viscous-dominant or inertia-dominant. The equation for Reynolds number can be seen in Equation 3.

$$\frac{\rho u D_h}{\mu} \quad (3)$$

ρ is the density of the fluid, u is the mean velocity of the fluid, D_h is the hydraulic diameter of the geometry and μ is the dynamic viscosity of the fluid.¹⁰ Water has a density of 998 kg/m^3 and a dynamic viscosity of $1 \cdot 10^{-3}$. The hydraulic diameter is above 1 m and the mean velocity is close to 1, resulting in the Reynolds number being close to 10^6 . This relatively high Reynolds number, means the flow is inertia-dominant. The Darcy-term is therefore neglected going forward.

Equation 1 is rewritten with the definition of S_i in Equation 2, and the Darcy-term removed. This results in Equation 4:

$$\frac{\Delta P}{L} = C_2 \frac{1}{2} \rho v^2 \quad (4)$$

From this, the equation is solved for the inertial resistance factor, C_2 . This can be seen in Equation 5:

$$C_2 = 2 \frac{\Delta P}{L \rho v^2} \quad (5)$$

ΔP is the difference in pressure, which can be calculated from the given head loss. L is the length of the porous media. If ΔP is rewritten as $\rho g \Delta h$, this leads to Equation 6:

$$C_2 = 2 \frac{g \Delta h}{L v^2} \quad (6)$$

¹⁰ANSYS, 'What is Reynolds Number?', <https://www.ansys.com/simulation-topics/what-is-reynolds-number>, (Retrieved: 2026-04-27)

Everything is now known except from the velocity magnitude, v . This velocity can be calculated from the given mass flow and the inlet area of the filter. The velocity calculation can be seen in Equation 7.

$$v = \frac{Q}{A \cdot 3600} \quad (7)$$

Q is the volume flow in m^3/h , and A is the inlet area of the filter. Three different flows are to be tested in the initial simulation for each filter. The velocity calculations for the different volume-flows can be seen in Table 7.

Table 7: Velocity calculation with given volume-flow and filter-inlet area

Filter	Volume-Flow [m^3/h]	Area [m^2]	Velocity [m/s]
Filter A	1688	0.630	0.744
	2250	0.630	0.992
	2800	0.630	1.23
Filter B	3000	1.05	0.794
	4000	1.05	1.06
	5000	1.05	1.32

With the known values, the inertial resistance factor, C_2 , can be calculated using Equation 6. The results are presented in Table 8.

Table 8: Inertial resistance factor for Filter A and Filter B

Filter	Volume-Flow [m^3/h]	Velocity [m/s]	Inertial resistance [C_2]
Filter A	1688	0.744	0.954
	2250	0.922	0.537
	2800	1.24	0.342
Filter B	3000	0.794	1.093
	4000	1.06	0.613
	5000	1.32	0.395

The direction of the porous media was set as the flow direction of the fluid, which is the z-direction in the model.

3.5 Boundary Conditions

3.5.1 Inlet

Mass flow was used as a boundary condition for the inlet. The company provided the values for the mass flow for Filter A and Filter B according to real world use. The values for the initial benchmark simulation are shown in Table 9. Flow 1 and Flow 2, are in use at operating filters at customers facilities. The largest flow, Flow 3, is an experimental flow to challenge if a higher velocity would be possible to implement at customer's facilities.

Table 9: Filters and volume-flows included in the initial simulation

Filter	Flow [m^3/h]		
	Flow 1	Flow 2	Flow 3
Filter A Wing Walls	1688	2250	2800
Filter A Inlet Channel	1688	2250	2800
Filter B Wing Walls	3000	4000	5000
Filter B Inlet Channel	3000	4000	5000

The surface upon which the boundary condition is placed can be seen in Figure 26.

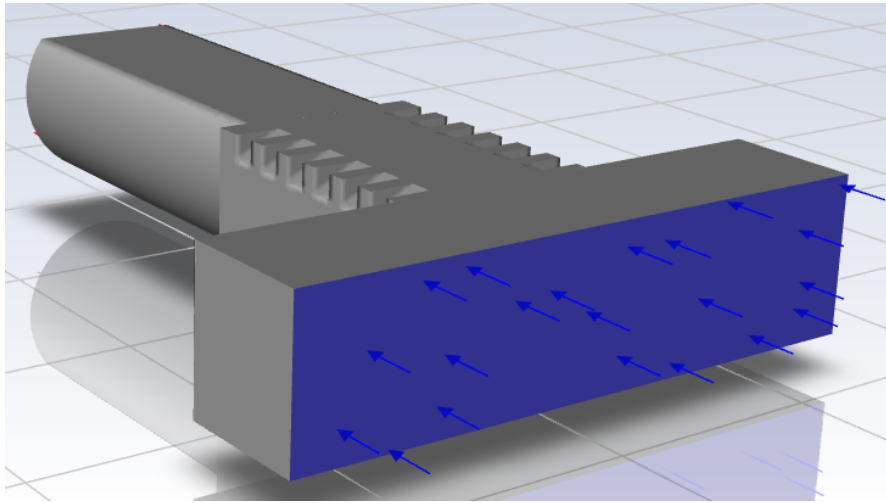


Figure 26: Illustration of the surface of the inlet boundary condition

3.5.2 Outlet

The outlet was set as a pressure outlet, with 0 Pa gauge pressure. The water is going out into an open pool with a head loss. The pressure loss occurs after the

porous media i.e after our point of interest, which is why the outlet is simplified as a 0 Pa pressure outlet. The surface upon which the outlet boundary condition is placed can be seen in Figure 27.

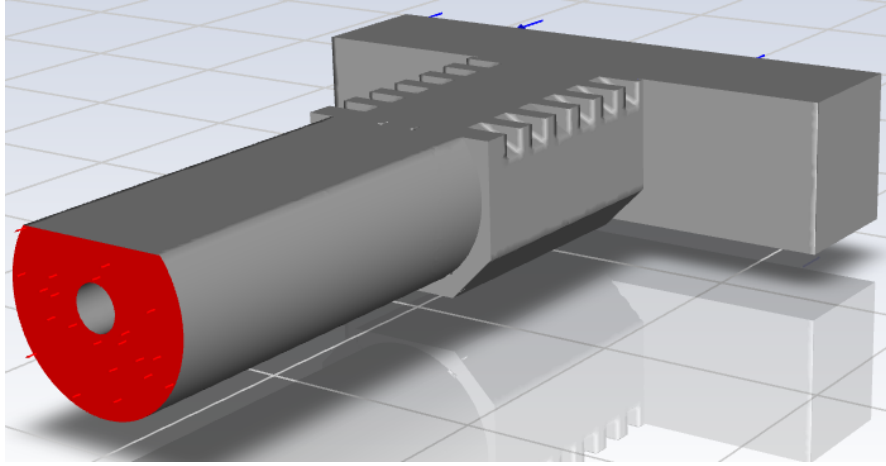


Figure 27: Illustration of the surface of the outlet boundary conditions

3.5.3 Walls

Every wall and geometry inside the model is set to "Wall" with standard settings, except the top surface seen in Figure 28. This surface is an open surface in the real scenario. Therefore, it was set with a specified shear of 0 Pa shear stress in all cartesian directions. This was to model a no-slip condition of the water surface, and to remove the impact of an actual wall.

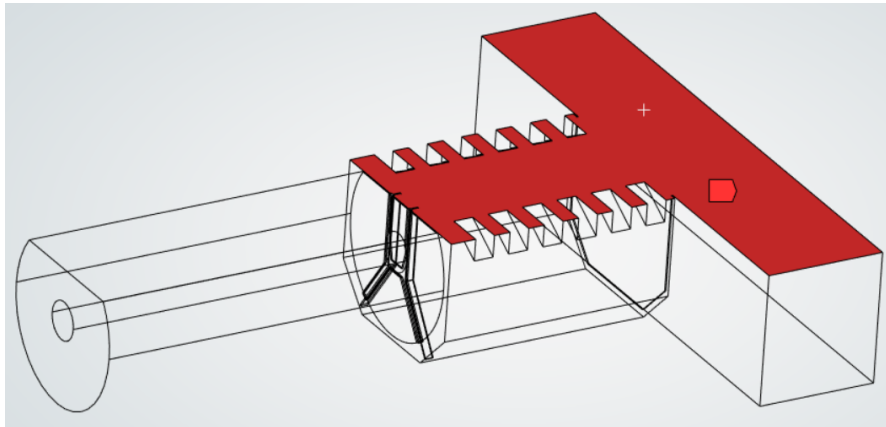


Figure 28: Top surface of fluid domain resembling contact surface air-water

3.6 Solver Settings

The solver settings were made by first simplifying the problem, and then increasing the complexity. The turbulence model used for all the simulations is K-Omega, which is a more conservative turbulence model made for increasing the complexity progressively. The wall formulation was set to correlation. In methods in ANSYS Fluent solver settings, there are different spatial discretization areas. Pressure is set to standard from Second Order. Momentum, Turbulent Kinetic Energy and Specific Dissipation Rate is all set to First Order Upwind from Second Order Upwind. This means that the continuity calculations and the Navier-Stokes equations will be approximated with first order equations, which is simplifying the simulation. The Controls are also changed. Pressure, Momentum, Turbulent Kinetic Energy, Specific Dissipation Rate and Turbulent Viscosity is set to 0.1 which means each value can only change by a maximum of 0.1 between each iteration. All residuals are set to 0.001 which is the measurement for when convergence is reached. This value was discussed with a supervisor in order to make the results as realistic as possible. When all parameters change by less than 0.001 compared to the last iteration, convergence has been reached.

The simulation is then initialized by Standard Initialization, from the water inlet. This creates start values for the simulation to start with. The simulation is then calculated, and when convergence is reached, the Methods are changed. When the first convergence is reached, one of the Methods is changed to Second Order Upwind. The calculations are then run again to convergence, and the process is then repeated until all categories except Momentum has been changed to Second Order Upwind. First Order Upwind solutions are generally more robust, however, the Second Order Upwind solutions are more accurate.¹¹ When the last calculation has converged, the Controls are switched back to default. This method ensures a stable flow field that is easier to converge, without compensating on the results.

3.7 Results

The maximum and mean velocity in the water domain bordering the porous body was measured as a benchmark point due to its critical importance for the velocity of water entering the filter. The velocities were calculated using the ANSYS function calculator. It is calculated according to description in Section 3.3.3. The area of the calculated velocity can be seen in Figure 25.

¹¹Ansyes Innovation Courses, 'Numerical Solution - Lesson 5', <https://innovationspace.ansys.com/courses/courses/turbulent-pipe-flow-rans/lessons/numerical-solution-lesson-5-5/>, (Retrieved: 2026-05-04)

3.7.1 Wing Walls

The results of the initial simulation for the Filter A wing walls can be seen in Table 10 and Filter B in Table 11. See Appendix B for the simulation images of the analysis shown in Table 10 and Table 11.

Table 10: Initial simulation of Filter A wing walls

	Flow 1	Flow 2	Flow 3
Volume-Flow [m^3/h]	1688	2250	2800
Body sizing [mm]	40	40	40
Element [#]	1 114 328	1 114 328	1 114 328
Mean Velocity [m/s]	0.944	1.27	1.57

Table 11: Initial simulation of Filter B wing walls

	Flow 1	Flow 2	Flow 3
Volume-Flow [m^3/h]	3000	4000	5000
Body sizing [mm]	40	40	40
Element [#]	1 877 426	1 877 426	1 877 426
Mean Velocity [m/s]	0.866	1.28	1.60

Large dead zones take place in front of the filter inlet. The dead zones causes severe recirculation in the whole area between the wing walls. The flow is separated going into the wing walls leading to a neck in the middle of the channel. The water in motions keeps a uniform velocity. The mean velocity is 0.86 m/s. The simulation results of Flow 1 in Filter B can be seen in Figure 29-30.

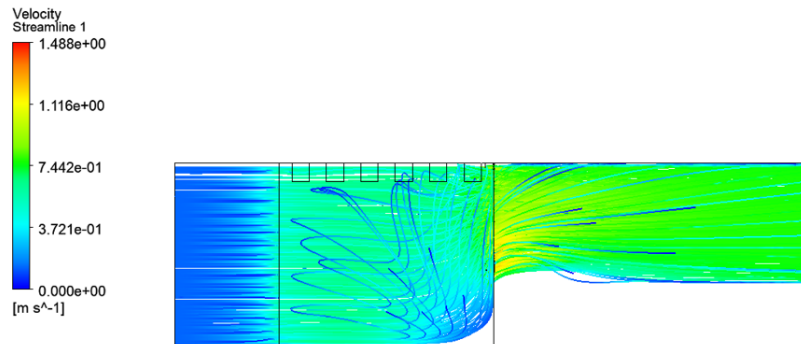


Figure 29: Streamlines for 3000 m^3/h in profile

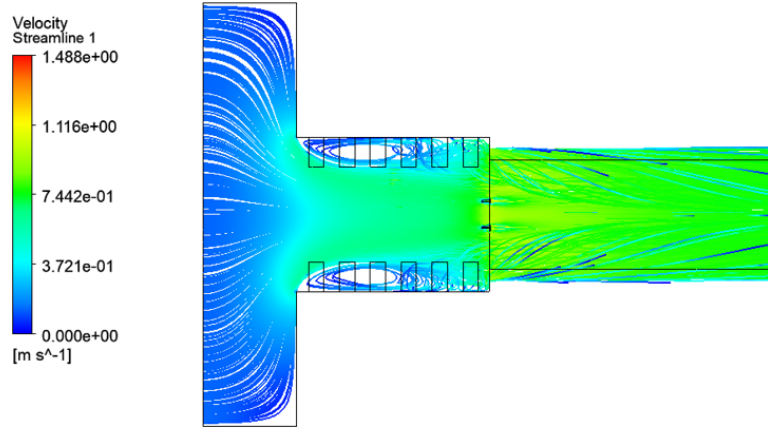


Figure 30: Streamlines for 3000 m^3/h in top view

3.7.2 Inlet Channel

The results of the initial simulation for the Filter A inlet channel can be seen in Table 12 and Filter B in Table 13. See Appendix B for the simulation images of the analysis shown in Table 12 and Table 13.

Table 12: Initial simulation of Filter A inlet channel

	Flow 1	Flow 2	Flow 3
Volume-Flow [m^3/h]	1688	2250	2800
Body sizing [mm]	40	40	40
Element [#]	730 053	730 053	730 053
Mean Velocity [m/s]	0.906	1.22	1.49

Table 13: Initial simulation of Filter B inlet channel

	Flow 1	Flow 2	Flow 3
Volume-Flow [m^3/h]	3000	4000	5000
Body sizing [mm]	40	40	40
Element [#]	1 295 082	1 295 082	1 295 082
Mean Velocity [m/s]	0.939	1.25	1.56

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. The water slows down and have a steep upward direction at the filter inlet. The mean velocity is 0.94 m/s. See the simulation results in Figure 31-32.

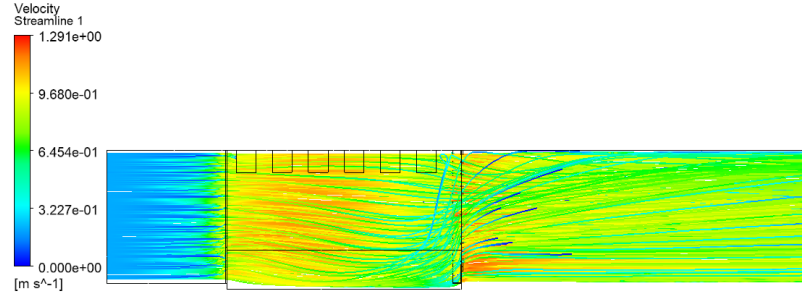


Figure 31: Streamlines for 3000 m^3/h in profile

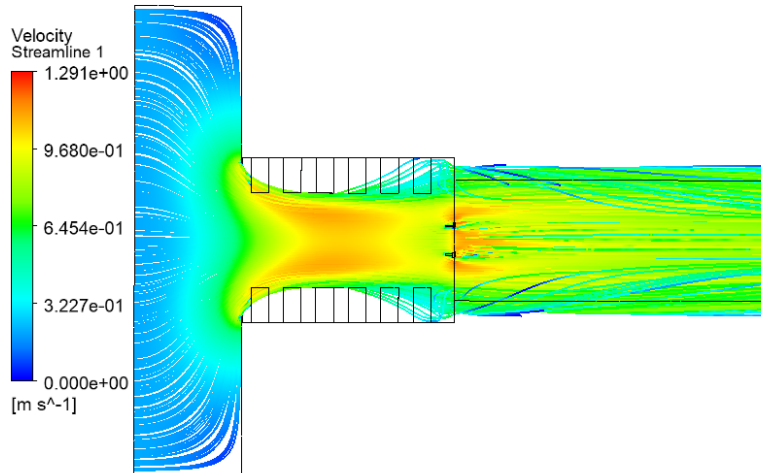


Figure 32: Streamlines for 3000 m^3/h in top view

The velocity of the water is accelerating after passing the middle of the channel and slows down again before entering the filter. A dead zone is identified along the bottom of the channel. The contour of velocity in profile can be seen in Figure 33.

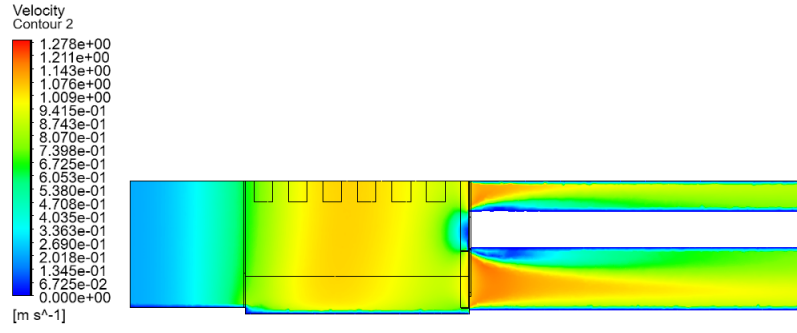


Figure 33: Contour of velocity in profile

The pressure drops when the water enters the channel and drops even further before entering the filter. The contour of pressure in profile can be seen in Figure 34.

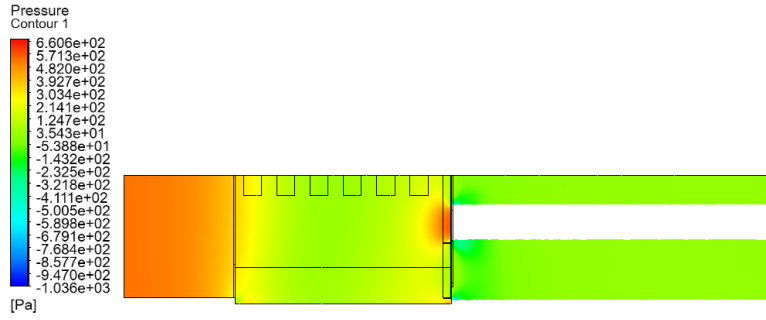


Figure 34: Contour of pressure in profile

Convergence is reached according to Section 3.6. The residuals of the convergence plot can be seen in Figure 35.

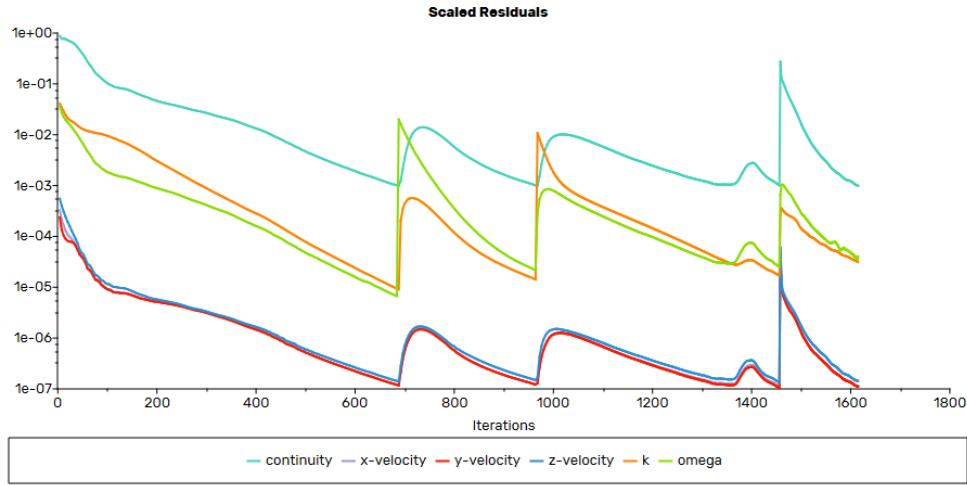


Figure 35: Residuals of the convergence plot

4 Product Specifications

The product specifications were established based on the results of the initial simulations in combination with a market analysis, which is presented below.

4.1 Benchmark

Analysis of products currently existing on the market. Showcasing competitor's products with a brief comment on our observation. The benchmarking was done as a market research and to gather inspiration of features to include or avoid.

Competitor 1: Adapter with sheet metal placed as slopes towards the inlet. The angled parts leads to the bottom of the inlet hole while the sides are left as perpendicular. The circular inlet hole is cut off on the top before reaching a full circle. This concept highlights a rectangular-shaped adapter with straight panels in the corners for a better fit to the circular hole. Competitor 1 can be seen in Figure 36.¹²

¹²Hydrotech, "Hydrotech Drum Filter Value series" 2026 <https://www.hydrotech.se/en/products/drum-filters/hydrotech-drum-filter-value-series-hdfv> (Retrieved: 2026-02-27)

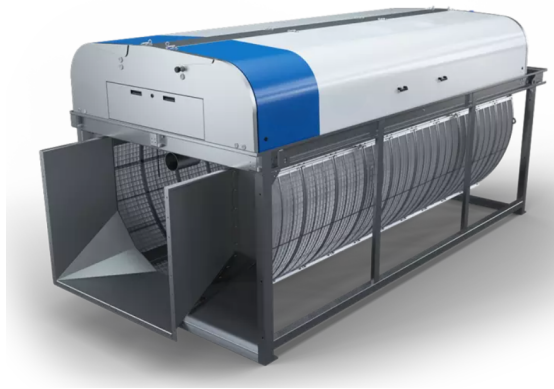


Figure 36: Filter of Competitor 1

Competitor 2: Adapter with sloped sheet metal around the majority of the inlet. The slopes are made up of multiple triangles that form a silhouette of a prism. A U-shaped channel is attached to the adapter. This concept highlights the possibility to create a close fit made of a prism to the circular hole. It also highlights the possibility of using two joint parts to narrow a wider entrance to a smaller hole. Competitor 2 can be seen in Figure 37.¹³



Figure 37: Filter of Competitor 2

¹³Hydrotech, "*Hydrotech Drum Filter Value series*", 2026 <https://www.youtube.com/watch?v=H0dd69T5wfU> (Retrieved: 2026-02-27)

Competitor 3: Water is available in a pond and the drum is directly exposed to the incoming water. This concept highlights the possibility to not use any inlet channel or other construction to lead the water into the filter. Competitor 3 can be seen in Figure 38.¹⁴

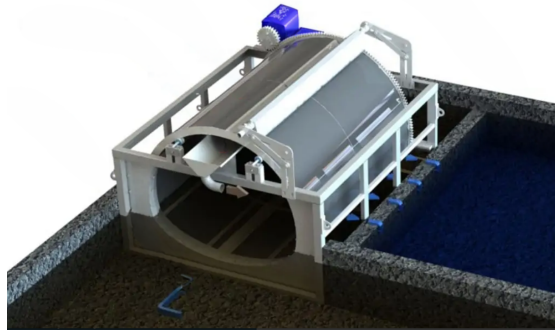


Figure 38: Filter of Competitor 3

Competitor 4: The construction uses two smaller circular inlet channels. The inlet water is collected in a chamber and then distributed evenly and controlled into the drum. This concept highlights the possibility of controlling the volume of water entering the filter. Competitor 4 can be seen in Figure 39.¹⁵

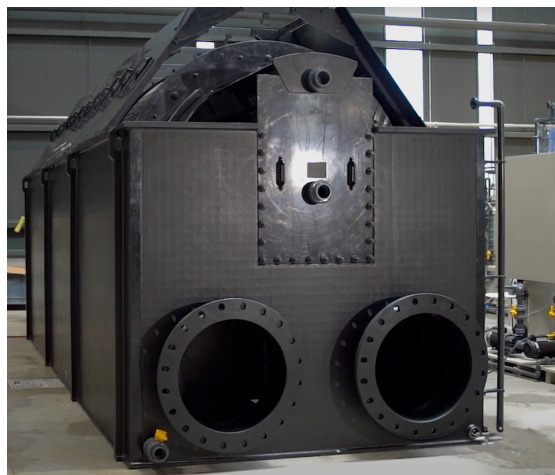


Figure 39: Filter of Competitor 4

¹⁴Mat-Kuling, *Drum Filters*, 2026, <https://matkuling.com/equipment/drum-filters-aquaculture/> (Retrieved: 2026-02-27)

¹⁵Ibid

Competitor 5: A smaller inlet hole leading to the lower half of the drum. The water inlet is low enough to allow water to enter under the drum. This concept highlights a inlet that is smaller and non-concentric with the filter hole. Competitor 5 can be seen in Figure 40.¹⁶



Figure 40: Filter of Competitor 5

Competitor 6: Water enters through a small pipe. This concept highlights a very small opening into the filter. Competitor 6 can be seen in Figure 41.¹⁷

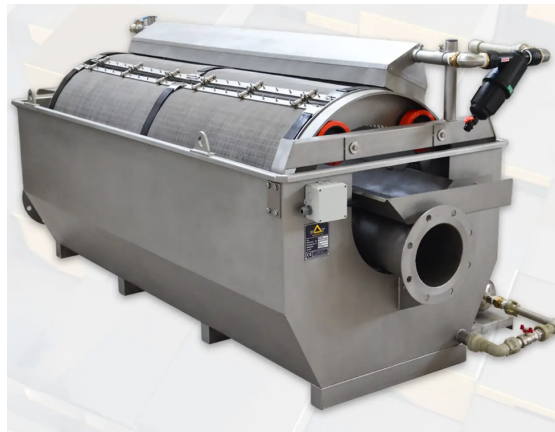


Figure 41: Filter of Competitor 6

¹⁶Ibid

¹⁷Ibid

Competitor 7: The inlet hole is half the size of the drum, placed in the middle vertically and to the right horizontally. This concept highlights a smaller opening into the filter, allowing the water to enter in one side. Competitor 7 can be seen in Figure 42.¹⁸



Figure 42: Filter of Competitor 7

Competitor 8: Inlet pipe in the center of the drum. The pipe leads to a chamber before allowing the water into the drum. This concept highlights the possibility for the water to enter through a circular pipe. Competitor 8 can be seen in Figure 43.¹⁹

¹⁸U&D Group, "*Fully Enclosed Disc Filter*" 2026 <http://otq.udwatertechnologies.com/disc-filter/fully-enclosed-disc-filter.html> (Retrieved: 2026-02-27)

¹⁹Huber, "*HUBER Disc Filter RoDisc*" 2026 <https://www.huber-se.com/products/detail/huber-disc-filter-rodisc/> (Retrieved: 2026-02-27)

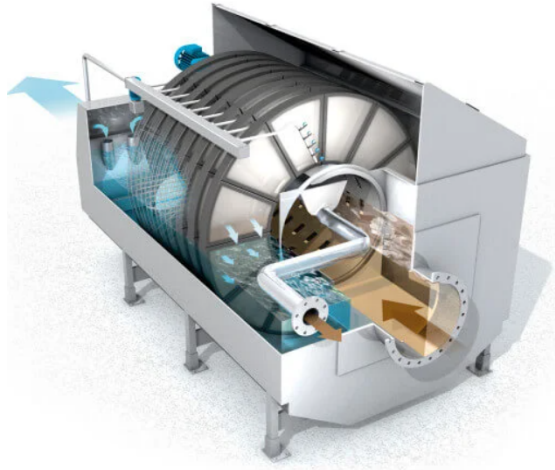


Figure 43: Filter of Competitor 8

Competitor 9: Sloped sheet metal towards the inlet. The inlet is shaped like a half circle, with the horizontal line slightly displaced upwards. This concept highlights the possibility of building a concave inlet with fewer straight sheets. Competitor 9 can be seen in Figure 44.²⁰

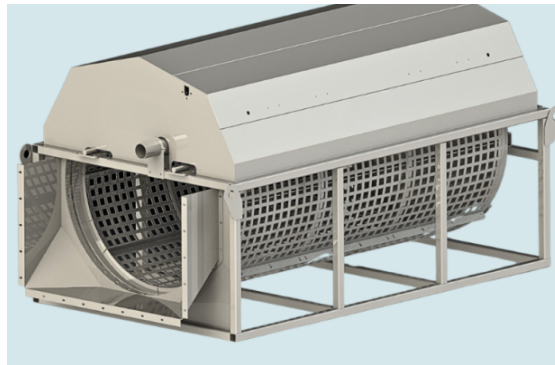


Figure 44: Filter of Competitor 9

4.2 Criteria

After studying the competitor's solutions, a meeting was held with the company in order to determine the criteria for the product. The company presented their criteria for the product, which were then combined with the criteria from the

²⁰Nak Clean Water, "Internal Rotary Drum Filter" 2026 <https://nakcleanwater.com/product/internal-rotary-drum-filter/> (Retrieved: 2026-02-27)

benchmark. From the information found in the benchmark, some features were decided not to be considered for the concepts, such as using no inlet channel and using an inlet off-center. Another trait that was deemed favorable to fit the criteria was for example flat panels for feasible manufacturing. The criteria for the concepts can be seen in Table 14.

Table 14: The benchmark criteria

Criteria
Manufacturability
Mean Velocity Outlet
Adapter to Inlet fit
Adapter to Channel fit
Recirculations

4.2.1 Manufacturability

The manufacturability, meaning the time and cost to produce effectively. Expert opinion from professionals in the sheet metal industry will be taken into consideration when evaluating the concepts. The geometry has to be able to be produced within reasonable complexity to remain relevant as a concept for further development. The criteria is judged from the CAD model.

4.2.2 Mean Velocity

This criterion handles the maximum velocity given by the company. The mean velocity in the outlet will not be allowed to exceed the highest successful velocity of facilities in operation. For $4000 \text{ m}^3/\text{h}$ volume flow, the maximum successful velocity is 1.81 m/s. This will be our maximum velocity regardless of volume flow. The mean velocity will be considered in the boundary between the channel and the filter.

4.2.3 Adapter to Inlet fit

Adapter to Inlet fit considers how well the adapter fits to the inlet hole. A closer fit implies a better flow. The criteria is judged from the CAD model.

4.2.4 Adapter to Channel fit

Adapter to Channel fit evaluates the complexity in merging the adapter and the channel. Since the final concept will consist of two adapters in different sizes fitting onto one channel, the fit will be essential. The criteria is judged from the CAD model.

4.2.5 Recirculations

Recirculations considers the flow inside the channel. Important aspects are dead zones, horizontal streamlines, high velocity zones and intact flow. The criteria is judged from the streamlines in the CFD analysis. A high score within this category symbolizes how well the concept decreases recirculations.

5 Concept Generation

The concept generation phase focuses on constructing an adapter and channel for Filter B. The adapter for Filter A will be constructed in the Concept Testing phase, which can be seen in Section 7.3. The Filter A adapter will also be fitted to Filter B's channel.

The approach of producing CAD and CFD follows the approach described in Section 3. The CAD model of each concept follow the simplifications stated in Section 3.1. In addition to the channel, the pool and porous zone are also included in the CAD model, also described in Section 3.1. Unlike the initial simulation, the concepts in the concept generation phase will be produced with a symmetry line. The symmetry line is arranged as a boundary condition (see Section 3.5) and are placed according to Figure 45. Since all concepts are symmetrical around the middle plane, cutting the model in half makes the computational calculation process more efficient.

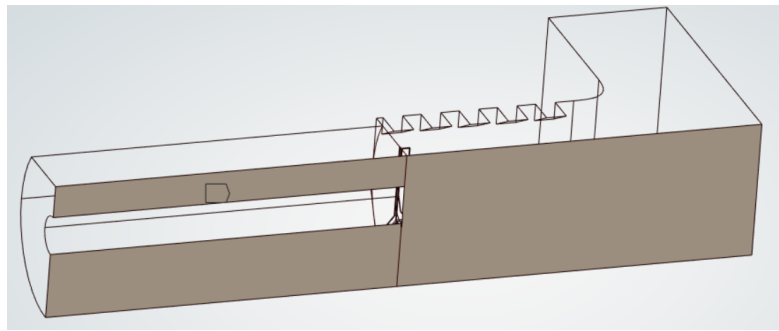


Figure 45: Symmetry wall

After producing a CAD model of the geometry, it is pre-processed in ANSYS Design Modeler as described in Section 3.2. For mesh and geometry specific aspects, a close as possible resemblance has been made to the initial simulation. Overall, our developed concepts follow the same strategy as described in Section 3.3. Due to geometric differences, the mesh of each concept are not strictly bound follow the initial simulation. Every concept are studied under the same mesh study as described in Section 3.3.3 to ensure mesh convergence. The mesh study for each concept can be seen in Appendix C.

The setup in ANSYS Workbench for each concept strictly follows the same method as for the initial simulation in Section 3.4-3.6. As the geometry of the concepts are most resembled to the inlet channel, those values are used for the analysis and demonstrated in Table 15. The lowest volume flow is simulated since it is the most

used at customer's facilities.

Table 15: Values for the analysis of each concept

Parameter	Value
Mass flow [m^3/h]	3000
Inertial resistance, [C_2]	1.093

Concepts was produced and evaluated through CFD analysis in an iterative process. A few concept was sketched and built in CAD and then evaluated. The results from the CFD analysis was an inspiration for future concepts. The process was built up progressivity. Other concepts was produced with inspiration of benchmarking, nature, or technology. The concepts are not shown in a specific order of chronological, results or other.

5.1 Concept 1

Ramp with 30° angle leading the water from the bottom floor to the filter's inlet. The idea was to make as little changes as possible to the company's current product. See the model in Figure 46.

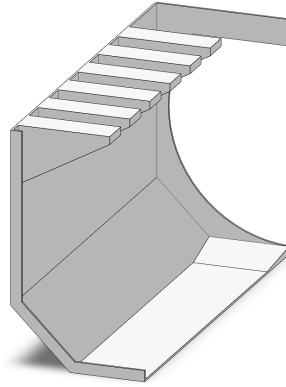


Figure 46: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. The water slows down and have a steep upward direction at the filter inlet. The mean velocity is 0.94 m/s. See the simulation results in Figure 47-48.

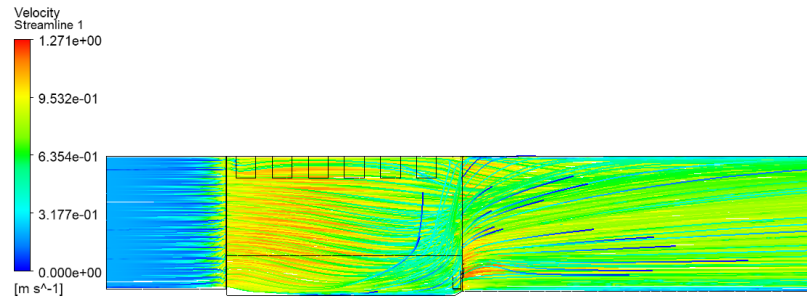


Figure 47: Streamlines in profile

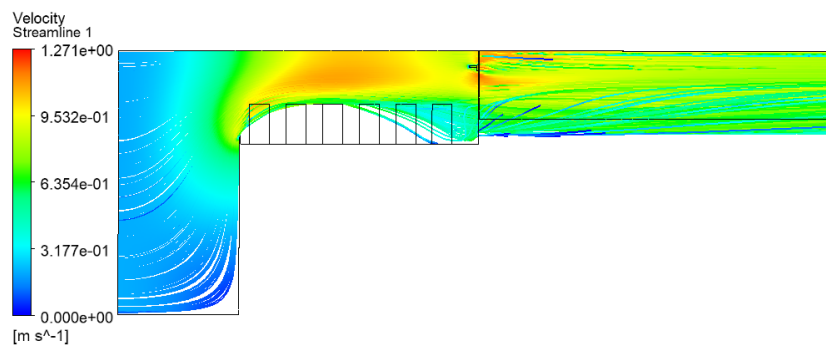


Figure 48: Streamlines in top view

5.2 Concept 2

Three ramps leading the water from the floor to the filter's inlet. The idea was to only make small changes to the company's product and to improve the *adapter to inlet fit*. See the model in Figure 49.

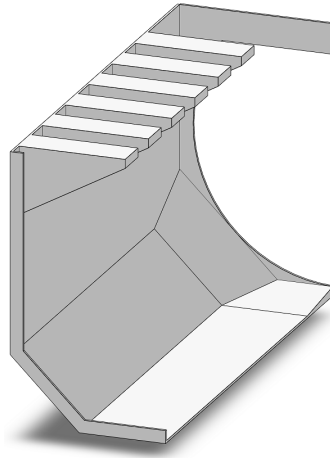


Figure 49: CAD model in sectional

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. The water slows down and have a steep upward direction at the filter inlet. The mean velocity is 0.96 m/s. See the simulation results in Figure 50-51.

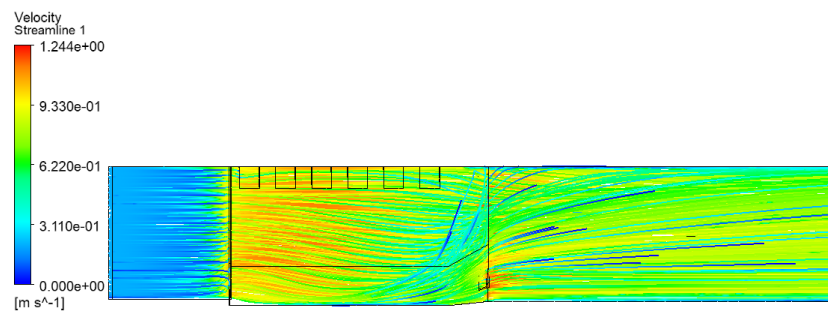


Figure 50: Streamlines in profile

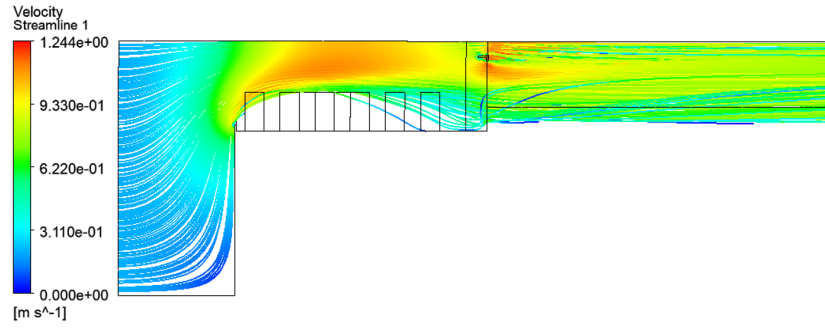


Figure 51: Streamlines in top view

5.3 Concept 3

Five ramps leading the water from the floor to the filter's inlet. The idea was to improve the *adapter to inlet fit* by features to the company's existing product enabling for retrofitting. See the model in Figure 52.

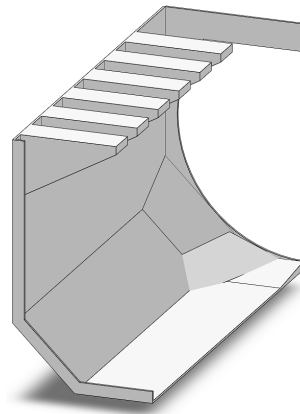


Figure 52: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. The water slows down by the bottom in front of the filter inlet. Some water have a steep upward direction at the filter inlet. The mean velocity is 0.92 m/s. See the simulation results in Figure 53-54.

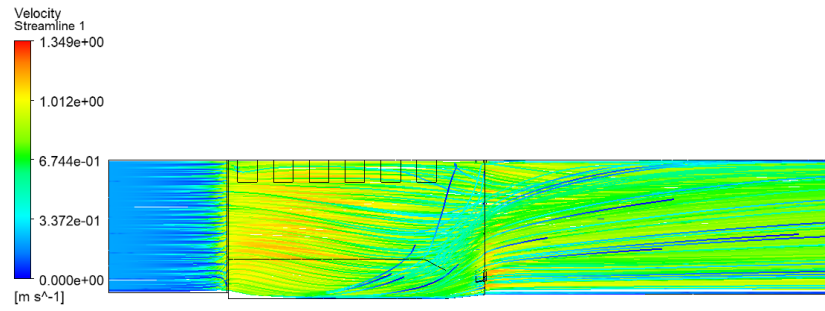


Figure 53: Streamlines in profile

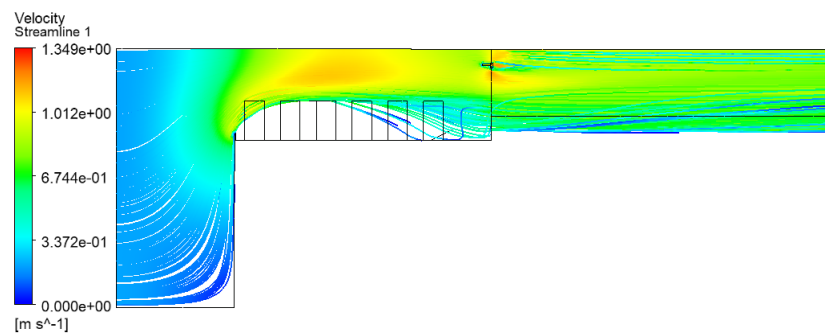


Figure 54: Streamlines in top view

5.4 Concept 4

This concept was made to fit the inlet of the filter with straight lines instead of a circular fitting. See the model in Figure 55.

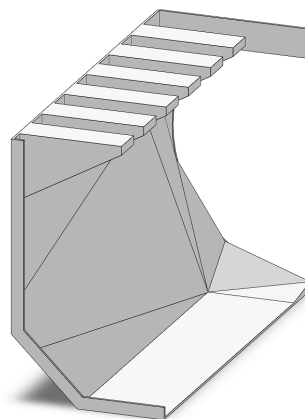


Figure 55: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate in the middle. The water flows mostly in a uniform velocity and slows down in front of the filter inlet. The mean velocity is 0.89 m/s. See the simulation results in Figure 56-57.

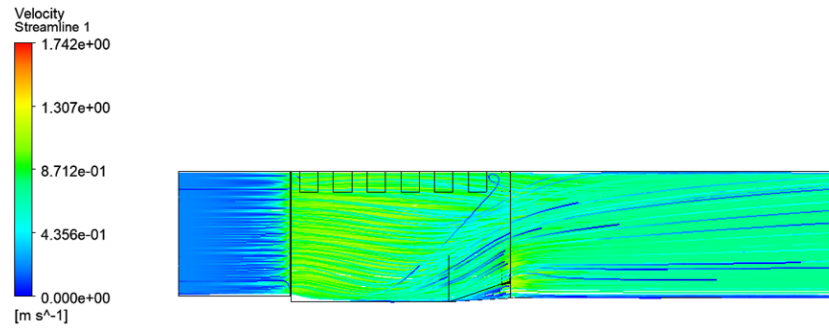


Figure 56: Streamlines in profile

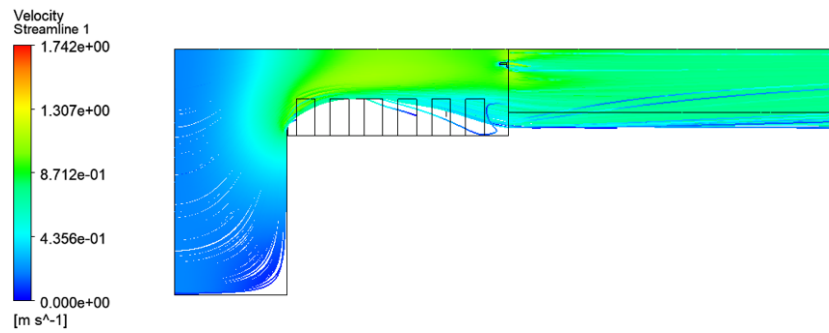


Figure 57: Streamlines in top view

5.5 Concept 5

Slope of flat panels between the channel's inlet and outlet. The idea was to use a slope with an easy gradient to lead the water over the existing edge under the filter inlet. See the model in Figure 58.

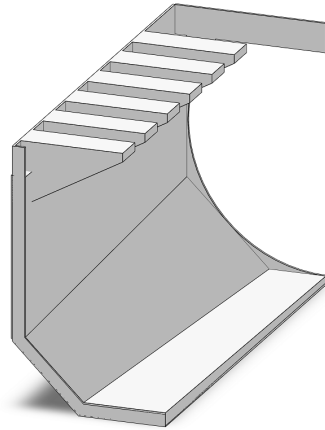


Figure 58: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. Some water slows down in front of the filter inlet. The mean velocity is 0.86 m/s. See the simulation results in Figure 59-60.

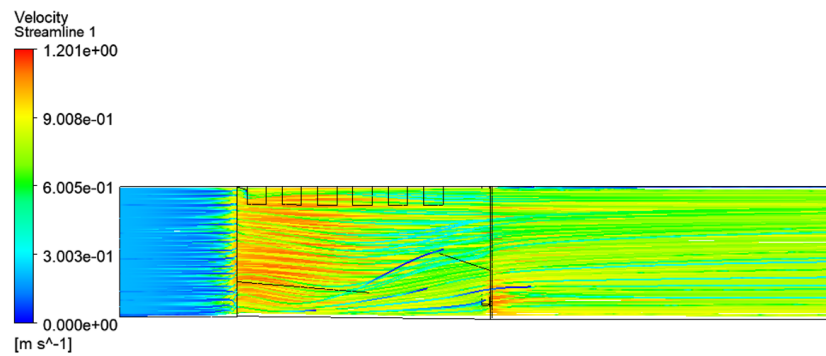


Figure 59: Streamlines in profile

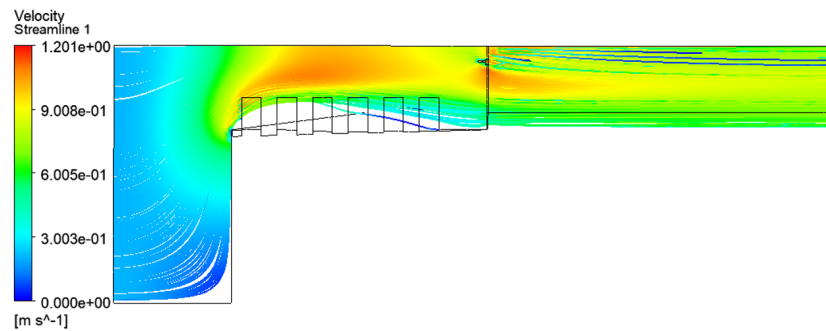


Figure 60: Streamlines in top view

5.6 Concept 6

Wider channel with the same width as the filter. Slope of flat panels between the channel's inlet and outlet. The idea was to widen the channel to give more space for the water to calm before entering the filter. See the model in Figure 61.

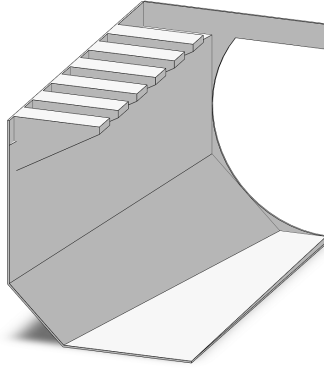


Figure 61: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate in a waist shape before filling out the edges. The water flows mostly in a uniform velocity. Some water closer to the sides is slowed down. The mean velocity is 0.84 m/s. See the simulation results in Figure 62-63.

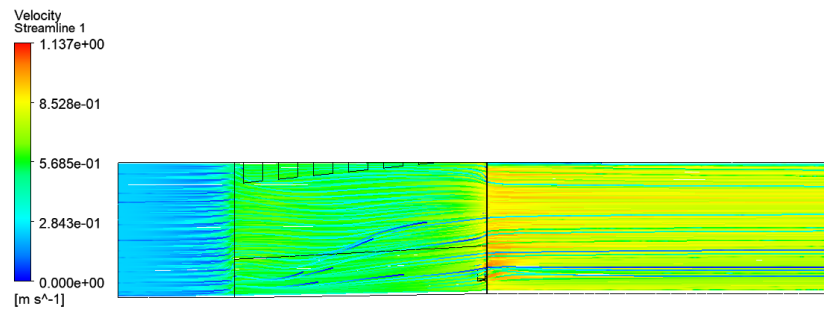


Figure 62: Streamlines in profile

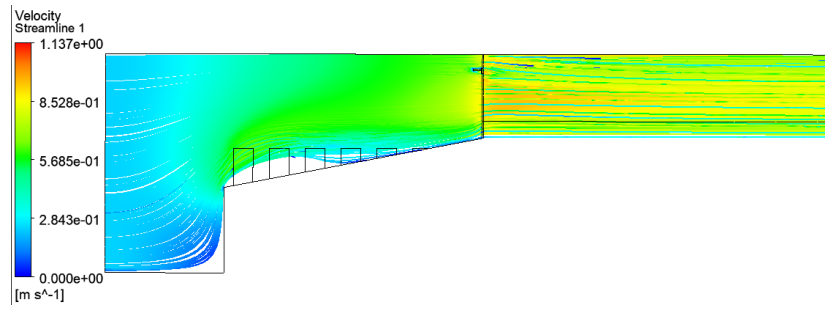


Figure 63: Streamlines in top view

5.7 Concept 7

Short loft with flat panels following the geometry of the channel with a circular fit to the filter's inlet. This concept tries to improve the *adapter to inlet fit*. See the model in Figure 64.

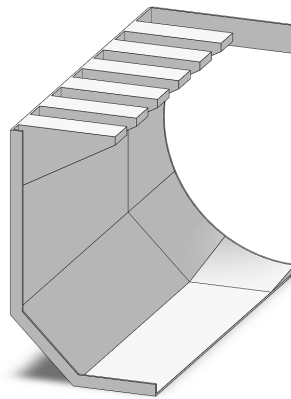


Figure 64: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. The water slows down and have a steep upward direction with recirculation in front of the filter inlet. The mean velocity is 0.92 m/s. See the simulation results in Figure 65-66.

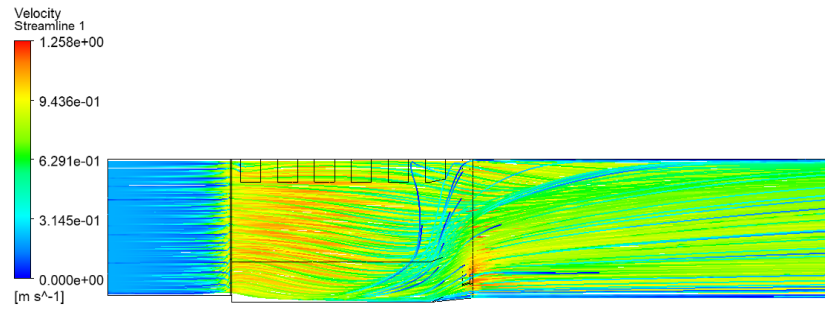


Figure 65: Streamlines in profile

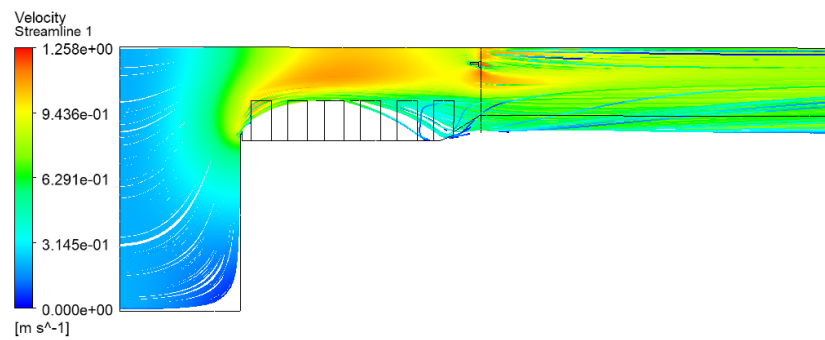


Figure 66: Streamlines in top view

5.8 Concept 8

Panels that are lofted, resulting in a circular fit around the inlet of the filter. The idea was to go from a wider geometry to the filter inlet with a slower decrease of the geometry. See the model in Figure 67.

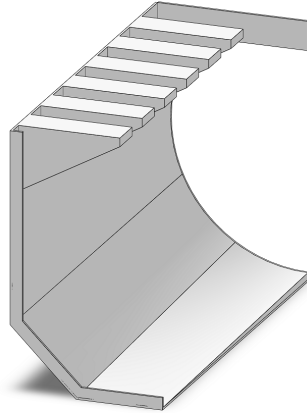


Figure 67: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. Some water slows down in front of the filter inlet when entering in an upward slope. The mean velocity is 0.90 m/s. See the simulation results in Figure 68-69.

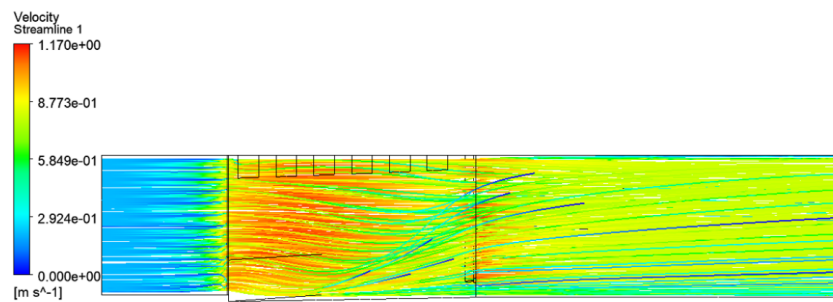


Figure 68: Streamlines in profile

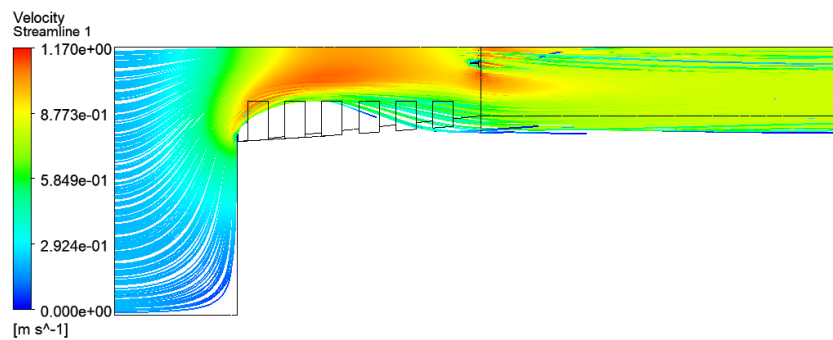


Figure 69: Streamlines in top view

5.9 Concept 9

Concave channel of flat straight panels with a close to circular fit to the filter hole. A wider opening by the entrance of the channel, in order to reduce the neck in previous concepts. The idea was to narrow the channel in the beginning and give more length for the water to stabilize before entering the filter. See the model in Figure 70.

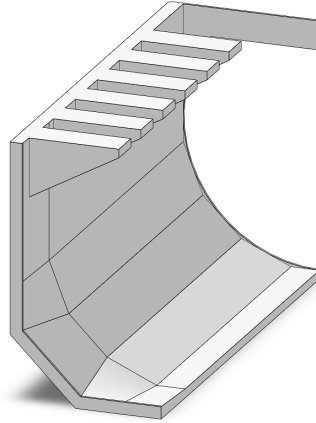


Figure 70: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. The water flows close to horizontally through the channel and into the filter inlet. The mean velocity is 0.90 m/s. See the simulation results in Figure 71-72.

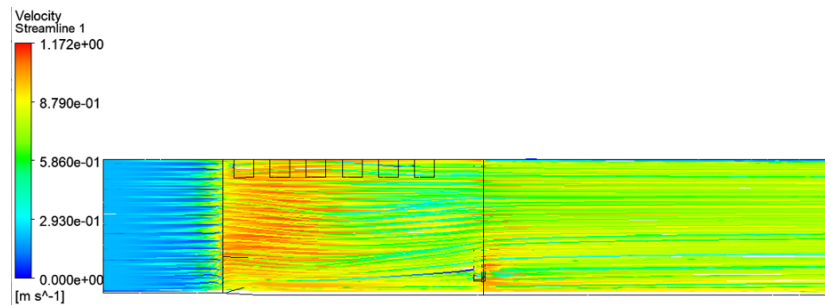


Figure 71: Streamlines in profile

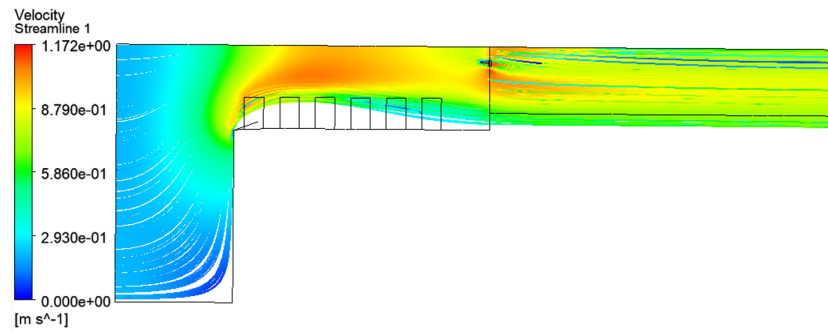


Figure 72: Streamlines in top view

5.10 Concept 10

A contraction section of a wind-tunnel scaled to the adapter's length. See the model in Figure 73.

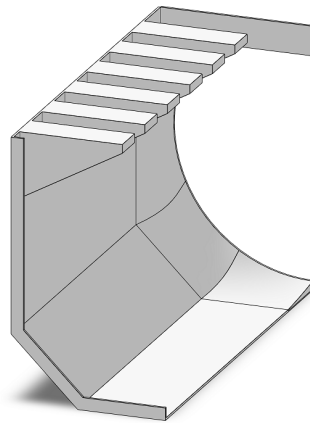


Figure 73: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. The water slows down and have a steep upward direction with recirculation in front of the filter inlet. The mean velocity is 0.91 m/s. See the simulation results in Figure 74-75.

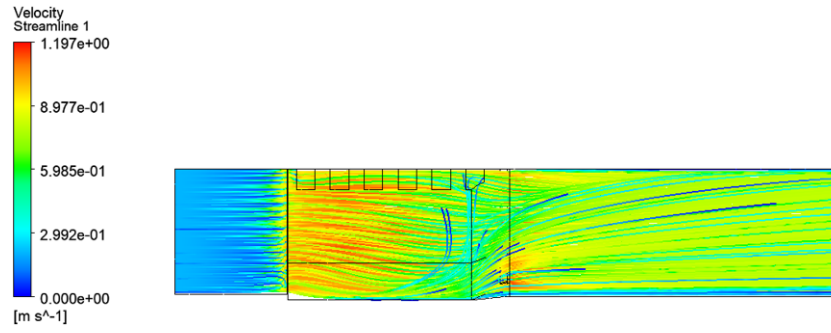


Figure 74: Streamlines in profile

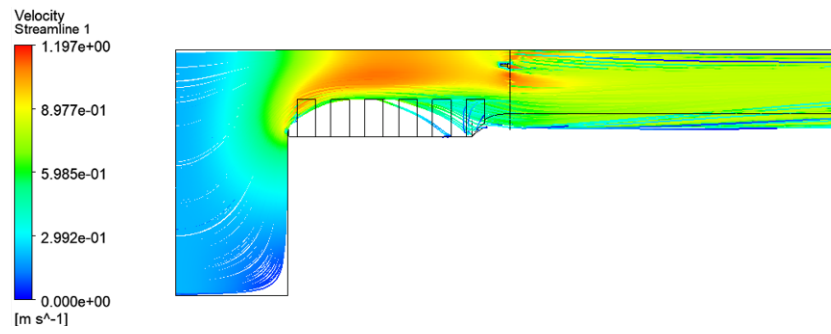


Figure 75: Streamlines in top view

5.11 Concept 11

A contraction section of a wind-tunnel scaled to the entire length of the combined channel and adapter. A wind tunnel uses the contraction section to prepare the air for the test section. The same philosophy was used in this concept. See the model in Figure 76.

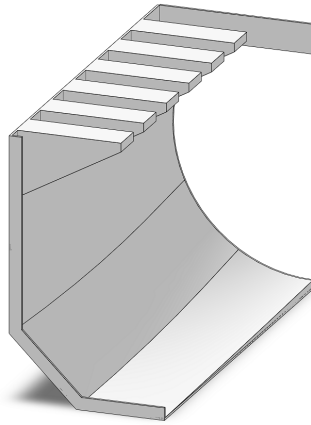


Figure 76: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. Some water slows down in front of the filter inlet when entering in a upward slope. The mean velocity is 0.90 m/s. See the simulation results in Figure 77-78.

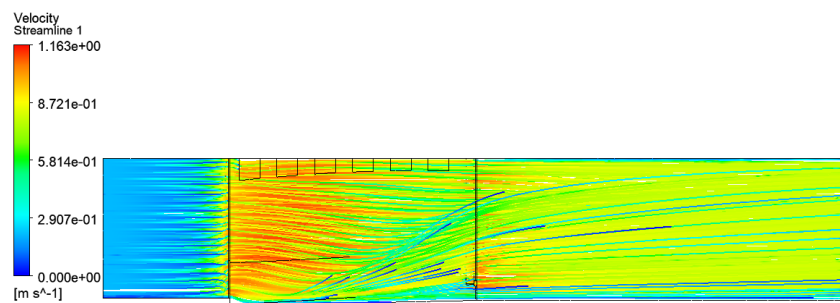


Figure 77: Streamlines in profile

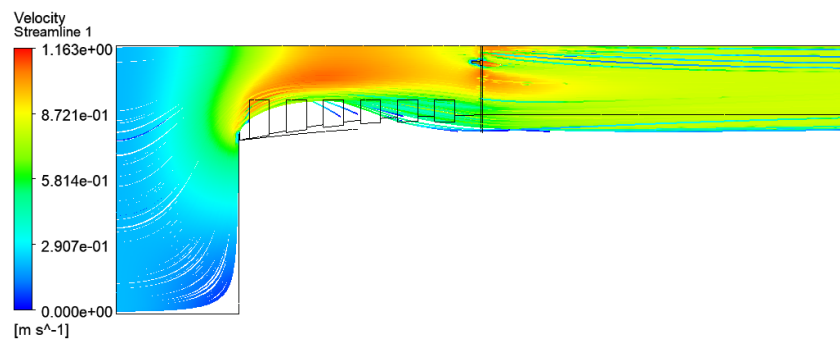


Figure 78: Streamlines in top view

5.12 Concept 12

Wider channel with the same width as the filter. Curved slopes between the channel's inlet and outlet. Circular fit to the filter hole. See the model in Figure 79.

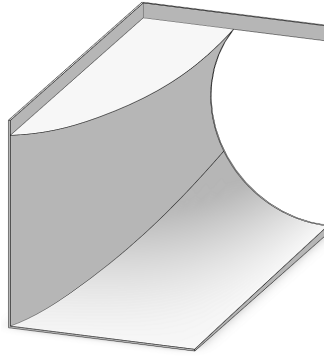


Figure 79: CAD model in sectional view

The water utilizes almost the full volume in the channel. Some water closer to the edge is slowed down. The flow follows the channels slightly upward slope. The velocity of the flow gradually increases closer to the inlet. The mean velocity is 0.89 m/s. See the simulation results in Figure 80-81.

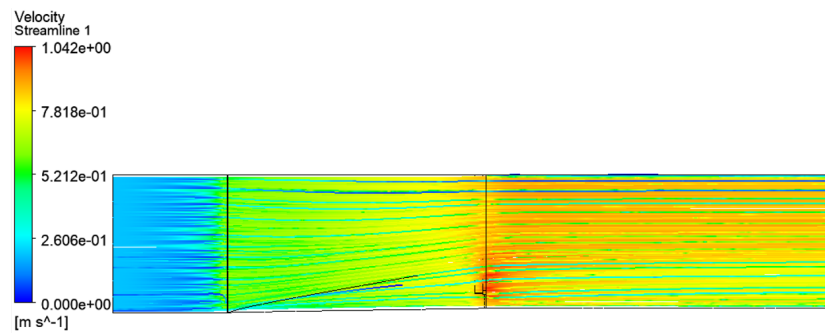


Figure 80: Streamlines in profile

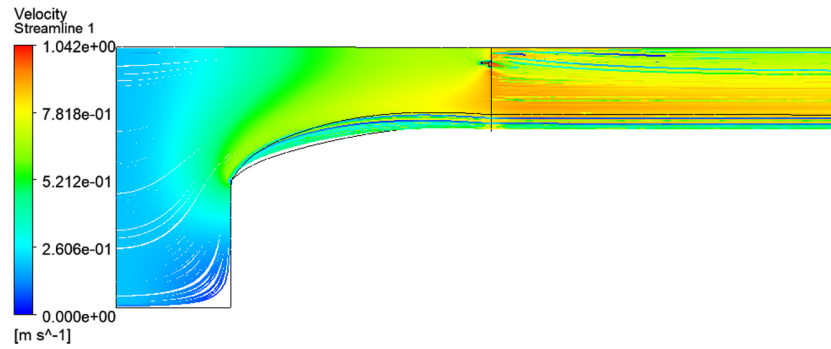


Figure 81: Streamlines in top view

5.13 Concept 13

A narrow section in the middle, in an attempt to gradually reduce the radius from the pool, going into the channel. See the model in Figure 82.

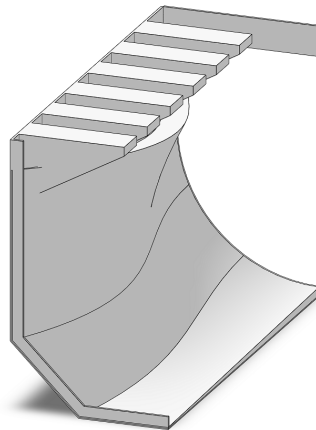


Figure 82: CAD model in sectional view

The flow follows the shape of the channel. Some water closer to the edge is slowed down. The velocity increases in the narrow section of the channel. The mean velocity is 0.90 m/s. See the simulation results in Figure 83-84.

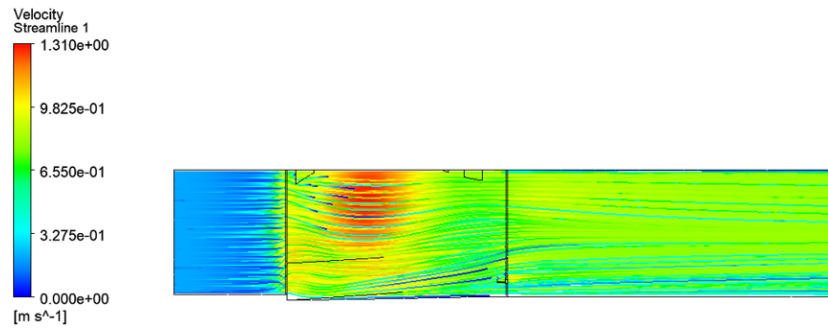


Figure 83: Streamlines in profile

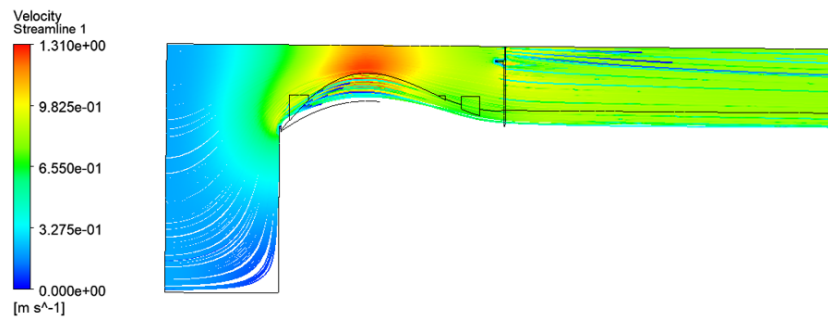


Figure 84: Streamlines in top view

5.14 Concept 14

A smaller section in the middle, with a straight section at the top. Gradually reducing the radius from the pool, going into the channel. See the model in Figure 85.

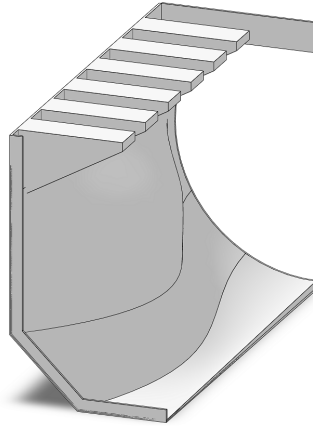


Figure 85: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. Some water closer to the edge is slowed down. The velocity increases in the narrow section of the channel. The mean velocity is 0.93 m/s. See the simulation results in Figure 86-87.

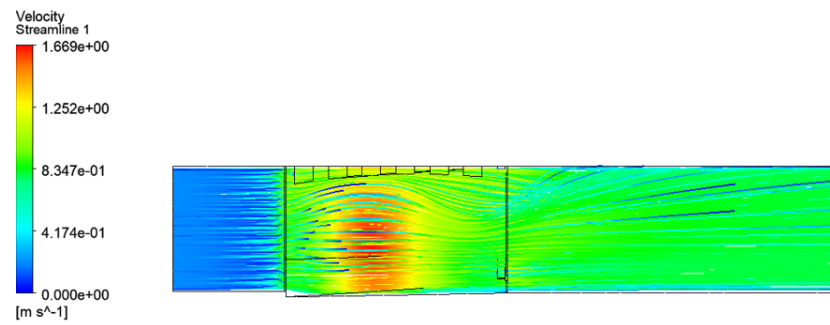


Figure 86: Streamlines in profile

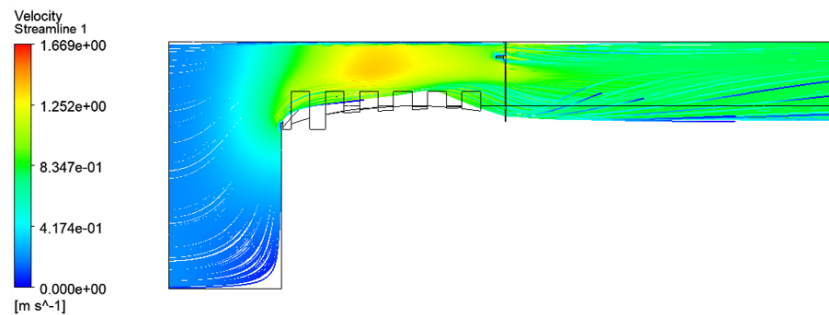


Figure 87: Streamlines in top view

5.15 Concept 15

A rounded wall going into the channel, with the channel itself having the shape of a pipe made to fit the inlet of the filter. The idea is to reduce the neck, seen in the majority of the concepts. See the model in Figure 88.

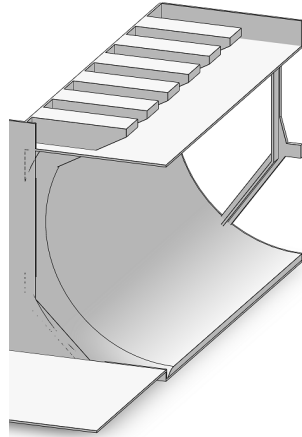


Figure 88: CAD model in sectional view

The flow is slightly disturbed by the pool edge causing the water to concentrate with a higher velocity in the middle. The water flows close to horizontally through the channel and into the filter. The mean velocity is 0.90 m/s. See the simulation results in Figure 89-90.

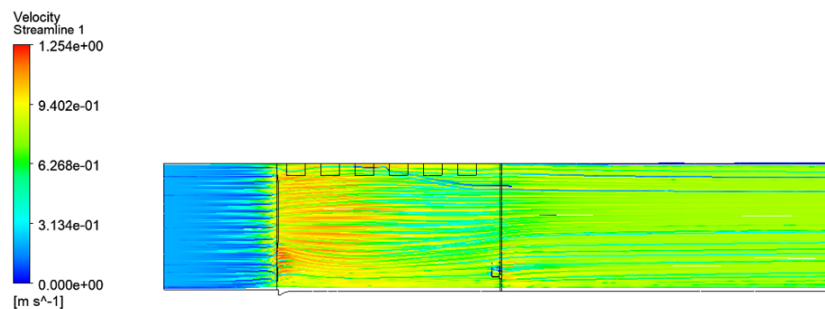


Figure 89: Streamlines in profile

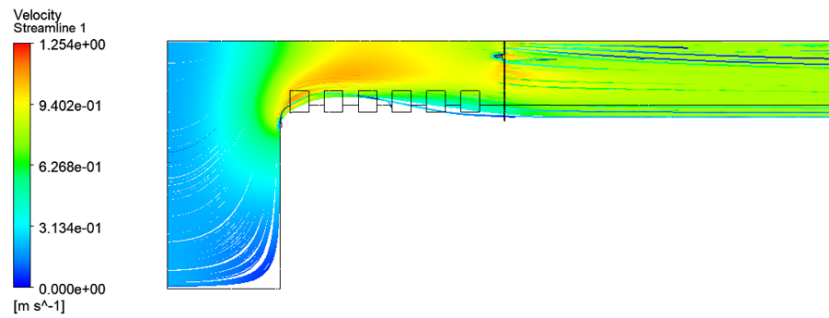


Figure 90: Streamlines in top view

5.16 Concept 16

Small grooves inspired by biomimicry on the adapter with a circular fit. The idea of the grooves concept was to take inspiration from nature. See the model in Figure 91.

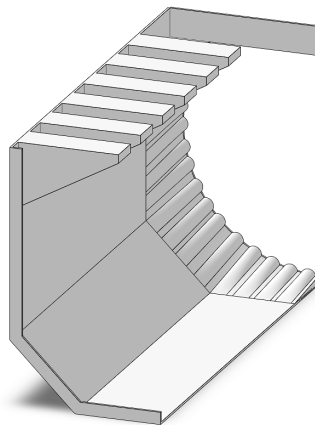


Figure 91: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. The water slightly slows down and have a steep upward direction at the filter inlet. The mean velocity is 0.89 m/s. See the simulation results in Figure 92-93.

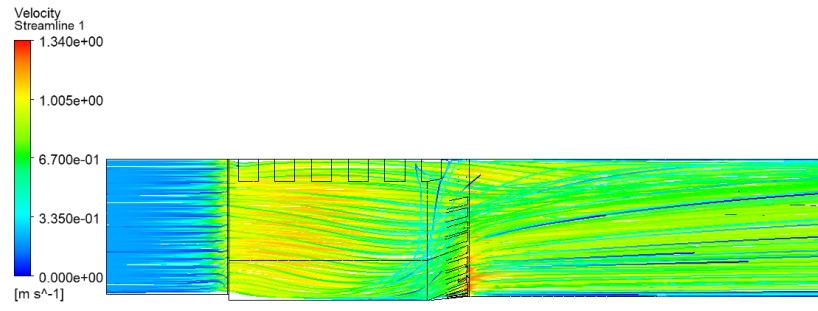


Figure 92: Streamlines in profile

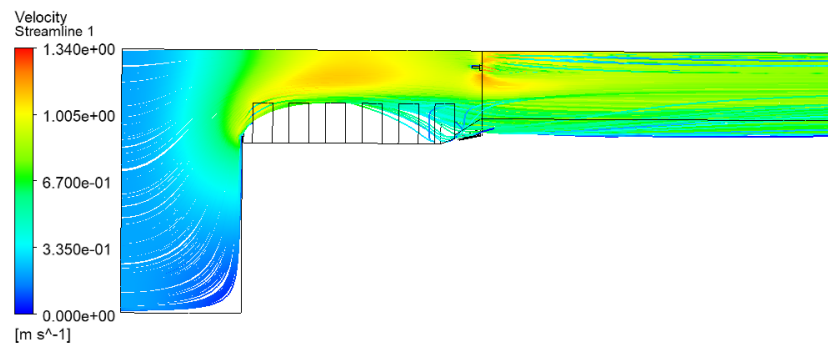


Figure 93: Streamlines in top view

5.17 Concept 17

Small grooves inspired by biomimicry on the full length with a circular fit. See the model in Figure 94.

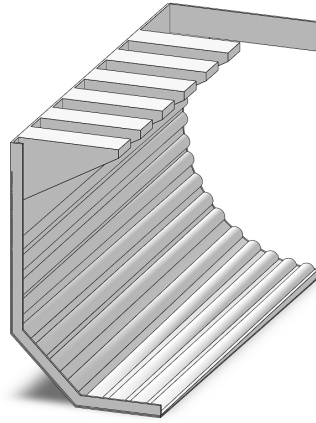


Figure 94: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. Severe recirculation occurs in the channel. Grooves that are supposed to guide the water are instead acting as an obstacle. The water slightly slows down and has a steep upward direction before the filter inlet. The mean velocity is 0.87 m/s. See the simulation results in Figure 95-96.

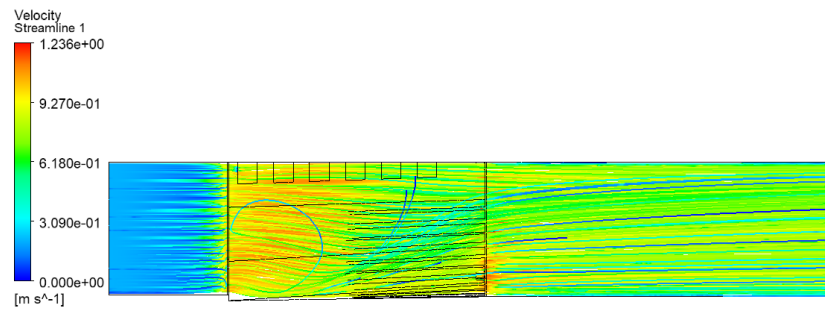


Figure 95: Streamlines in profile

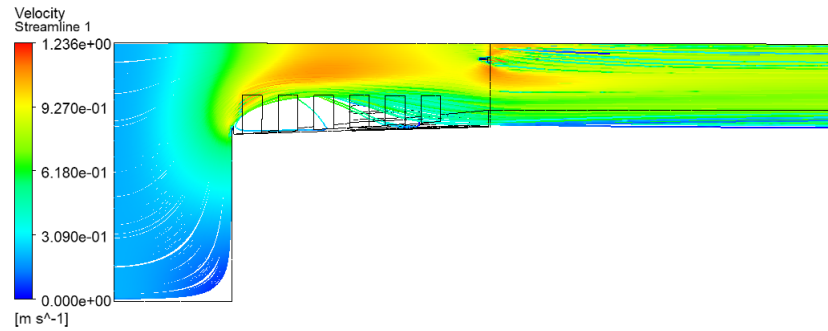


Figure 96: Streamlines in top view

5.18 Concept 18

Medium grooves inspired by biomimicry on the adapter with a circular fit. See the model in Figure 97.

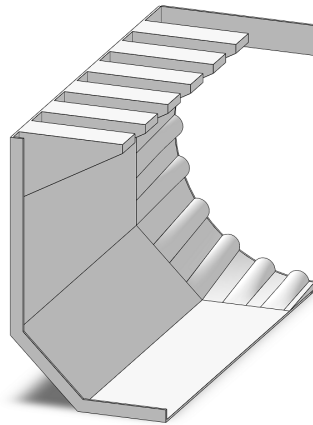


Figure 97: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. The water slightly slows down and has a steep upward direction at the filter inlet. The mean velocity is 0.91 m/s. See the simulation results in Figure 98-99.

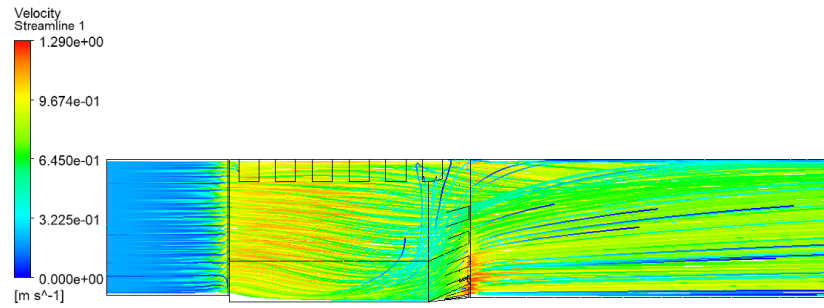


Figure 98: Streamlines in profile

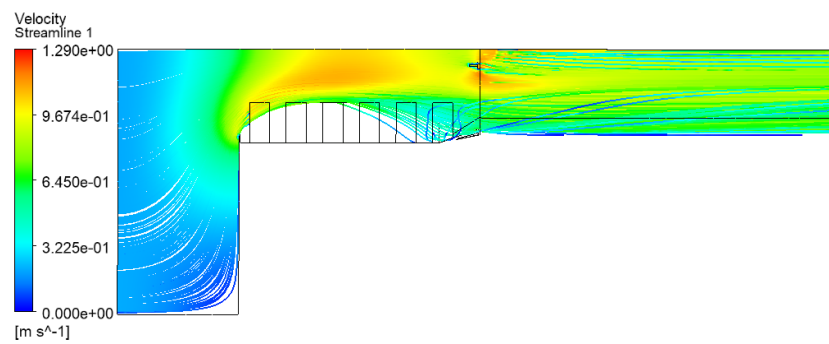


Figure 99: Streamlines in top view

5.19 Concept 19

Medium grooves inspired by biomimicry on the full length with a circular fit. See the model in Figure 100.

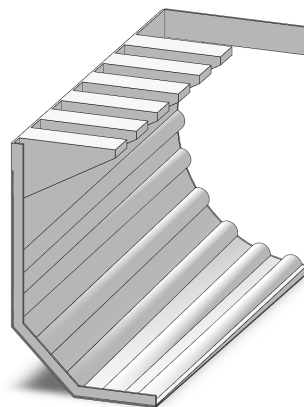


Figure 100: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. Severe recirculation occurs in the channel. Grooves that are supposed to guide the water are instead acting as an obstacle. The water slightly slows down and have a steep upward direction by the filter inlet. The mean velocity is 0.90 m/s. See the simulation results in Figure 101-102.

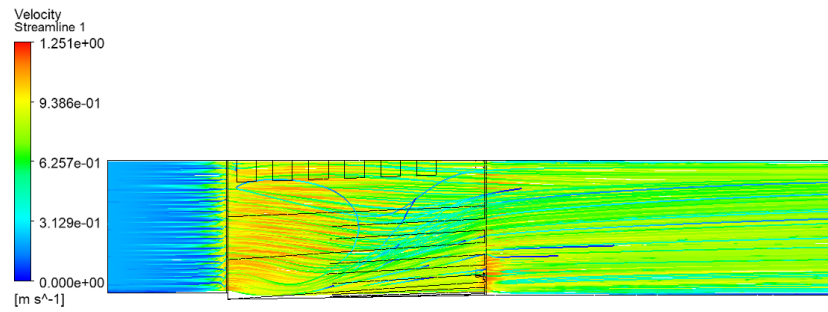


Figure 101: Streamlines in profile

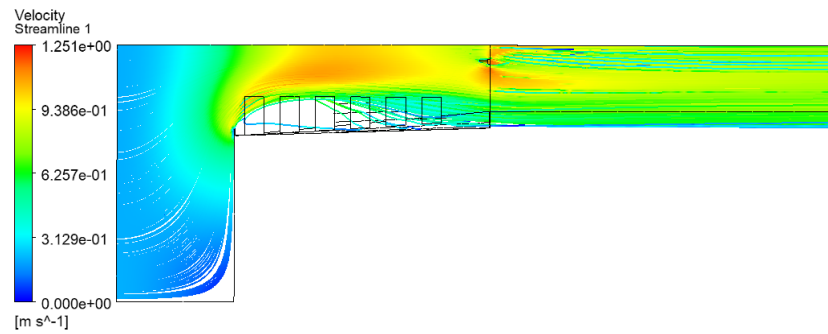


Figure 102: Streamlines in top view

5.20 Concept 20

A wave-shape inside the channel, made with a circular fit to the filter. See the model in Figure 103.

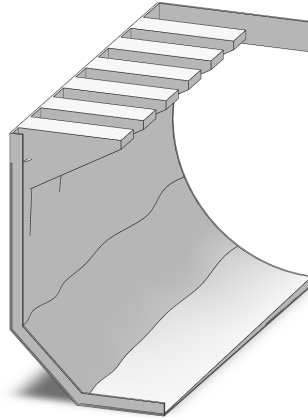


Figure 103: CAD model in sectional view

The flow is cut off by the pool edge causing the water to concentrate with a higher velocity in the middle. Some water slows down in front of the filter inlet when entering in an upward slope. The mean velocity is 0.87 m/s. See the simulation results in Figure 104-105.

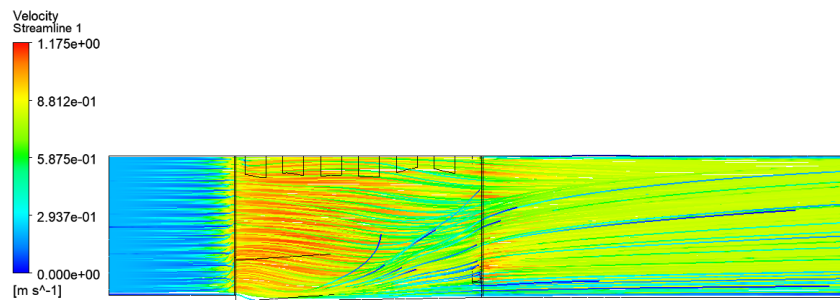


Figure 104: Streamlines in profile

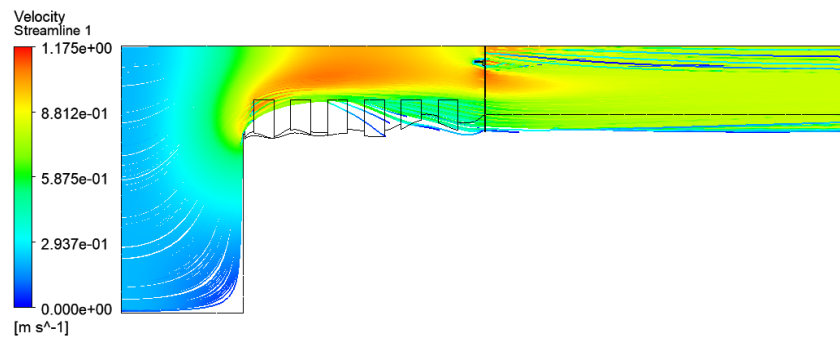


Figure 105: Streamlines in top view

5.21 Concept 21

A U-shaped obstacle in the middle of the channel with a circular fit to the filter.
See the model in Figure 106.

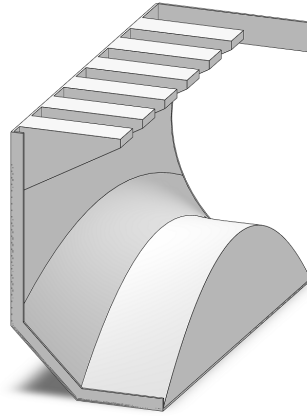


Figure 106: CAD model in sectional view

The flow separates when entering the channel, leading to a neck in the middle of the channel with high velocity fluid. The streamlines close to the wall are very violent when hitting the U-shaped geometry. The mean velocity is 0.93 m/s. See the simulation results in Figure 107-108.

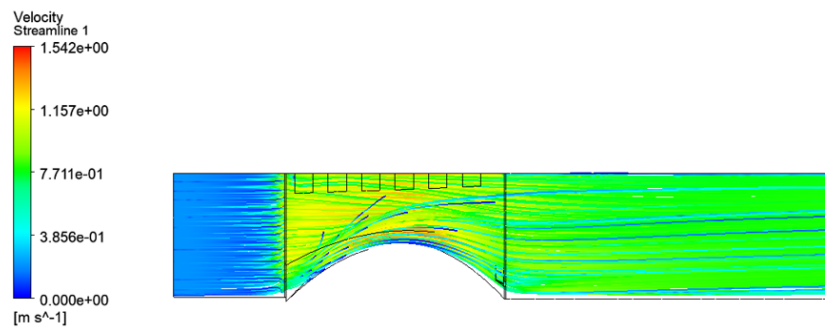


Figure 107: Streamlines in profile

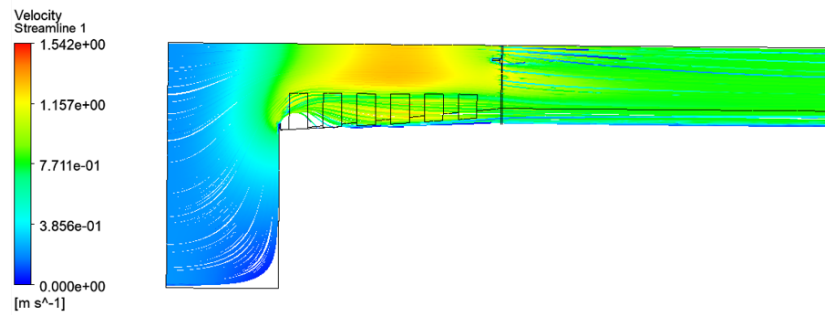


Figure 108: Streamlines in top view

5.22 Concept 22

A big block with round edges in the middle of the channel. See the model in Figure 109.

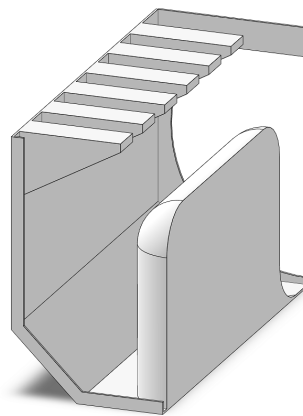


Figure 109: CAD model in sectional view

The flow separates when entering the channel. The flow is accelerating around the big block in the middle. The flow close to the walls is disrupted by the filter wall. The mean velocity is 0.90 m/s. See the simulation results in Figure 110-111.

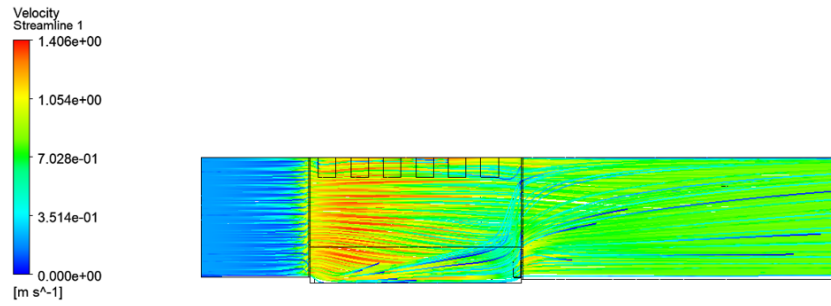


Figure 110: Streamlines in profile

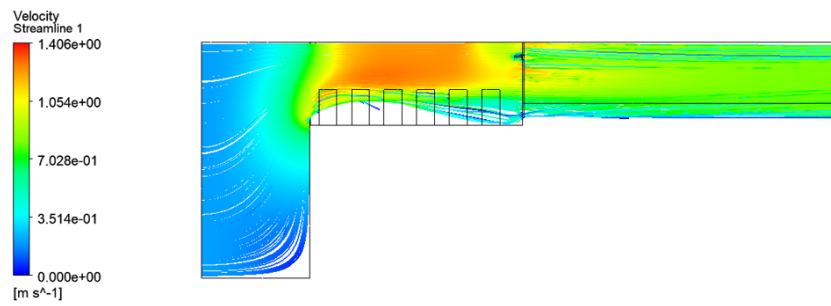


Figure 111: Streamlines in top view

5.23 Concept 23

A trapezoidal shape blocks the lower middle section of the channel's outlet. Slope of flat panels between the channel's inlet and outlet. See the model in Figure 112.

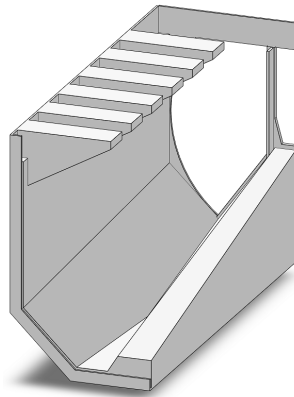


Figure 112: CAD model in sectional view

The flow separates going into the channel. It is then pressed out towards the walls of the channel. Close to the filter, no water is entering through the bottom due to the geometry. The mean velocity is 1.10 m/s. See the simulation results in Figure 113-114.

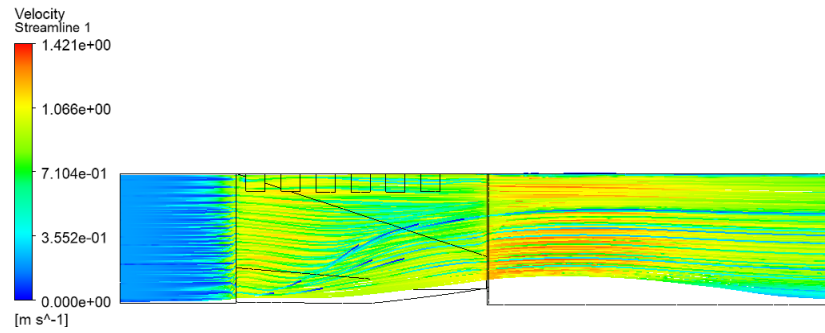


Figure 113: Streamlines in profile

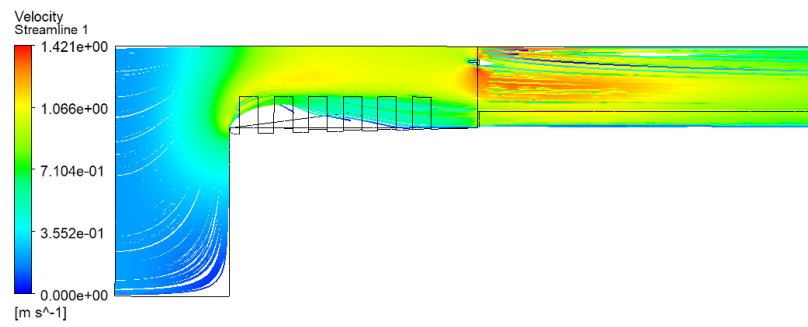


Figure 114: Streamlines in top view

6 Concept Selection

6.1 Concept Screening

Selection of the concepts was first made with a concept screening matrix to evaluate each concept's alignment with the criteria. The company's already existing inlet channel was set as the reference point. All concepts were placed in comparison against it. The concept screening matrices can be seen in Table 16 and Table 17.

Table 16: Concept Screening Matrix

CRITERIAS	1	2	3	4	5	6	7	8	9	10	11	12	REF
Manufacturability	-	-	-	-	-	-	-	-	-	-	-	-	0
Mean Velocity Outlet	0	+	-	-	-	-	-	-	-	-	-	-	0
Adaptor to Inlet Fit	+	+	+	+	+	+	+	+	+	+	+	+	0
Adaptor to Channel Fit	0	0	-	-	0	0	0	-	0	0	-	-	0
Recirculations	0	0	0	+	+	+	0	+	+	-	+	+	0
Sum +’s	1	2	1	2	2	2	1	2	2	1	2	2	0
Sum 0’s	3	2	1	0	1	1	2	0	1	1	0	0	5
Sum -’s	1	1	2	2	2	2	2	3	2	3	3	3	0
Net Score	0	+1	-1	0	0	0	-1	-1	0	-2	-1	-1	0
Rank	2	1	3	2	2	2	3	3	2	4	3	3	2

Table 17: Concept Screening Matrix (cont.)

CRITERIAS	13	14	15	16	17	18	19	20	21	22	23	REF
Manufacturability	-	-	-	-	-	-	-	-	-	-	-	0
Mean Velocity Outlet	-	-	-	-	-	-	-	-	-	-	+	0
Adaptor to Inlet Fit	+	+	+	+	+	+	+	+	+	0	-	0
Adaptor to Channel Fit	-	-	0	-	-	-	-	-	-	0	-	0
Recirculations	+	+	+	0	-	-	-	0	-	+	+	0
Sum +’s	2	2	2	1	1	1	1	1	1	1	2	0
Sum 0’s	0	0	1	1	0	0	0	1	0	2	1	5
Sum -’s	3	3	2	3	4	4	4	3	4	2	3	0
Net Score	-1	-1	0	-2	-3	-3	-3	-2	-3	-1	-1	0
Rank	3	3	2	4	5	5	5	4	5	3	3	2

6.2 Concept Combination

Concepts ranked 1 or 2 qualified to be further investigated in the concept combination phase. Note that rank 2 represents equally scored as the reference and rank 1 represents a better score than the reference. The inlet channel was divided into three main geometric sections. The sections are the concept's transition from pool to channel, the internal shape of the channel and the fit between the channel and the filter's inlet. The geometric traits used for the concept combination can be viewed in Table 18.

Table 18: Geometric traits for concept combination

Translation from Pool to Channel	Internal Shape	Fit to Filter-Inlet
Sharp Edges	Straight	One Panel
Round Edges	Draft	Multiple Panels

Possible combinations of the geometric groups are shown in Table 19. Concepts that already exist within the combination are noted in the right column. According to the analysis of our concepts in Section 5, sharp edges in the transition from the pool to the filter have proven to be inefficient. Sharp edges causes necking in the channel and an increased velocity. The concept with one ramp did not prove superior advantage in the analysis in Section 5. Hence it was decided unnecessary to explore further into sharp edges and one ramp.

Table 19: Possible Combinations

Possible Combinations	Concept
Sharp Edges → Straight → One Panel	1
Sharp Edges → Draft → One Panel	-
Sharp Edges → Straight → Multiple Panels	2, 9
Sharp Edges → Draft → Multiple Panels	4, 5, 6
Round Edges → Straight → One Panel	15
Round Edges → Draft → One Panel	-
Round Edges → Straight → Multiple Panels	-
Round Edges → Draft → Multiple Panels	-

6.3 Combined Concepts

Combined concepts are generated to fill the gap according to Table 19, with exemptions from combinations including the geometry of sharp edges in the transition from pool to channel and concepts with one ramp.

6.3.1 Concept 24 (Combined)

Combination of: *Round Edges* $\rightarrow$ *Straight* $\rightarrow$ *Multiple Panels*. Concave shape of flat and rounded panels with a close to circular fit to the filter inlet. Rounded edges in the pool-channel transition. Maximal width of the channel corresponds to the filters width. See the model in Figure 115.

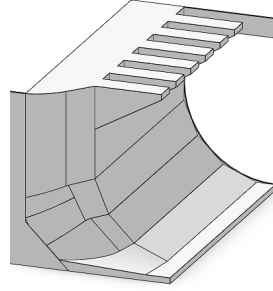


Figure 115: CAD model in sectional view

The flow separation has almost completely been resolved. The flow through the channel is uniform, with a small area in the middle having increased fluid velocity. Close to the filter, the streamlines are continuous. The mean velocity is 0.91 m/s. See the simulation results in Figure 116-117.

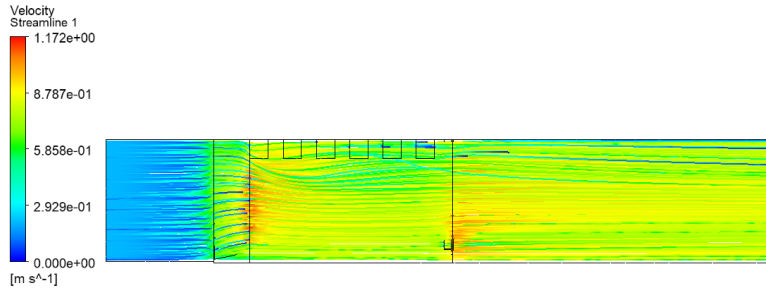


Figure 116: Streamlines in profile

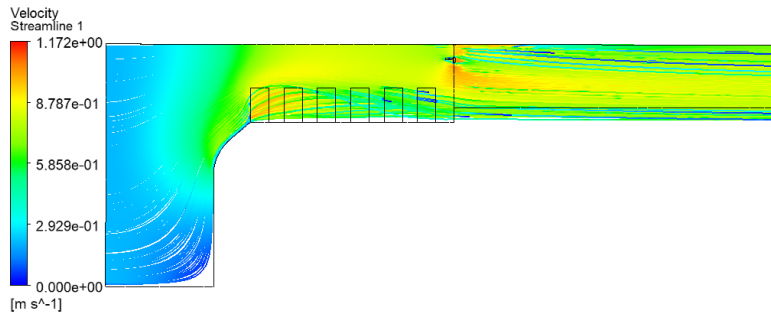


Figure 117: Streamlines in top view

6.3.2 Concept 25 (Combined)

Combination of: *Round Edges* → *Draft* → *Multiple Panels*. Slope of flat panels between the channel's inlet and outlet with rounded edges in the transition to the pool. Maximal width of the channel corresponds to the filters width. See the model in Figure 118.

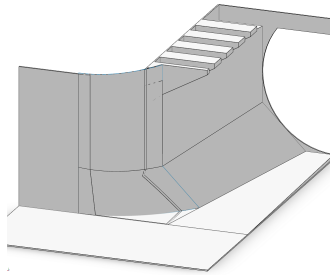


Figure 118: CAD model in sectional view

There is no flow separation going into the channel. The velocity increases closer to the filter due to the geometry. The streamlines close to the filter are continuous. The mean velocity is 0.86 m/s. See the simulation results in Figure 119-120.

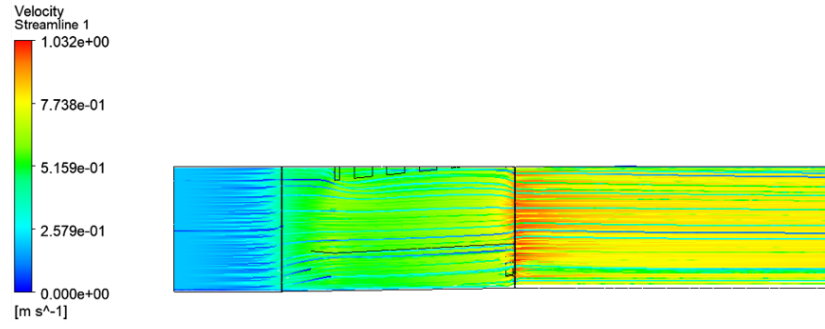


Figure 119: Streamlines in profile

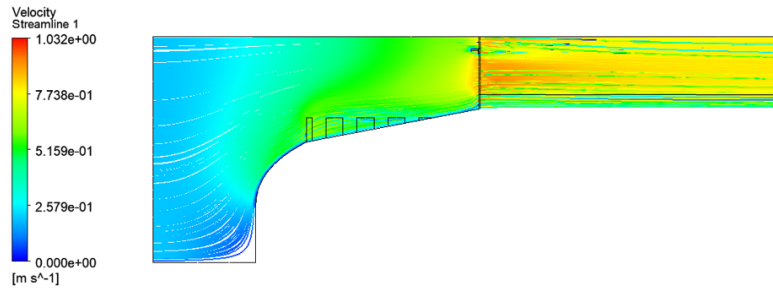


Figure 120: Streamlines in top view

6.4 Weighting

The criteria established in Section 4.2 needed to be weighted before performing the concept scoring. The criteria was weighted in accordance with the stakeholders opinions. The weight symbolizes the importance for each criteria, in relation to further development. The weighting can be seen in Table 20.

Table 20: The benchmark criteria with the weight of each criteria

Criteria	Weight
Manufacturability	0.25
Mean Velocity Outlet	0.10
Adapter to Inlet fit	0.20
Adapter to Channel fit	0.15
Recirculations	0.30

6.5 Concept Scoring

The concepts that were better than the reference in Section 6.1, and the concepts from the concept combination were further narrowed down in a concept scoring matrix. The weighting from Section 6.4 and the company's existing channel are included in the matrix. The concept scoring matrix can be seen in Table 21.

Table 21: Concept Scoring Matrix

		Concept							
		Reference		Concept 2		Concept 24		Concept 25	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Manufacturability	25%	4	1	3	0.75	2	0.5	1	0.25
Mean Velocity Outlet	10%	3	0.3	5	0.5	2	0.2	1	0.1
Adaptor to Inlet Fit	20%	2	0.4	3	0.6	5	1	4	0.8
Adaptor to Channel Fit	15%	3	0.45	3	0.45	3	0.45	3	0.45
Recirculations	30%	2	0.6	3	0.9	4	1.2	5	1.5
	Total Score	2.75		3.20		3.35		3.10	
	Rank	4		2		1		3	
Continue?		No		No		Develop		No	

7 Concept Testing

The final concept is developed as a Channel + Filter B adapter, as stated earlier. Thus, the testing will primarily be conducted for that model and secondarily for the Filter A adapter.

7.1 Refinement

Before the concept testing could be performed, the concept needed to be refined. The number of panels were reduced and the original fillets has now been made into smooth transitions as extensions to the panels in the channel. Refinements are made according to the elaboration in Section 8. The earlier model can be seen in Figure 115 and the refined model can be seen in Figure 121.

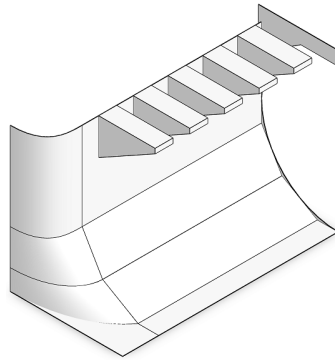


Figure 121: CAD model in sectional view

7.2 Flow

7.2.1 Flow size

The final model will be tested for the same three flows as the initial simulation, presented in Table 9. As described in 3.5.1, the two lower flows are operating while the largest flow is experimental. The results of the testing can be seen in Table 22.

Table 22: Testing of inlet channel with Filter B-sized adapter

	Flow 1	Flow 2	Flow 3
Volume-Flow [m^3/h]	3000	4000	5000
Body sizing [mm]	20	20	20
Element [#]	4 617 029	4 617 029	4 617 029
Mean Velocity [m/s]	0.90	1.20	1.50

7.2.2 Flow direction

The final concept was tested for flow from different incoming directions. The directions resemble possible setups at customer's facilities. In addition to the flow coming straight into the inlet channel, the flow can also enter the pool from the floor as in Figure 122 and from both sides as in Figure 125.

7.2.3 Flow from the floor

Concept testing with the water entering from the floor. At customer facilities, the water enters through a pipe. This is approximated by the full area of the floor. See the inlet in Figure 122.

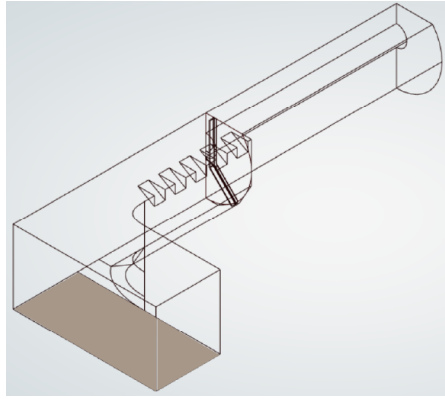


Figure 122: CAD model with the inlet highlighted

The flow utilizes the full space in the channel. The flow moves with a lower velocity through the channel close to the floor. The velocity increases slightly at the center of the channel. By the edge of the channel, it increases in speed and keeps contact with the wall. The mean velocity is 0.92 m/s. See simulation results in Figure 123-124.

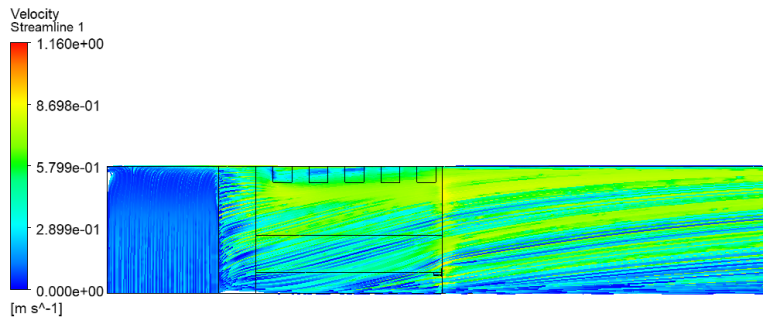


Figure 123: Streamlines in profile

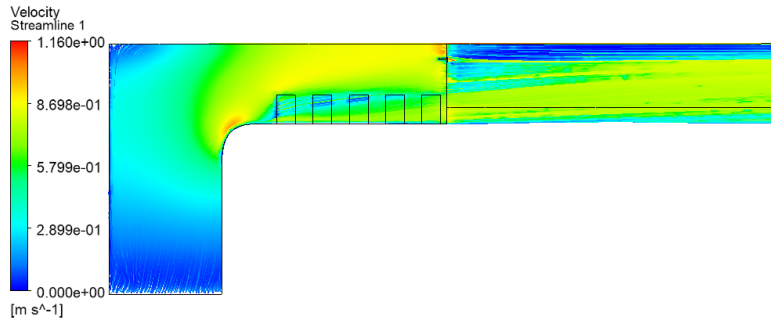


Figure 124: Streamlines in top view

7.2.4 Flow from the side

Concept testing with the water entering from both sides. At customer facilities, the water enters through a pipe, this is approximated by the full area of the wall. See the inlet in Figure 125.

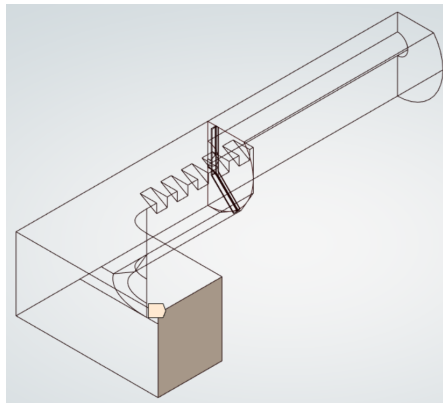


Figure 125: CAD model with the inlet highlighted

The flow utilizes the full space in the channel. The velocity in the channel is almost uniform, but increases closer to the center of the channel. By the edge of the channel, it increases in velocity and keeps contact with the wall. It flows close to horizontally through the channel. The mean velocity is 0.90 m/s. See simulation results in Figure 126-127.

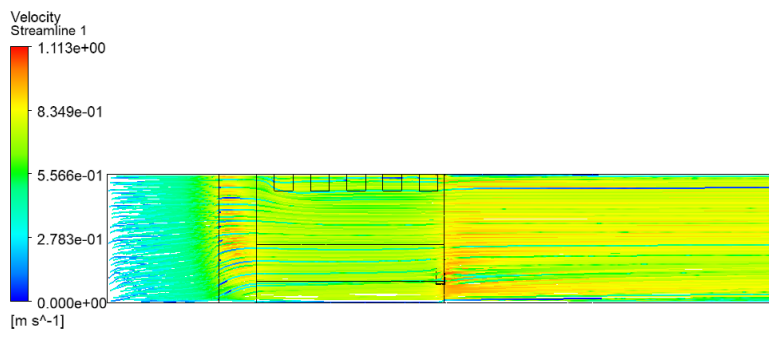


Figure 126: Streamlines in profile

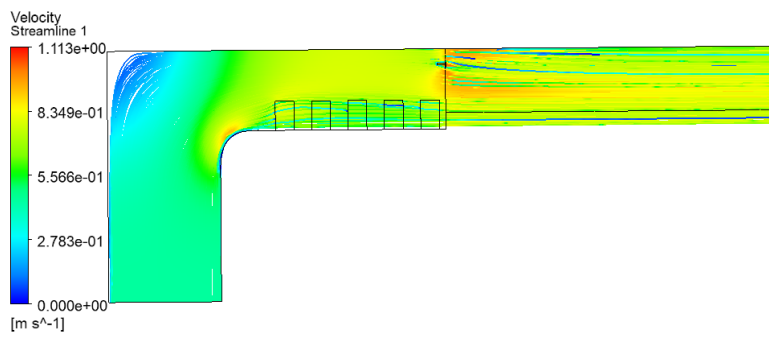


Figure 127: Streamlines in top view

7.3 Filter A - Adapter

In the purpose of this project, as seen in Section 1.3, it was stated that two different adapters was supposed to be developed. The adapter for Filter A was designed with regards to the screening in Section 6.1, especially for the criteria *Adapter to Inlet Fit* and *Adapter to Channel Fit*. The final concept for Channel + Filter A can be seen in Figure 128.

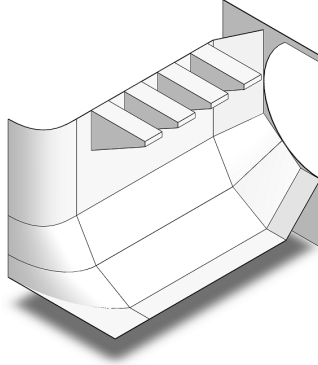


Figure 128: CAD model in sectional view

7.3.1 Flow size with Filter A

The final model will be tested for the same three flows as the initial simulation, presented in Table 9. As described in 3.5.1, the two lower flows are operating while the largest flow is experimental. The results of the testing can be seen in Table 23.

Table 23: Final simulation of inlet channel with Filter A-sized adapter

	Flow 1	Flow 2	Flow 3
Volume-Flow [m^3/h]	1688	2250	2800
Body sizing [mm]	20	20	20
Element [#]	4 003 266	4 003 266	4 003 266
Mean Velocity [m/s]	1.01	1.35	1.68

8 Design For Manufacturing

The concept development phase is primarily driven by the product specifications. However, during the later design phases, it is often problematic to link the product specifications to the design issues.²¹ Therefore, Design For Manufacturing (DFM) was performed. It was implemented during the concept development phase, and further refined in the post-processing phase.

When performing DFM, there are different aspects to consider. One of the aspects is the manufacturing cost. The cost was taken into consideration during the concept screening and scoring, and was evaluated against the company's current channel. Firstly, the straight walls at the top of the channel was kept intact. Some concepts had wavy sections at the top, which would be expensive to manufacture in and of itself. These concepts would also require a solution for fastening the weir extensions that are acting as a fail-safe.

Secondly, before the concept scoring, a sheet-metal company was contacted. They evaluated the different concepts and explained the complexity of manufacturing each concept. This led to the decision to keep the straight shape of the channel instead of developing a drafted shape. A drafted shape would be hard to manufacture since it is double-angled. The metal would have to be angled, and stretched, which would be possible to manufacture, but not ideal when it comes to keeping down the manufacturing cost.

Another aspect that was considered during the design-process was how the adapter should fit with the channel. If the border is too complicated, it would be hard to merge the two components. Therefore, it was decided to keep the straight panels, similar to what the company has now. This makes it easy to bend the sheets and use bolts to merge the two components.

Furthermore, the number of components was kept to a minimum. Keeping down the number of components, means also keeping down the number of intersections and merging points. This would otherwise increase complexity and cost. Therefore, it was decided to reduce the number of panels in the final concept from nine panels to seven panels. The original concept had a better fit to the inlet of the filter, however, a trade off needed to be made between performance and manufacturing costs.

The most complex part of the final concept is the rounds at the beginning of the channel. These are essential for the concept itself, and rather than trying to avoid them, solutions were made to keep them. They can be manufactured at

²¹K.T. Ulrich & S.D. Eppinger, *Product Design and Development*, 6th Edition, (McGraw-Hill Education, 2016) page 257

a reasonable cost. However, they need to be welded onto the main part of the channel, which reduces the structural integrity.

9 Final Concept

The final concept for the channel and the two adapters is presented below. In addition, simulation results are presented for each concept.

9.1 CAD Model

9.1.1 Filter A - Adapter

The final Filter A adapter can be seen in Figure 129.

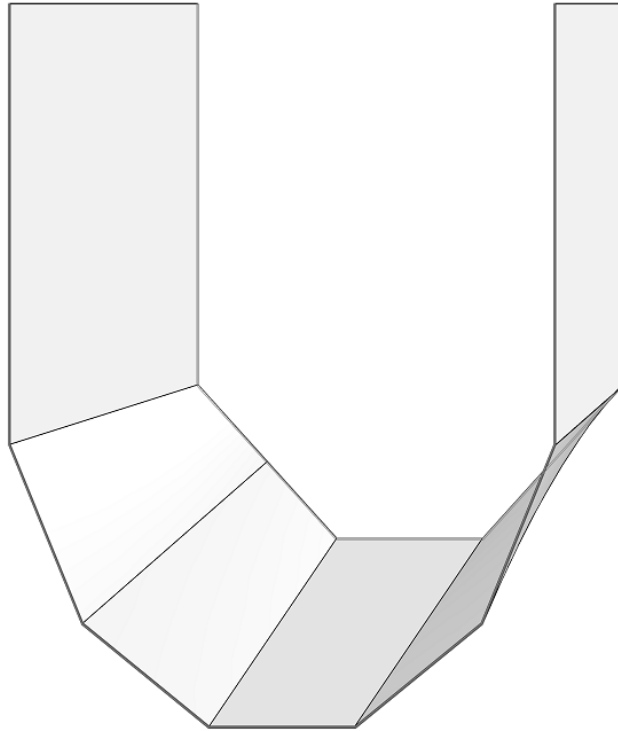


Figure 129: CAD Model of the final Filter A - Adapter

9.1.2 Filter B - Adapter

The final Filter B adapter can be seen in Figure 130.

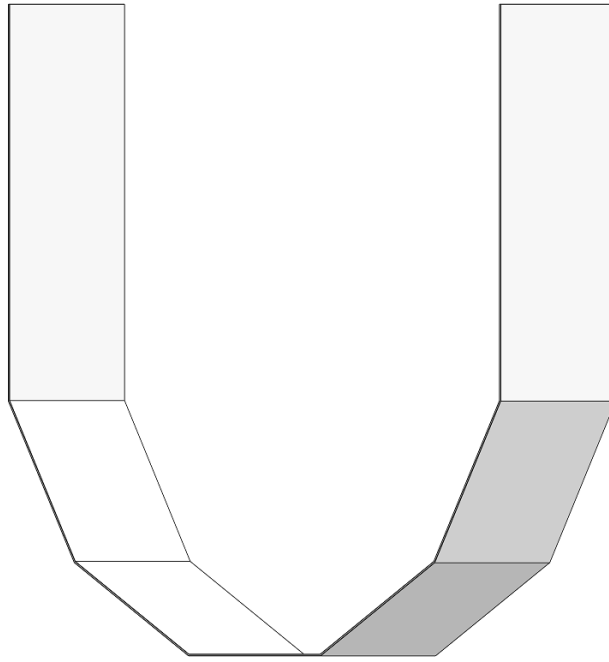


Figure 130: CAD Model of the final Filter B - Adapter

9.1.3 Channel

The final inlet channel can be seen in Figure 131.

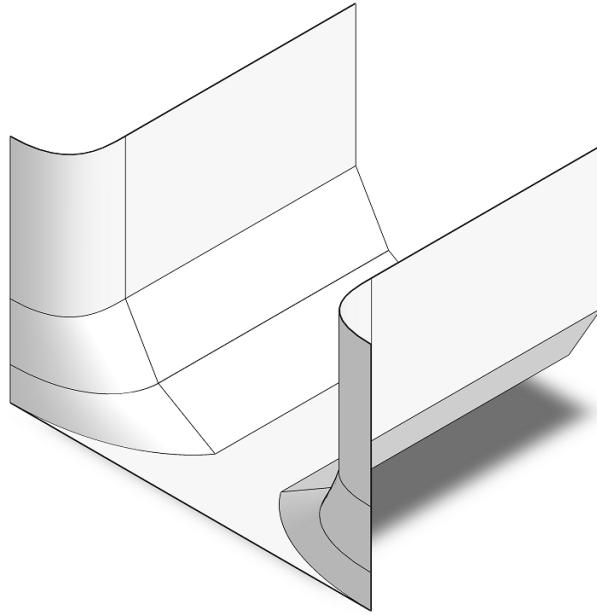


Figure 131: CAD Model of the final channel

9.2 Channel + Filter A - Adapter

9.2.1 CAD Assembly

The CAD assembly of the inlet channel and Filter A adapter can be seen in Figure 132-134.

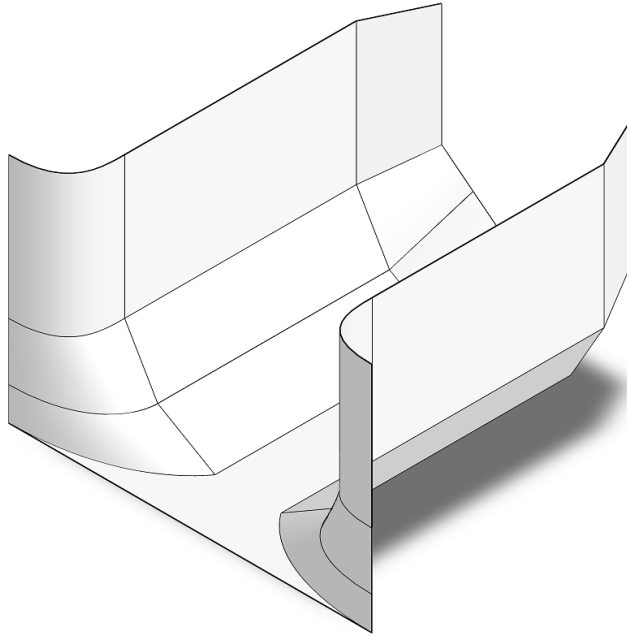


Figure 132: CAD assembly of channel and Filter A adapter

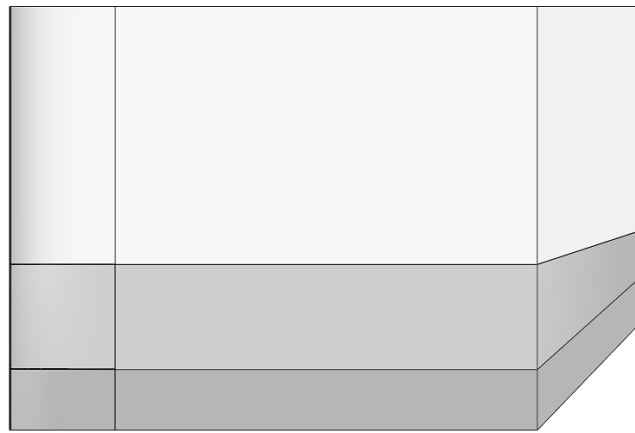


Figure 133: CAD assembly of channel and Filter A adapter in profile

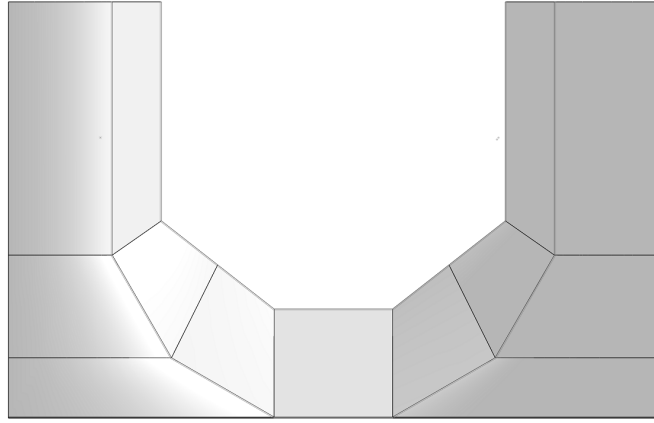


Figure 134: CAD assembly of channel and Filter A adapter in front view

9.2.2 Mesh

The method for meshing is described in Section 3.3.2. The volume of the body sizing can be seen in Figure 135.

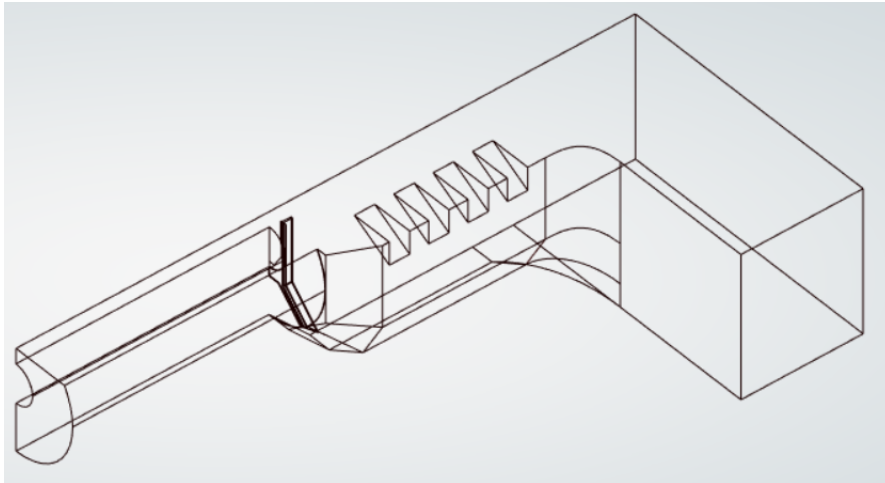


Figure 135: Mesh volume for the body sizing

Inflation on the water domain with a highlighted boundary can be seen in Figure 136.

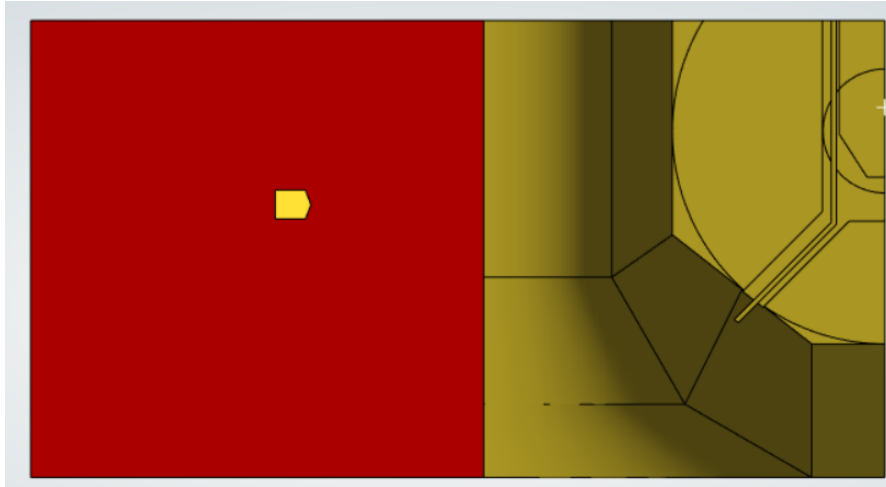


Figure 136: Inflation on the boundary between the pool and the inlet channel

Face sizing on the internal contacts surface between the water and porous domain can be seen in Figure 137.

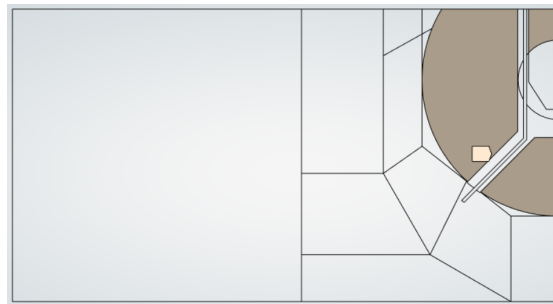


Figure 137: Mesh of the water face in the boundary

Face sizing on the wall between the internal contact zone with 20 mm element size, can be seen in Figure 138.

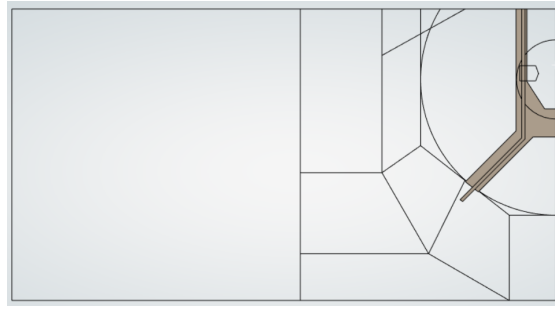


Figure 138: Mesh area of the structure in the boundary between inlet channel and filter

Edge sizing around the earlier described area with 20 mm element size, can be seen in Figure 139.

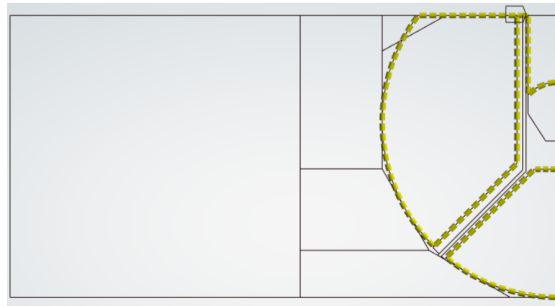


Figure 139: Mesh area of the edge in the boundary between face and wall

Face sizing and edge sizing on the rounded wall with 20 mm element size, can be seen in Figure 140.

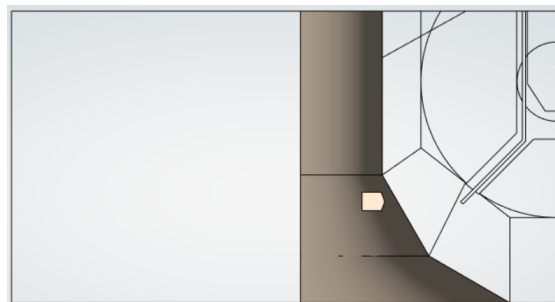


Figure 140: Mesh area of edge of the rounded wall

The majority of the element scored 0.78 or higher where 1.0 is ideal. The element quality can be seen in Figure 141.

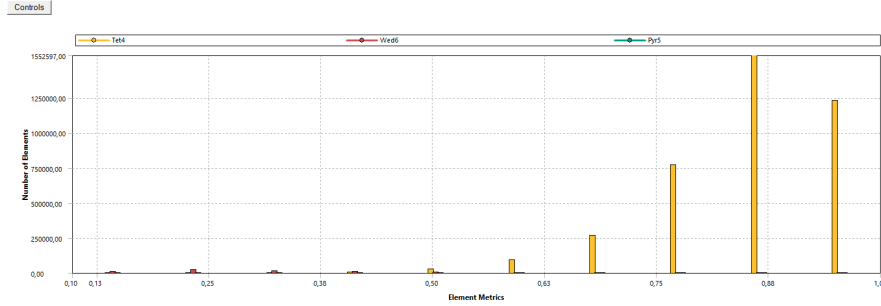


Figure 141: Element quality for the meshing of the final concept, Channel + Filter A adapter

The majority of the element had a metric of 0.28 or lower where the ideal is 0.0. The element skewness can be seen in Figure 142.

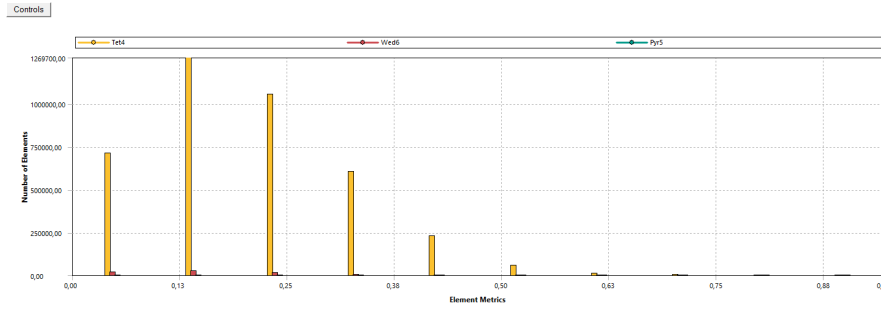


Figure 142: Element skewness for the meshing of the final concept, Channel + Filter A adapter

9.2.3 Mesh Study

The method for meshing is described in Section 3.3.3. The last four iterations from the mesh study are displayed in Table 24, where the fourth is the last.

Table 24: Mesh study on final concept, Channel + Filter A adapter

	Iteration 1	Iteration 2	Iteration 3	Iteration 4
Body sizing [mm]	160	80	40	20
Element [#]	110 251	145 019	547 322	4 003 266
Max velocity [m/s]	1.53	1.47	1.48	1.54
Difference [%]		4.16	-0.90	-3.59

9.2.4 Fluid Analysis

The flow utilizes the full space of the channel. The velocity in the channel is almost uniform, with smaller fragments of slower zones by the channel inlet and by the adapter's narrowing section. Some recirculation occurs at the top due to the weir extensions. The water flows close to horizontally through the channel and follows the upward slope of the adapter. The mean velocity is 1.01 m/s. Compared to the initial simulations, the neck has disappeared and the water has a uniform velocity through the channel. The analysis of Flow 1, for Filter A, is shown in Figure 143 - 144.

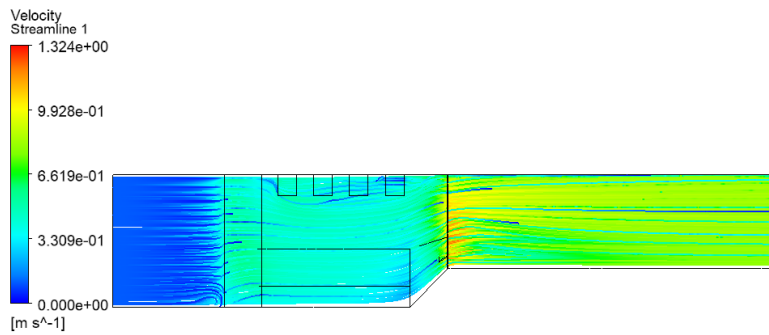


Figure 143: Streamlines in profile for Flow 1 in Table 23

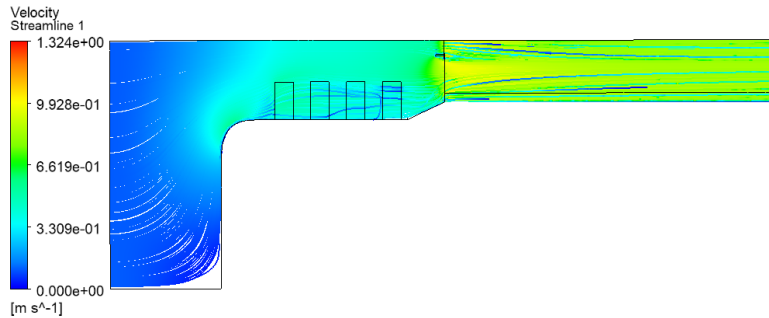


Figure 144: Streamlines in top view for Flow 1 in Table 23

See Appendix D for the analysis results of the remaining flow cases, presented in Table 23.

The water holds a uniform velocity through the channel except for by the ramp to the filter inlet where it is slowed down. The contour of velocity in profile can be seen in Figure 145.

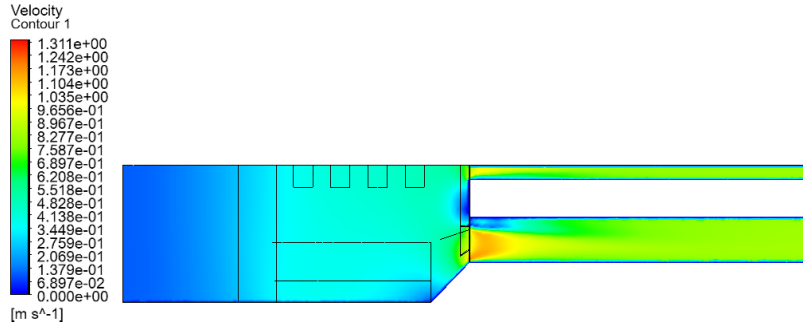


Figure 145: Contour of velocity in profile

The pressure in the channel is uniform, same as the pressure in the pool, and higher than the pressure in the porous media. The contour of pressure in profile can be seen in Figure 146.

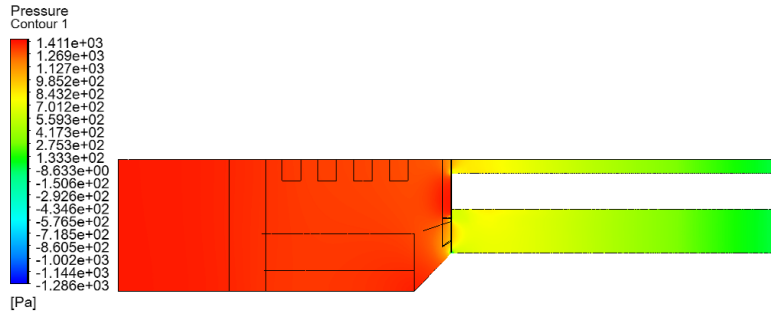


Figure 146: Contour of pressure in profile

Convergence is reached according to Section 3.6. The residuals of the convergence plot can be seen in Figure 147.

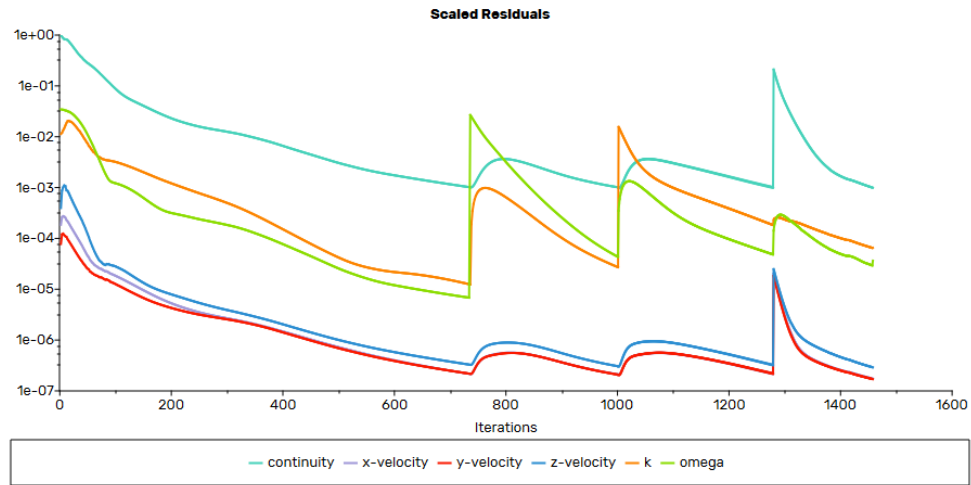


Figure 147: Residuals of the convergence plot

9.3 Channel + Filter B - Adapter

9.3.1 CAD Assembly

The CAD assembly of the inlet channel and Filter B adapter can be seen in Figure 148-150.

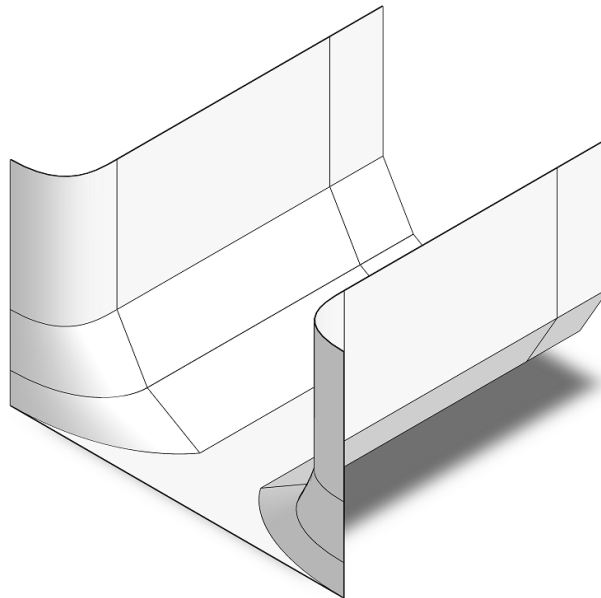


Figure 148: CAD assembly of channel and Filter B adapter



Figure 149: CAD assembly of channel and Filter B adapter in profile

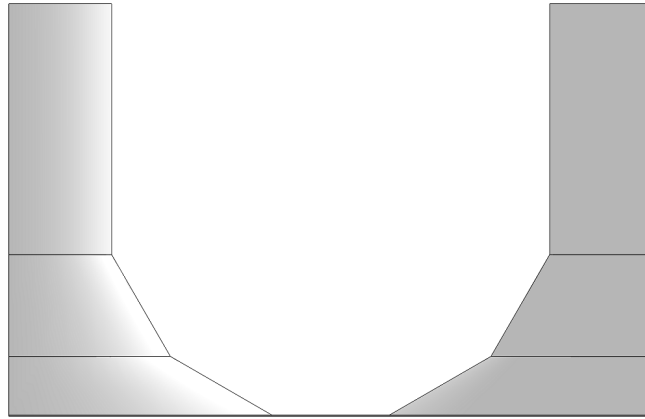


Figure 150: CAD assembly of channel and Filter B adapter in front view

9.3.2 Mesh

The method for meshing is described in Section 3.3.2. The volume of the body sizing can be seen in Figure 151.

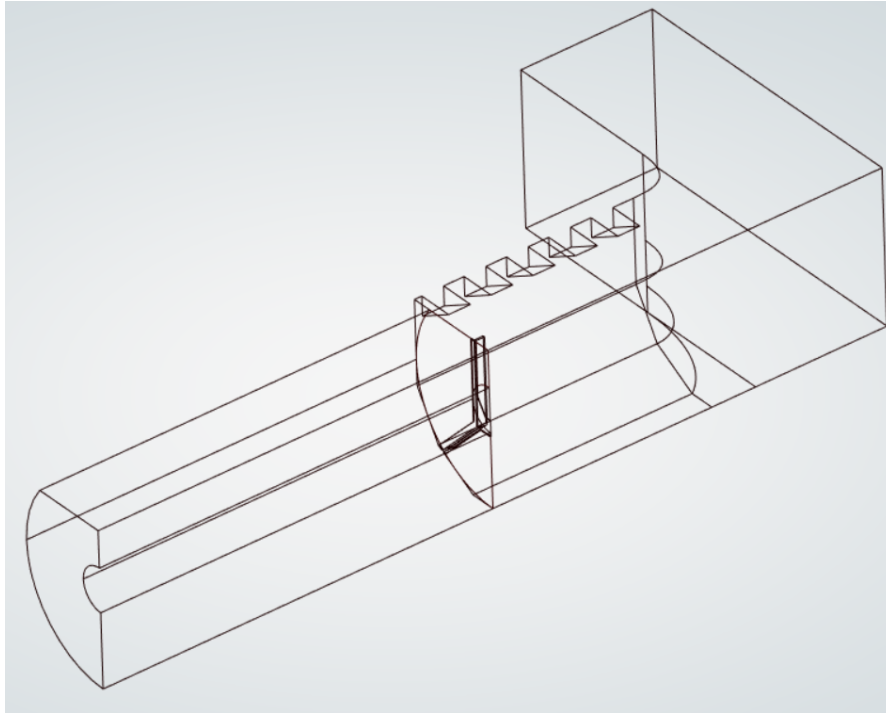


Figure 151: Mesh volume for the body sizing

Inflation on the water domain with a highlighted boundary, can be seen in Figure 152.

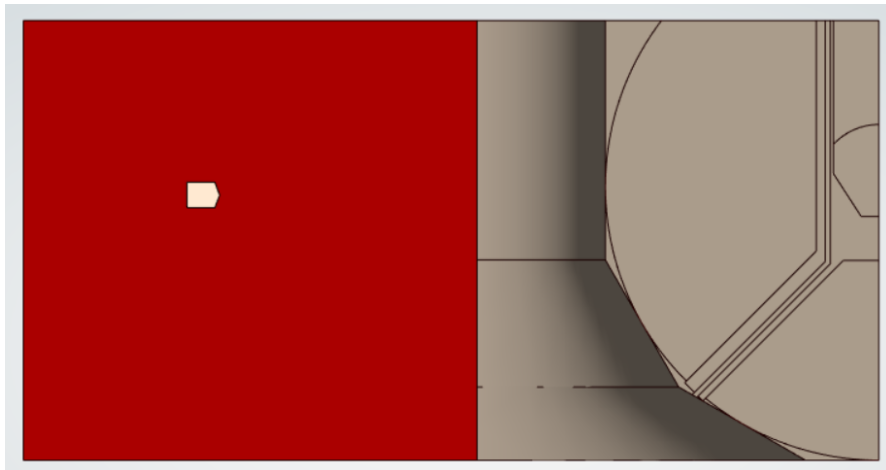


Figure 152: Inflation on the boundary between the pool and the inlet channel

Face sizing on the internal contact surface between the water and porous domain,

can be seen in Figure 153.

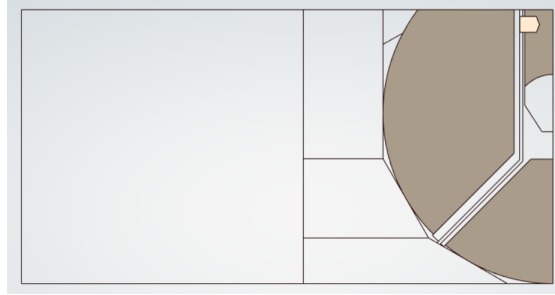


Figure 153: Mesh of the water face in the boundary

Face sizing on the wall between the internal contact zone with 20 mm element size, can be seen in Figure 154.

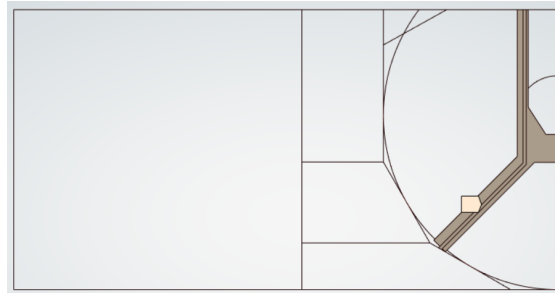


Figure 154: Mesh area of the structure in the boundary between inlet channel and filter

Edge sizing around the earlier described area with 20 mm element size, can be seen in Figure 155.

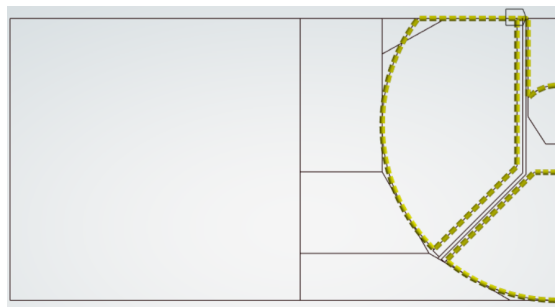


Figure 155: Mesh area of the edge in the boundary between face and wall

Face sizing and edge sizing on the rounded wall with 20 mm element size, can be seen in Figure 156.

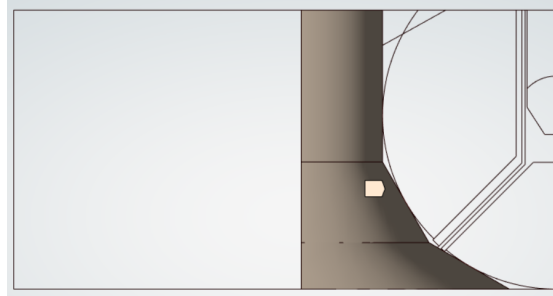


Figure 156: Mesh area of edge of the rounded wall

The majority of the element scored 0.75 or higher where 1.0 is ideal. The element quality can be seen in Figure 157.

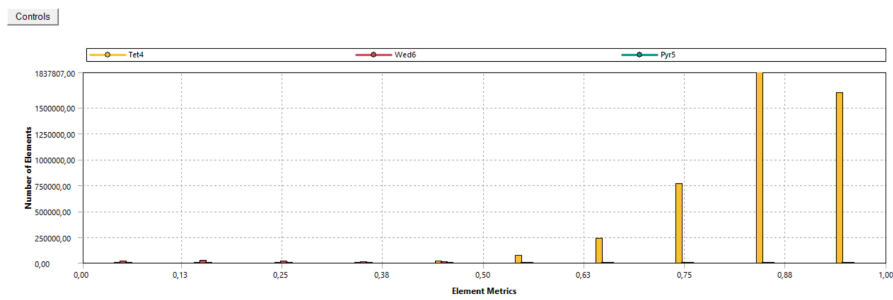


Figure 157: Element quality for the meshing of the final concept, Channel + Filter B adapter

The majority of the element had a metric of 0.24 or lower where the ideal is 0.0. The element skewness can be seen in Figure 158.

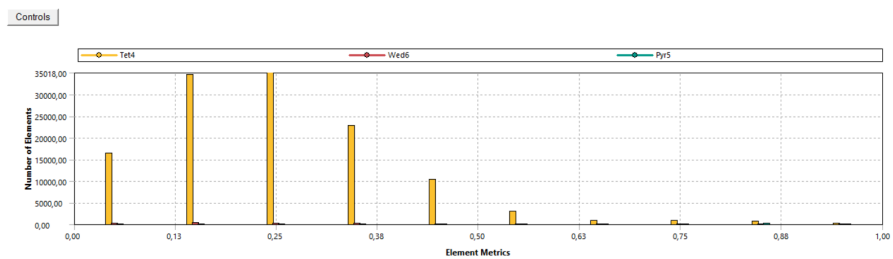


Figure 158: Element skewness for the meshing of the final concept, Channel + Filter B adapter

9.3.3 Mesh Study

The method for meshing is described in Section 3.3.3. The last four iterations from the mesh study are displayed in Table 25, where the fourth is the last.

Table 25: Mesh study on final concept, Channel + Filter B adapter

	Iteration 1	Iteration 2	Iteration 3	Iteration 4
Body sizing [mm]	160	80	40	20
Element [#]	125 365	167 107	633 489	4 617 029
Max velocity [m/s]	1.13	1.11	1.09	1.11
Difference [%]		1.78	1.34	-1.44

9.3.4 Fluid Analysis

The flow utilizes the full space in the channel compared to the neck shape in the current design. The velocity in the channel is almost uniform and does not accelerate through the channel. By the edge of the channel, it increases in speed and keeps contact with the wall. It flows close to horizontally through the channel. The mean velocity is 0.90 m/s. The analysis of Flow 1, for Filter B, is shown in Figure 159 - 160.

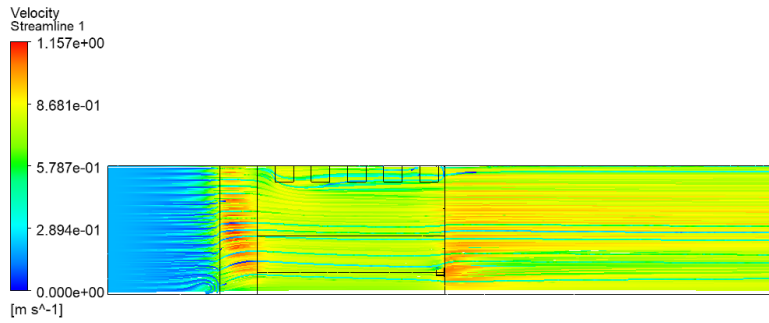


Figure 159: Streamlines in profile for Flow 1 in Table 22

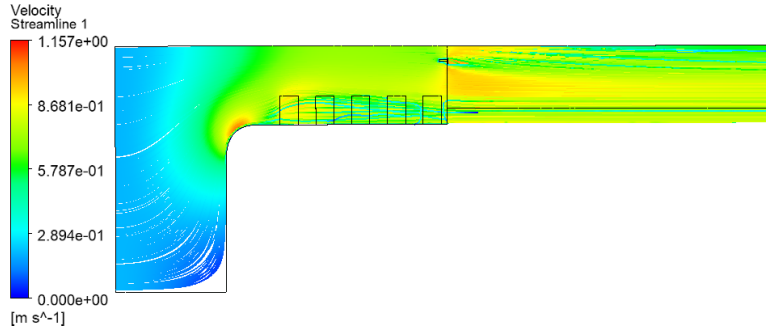


Figure 160: Streamlines in top view for Flow 1 in Table 22

See Appendix D for the analysis results of the remaining flow cases, presented in Table 22.

The water holds a uniform velocity through the channel. The contour of velocity in profile can be seen in Figure 161.

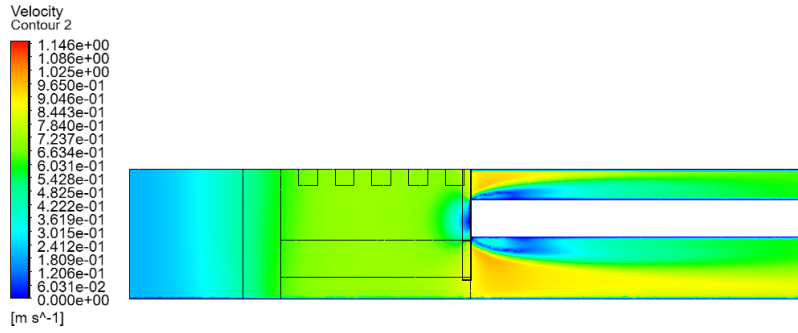


Figure 161: Contour of velocity in profile

The pressure in the channel is uniform, lower than the pressure in the pool, and higher than the pressure in the porous media. The contour of pressure in profile can be seen in Figure 162.

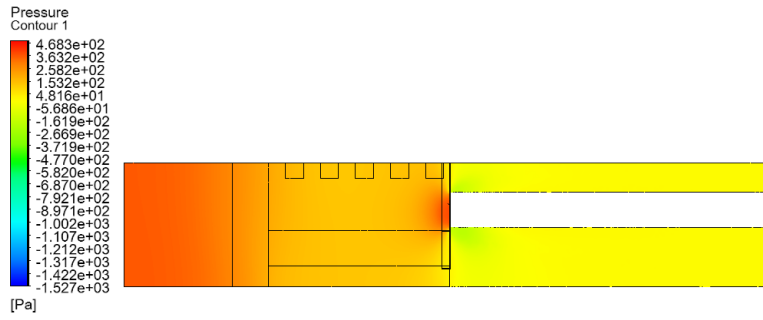


Figure 162: Contour of pressure in profile

Convergence is reached according to Section 3.6. The residuals of the convergence plot can be seen in Figure 163.

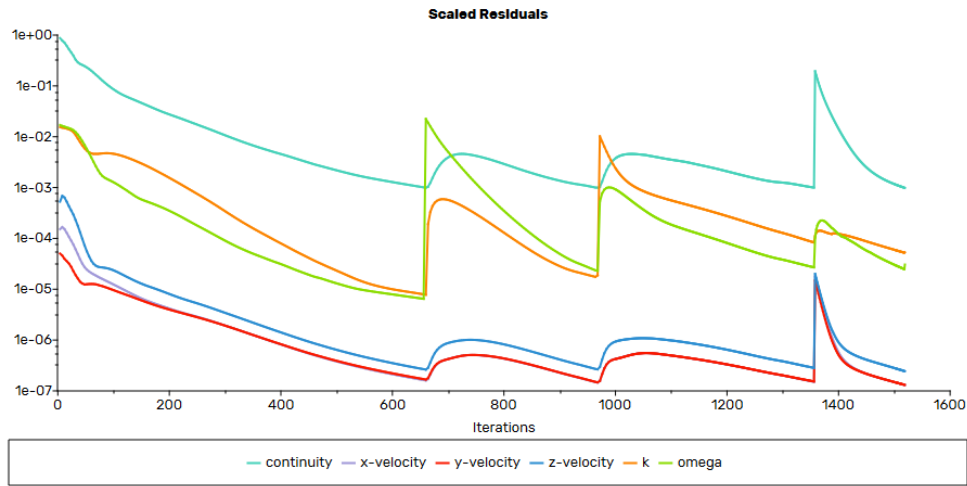


Figure 163: Residuals of the convergence plot

10 Discussion

This section revisits our engineering decisions, acknowledges limitations and explores possible improvements. It discusses the final outcome in relation to the expected outcome, in terms of project management and final outcome. We address potential sources of error by discussing other potential solutions. Furthermore, we give our perspective on how further development can be implemented.

10.1 Planning

Overall, we created a project plan that we were able to follow. Deviations in the outcome from the plan occurred mainly in the beginning of the project. The planning phase and benchmarking phase required less time than planned, while the initial simulation required more time. The initial simulation delayed us in the planning, even though we had some leftover time from earlier, less time consuming phases. One significant improvement to adjust the planning in retrospect is to add time for software setup. In the beginning of the initial simulation, we started with software setup and adjustment to the program, an activity that had not been taken into account in the planning. A couple of days of the initial simulation were spent familiarizing ourselves with the software before actually starting the initial simulation. The initial simulation also ran out of time when we discovered some potential sources of error in our first setup of the fluid analysis. These uncertainties had to be adjusted before continuing the process, as the whole project is based on the same analysis as the initial simulation. After the initial simulation was performed, we were ready to start the concept generation including fluid analysis for each concept. The half-way presentation marked a natural end to the concept generation phase and we started selecting which concept to continue with. From there, we developed as much as we could on the final concept that was chosen, before reaching our deadline for the final concept. The remaining time was spent on the report and other activities, connected to the master thesis. The buffer time at the end came in handy, since we needed the extra time to finish the report.

10.2 Simplifications in the fluid analysis

The results are relatively realistic compared to the simplifications. The simplifications made are mostly made to cut simulation time, however, there are some areas that could affect the results. The first one is the roof. We have made a solid roof with no shear stress to simulate an open pool where air would normally enter. This could affect the results regarding water velocity since wind and the water-air contact could decrease the velocity. However, there are a lot of different solutions

to how the water is entering the channel. Therefore, our setup is more realistic to some of the customer's installations, compared to others.

Another area is the mesh. The mesh has been simplified, with the most critical areas being targeted. The mesh could be more refined, possibly resulting in a small change in velocity, however, this would increase simulation time drastically. The mesh study, in and of itself, is performed according to standard procedure. The finest and most critical areas has been refined and the body sizing is reduced in half between each iteration.

An additional factor could be the porous media. The porous media has been calculated with some assumptions and simplifications that could affect the inertial resistance the water is experiencing going into the filter. The Reynold's number was used as a reference of how the water is behaving. We therefore neglected the viscous term in the Darcy-Forchheimer equation. Including this term could slightly affect the velocity of the water going into the filter. However, since we are not close to the maximum allowed velocity, it probably wouldn't have affected the overall results.

Another thing to discuss is the convergence of the simulation. In Methods, everything is set to second order except momentum. This residual didn't meet the convergence criteria, but reached a stable value. This could still mean the solution is converged, however the results could change if second order convergence is reached. The argument for not getting it to converge is that a second order upwind solution is generally more unstable than a first order upwind solution. However, the results are generally more accurate. If second order upwind were to be reached, the mesh would have to be more refined, which would increase the simulation time. A more refined mesh would require a more advanced computer which we did not have access to in this project.

10.3 Fluid analysis - Mean velocity

Mean velocity in the contact area between the outlet from the channel and the inlet of the filter, is used as a criterion for evaluating our concepts against each other and against the company's existing inlet channel. The mean velocity can be repeatedly measured for a quantified number that can be objectively compared against other concepts. Uncertainty arises in how the mean velocity is measured. Since the mean velocity only considers the water actually passing through the opening (as shown in Figure 25), potential water stuck around the inlet is not considered. A clear example of how this gives a limited view of the water flow, is the differences and similarities between the company's wing walls and inlet channel. The mean velocity reported in Table 10-13 shows a difference of less than 10% between the

wing walls and the inlet channel for corresponding sizes. The simulation results reported in Appendix B show significant recirculation and dead zones around the filter inlet for the wing walls, but not as extreme for the inlet channel. The water flow around the inlet is of great importance, dead zones and recirculations are something we really want to avoid. Although we aim for a more efficient flow, the velocity should not be too high resulting in other potential issues instead. An example of a too high velocity is above 1.0 m/s for the standard flow of $3000 \text{ m}^3/\text{h}$. This is a maximum velocity set by the company. Therefore, only measuring the mean velocity in the filter inlet is misleading, since it takes no account to what was previously mentioned.

A potential solution for this could be to measure the mean velocity of the total cross-section including the filter inlet. Potentially, it would take recirculation and dead zones around the inlet into account. A problem with measuring the full cross section including the filter inlet is that the velocity just by the wall is zero regardless. The mean velocity around the inlet should have been measured at a fixed distance before the inlet, separately from the mean velocity in the inlet. Another solution could be to look at the head loss. This would have given us another aspect of how the velocity affected the pressure of the water. If the velocity increased but the pressure stayed the same, we would have increased the efficiency in the system.

Generated concepts in the future, are not guaranteed to be able to follow a geometry that is possible to measure and therefore causing the measuring to be inconsistent. The fixed geometry of the filter's inlet is one reason we chose to measure the mean velocity there. Another reason is to avoid unnecessary complexity in the measuring. To compensate for the potential delusive information from the mean velocity, the mean velocity was weighted the lowest criterion in Table 14.

10.4 Difference in calculated velocity

The area and the mass flow are used to calculate the fluid velocity going into the filter. The calculated velocity going into the filter can be seen in Table 7. If each average velocity in Table 10-13 is compared to a calculated value, it can be seen that each result is higher than the calculations. There is a controlled mass flow pumped into the pool that is going through the filter. Hence the mass flow is not directly for the filter but for the pool that leads to the filter. The calculation of mass flow and inlet area does not take deadzones and head loss into consideration, possibly modifying the mass flow. This can be a reason for the difference in calculated velocity and measured velocity from the simulation.

Another reason could be the simplifications that were previously discussed. We

only have a fixed mass flow at the inlet of the pool. Perhaps the mass flow changes over the model due to the simplifications applied in the model. Both the porous media and the top wall without shear stress could have an impact on the mass flow. Another aspect that is worth mentioning is the boundaries set for the model. We have a fixed height, but in the real world, the water height fluctuates. That is why there is a fail safe if the water level gets too high. The fluctuation of the water level increases and decreases the area, which affects the velocity at the filter inlet.

10.5 Different volume flows

Neither the company's current inlet channel (see Appendix B) nor our final concept (see Appendix D) is significantly affected by increased volume flow. From the fluid analysis at the initial simulation in Section 3, and the final simulation in Section 7.2.1 and 7.3.1, higher volume flow and higher velocity of the water does not worsen the recirculation significantly. One hypothesis was that increased volume flow and higher velocity would create a more narrow waist shape of the flow. According to our analysis, this did not occur. A suggested reason is that even the smallest volume flow, has a velocity that is too high to pass the sharp edge smoothly.

10.6 Different flow directions

Different directions of the incoming flow, reported in Section 7.2.3 and Section 7.2.4, made significant difference for the flow through the inlet channel. When the water enters from the floor it moved more slowly through the channel and created more dead zones compared to the regular set up. Water entering from the full floor is a simplification of the water entering from a pipe from the floor. The simulation shows the water entering from the full area and filling up the pool steadily. This removes the turbulence that arises from the water leaving the pipe. Meaning this observation is only representative of a real scenario if the water is distributed evenly from the floor. The water entering from the side better represents customer's facilities. Comparing the water entering from the side with the regular setup, the water coming from the side better adjusts to the curve by the pool edge and results in straighter streamlines.

10.7 Development of Filter A Adapter

The Filter A adapter has not been undergoing the same development process as the Filter B adapter due to time limitations within the scope. The analysis focused on the Filter B construction. The Filter A adapter was developed after the Filter B adapter was established. This way, the knowledge from the previous process could

be applied to the Filter A adapter as well. However, during the short development process for the Filter A adapter, the criteria in the product specifications were still considered. In addition, Design for Manufacturing was also still considered.

10.8 Further Development

We recommend a parameter study, for example Design Of Experiments (DOE) or similar, as further development. This study is not conducted in our project due to its extension outside our scope. A parameter study would give a deeper study in optimization of our final concept. With a Design of Experiments, we would have parametrized the full length of the channel and adapter, the radius in the beginning of the channel and the width of the curved parts in the beginning of the channel. The DOE would then create design points within fixed intervals of the different parameters. From this, we would have been able to analyze if there was a combination of parameters that increased velocity or perhaps decreased the pressure.

We would also further develop the Filter A adapter. As previously stated, the development of the Filter A adapter was limited due to time constraints. We would have liked to perform a separate concept generation for this part, that would then lead to a concept selection. Even though the final Filter A adapter is satisfactory, there is a lot of development potential in this area.

We would also like to study sheet metal, in order to make better design decisions going forward. Our limited knowledge of sheet metal in this project has affected the outcome. We scored concepts partly based on our knowledge, and partly on a consultants knowledge. However, the contact with the consultant was very limited, and it would have been more efficient for the project if we had more knowledge about sheet metal. The final concept could have been different if we had more knowledge within the subject, perhaps even better if we knew what design changes could be made to improve manufacturing.

Going forward, we would also like to perform FEA on the product to improve the strength and robustness. We would also like to manufacture a prototype and test the product in fish farms with different setups to evaluate the real world results against the simulations.

10.9 Ethics

The results for this project has been presented honestly and transparent. The simplifications has been stated and consequences on the basis of those simplifications has been discussed. There could be other consequences that we have not thought

of which is why we have discussed the further development of the product that we would like to perform before the product can be used in fish farms.

10.10 Sustainability

The project helps develop more sustainable solutions for the world. Not only does the product help the fish in the tanks, but it also helps the fish and the marine life outside the tank. The resources in the world are slowly decreasing. By having land based fish farming, marine life can stay untouched while humans have a sustainable protein source that requires a much smaller ecological footprint to produce.

10.11 Use of Generative Tools

No generative tools have been used in any form for any part of the process.

10.12 Contribution

Both authors, Mimmi Cassé and Oliver Vester Stephensen, takes equal ownership and acknowledgment of all parts written in this report.

11 Conclusion

The purpose of this project was to improve and optimize the flow in the inlet channel by suggesting a new design. The final concept of the channel and adapter is slightly more complex in manufacturing compared to the company's current. However, our concept improves the production line by consisting of only one channel and two adapters, while improving the flow in the channel and maintaining the fluid velocity.

The fluid analysis found the inlet of the channel and the outlet of the channel (i.e the inlet to the filter) essential for the flow. The sharp edge at the inlet of the channel bordering to the pool is a major obstacle for the flow. The water separates into a waist in the channel for all tested concepts with a sharp edge. A rounded entrance to the channel evens out the flow and dissolves the waist. This means for the company's current inlet channel, only adding a rounded inlet to the channel would most likely improve the flow significantly.

A good fit of the adapter to the filter inlet is essential. Wing walls has no fitting to the filter hole, which results in tremendous recirculation and dead zones in front of the filter inlet. Concluded from the analysis of different concepts, a precise fit does not generate a significant improvement compared to a very close fit to the filter inlet.

The final concept performs well in CFD analysis and is possible for manufacturing in sheet metal. Physical prototypes subjected to testing are necessary to address practical issues before market introduction. The project addresses the theoretical flow of a suggested geometry for the inlet channel. This work provides a base concept that can be further investigated by design of exploration and simpler manufacturing.

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Figure References

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A Project Planning

Planned activities are marked with a full cell, and the actual outcomes are marked with a half shaded cell. The project planning schedule can be seen in Figure 164.

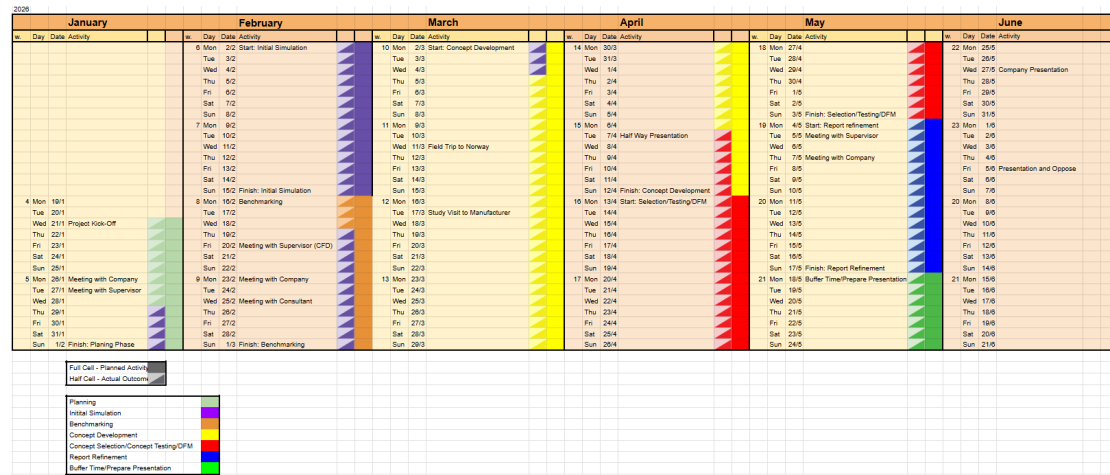


Figure 164: Project planning schedule

B Initial Simulation Results

Appendix including simulation results for the simulated flows presented in Table 10-13.

Simulated flows the Filter A wing walls in Table 10 are presented in Figure 165-170.

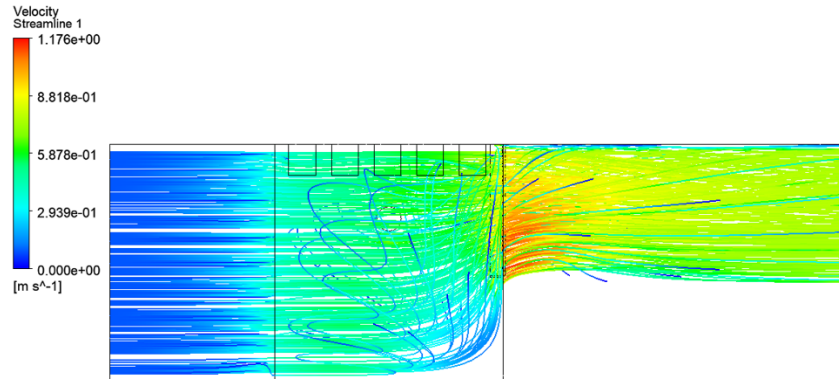


Figure 165: Streamlines for $1688 \text{ m}^3/\text{h}$ in profile

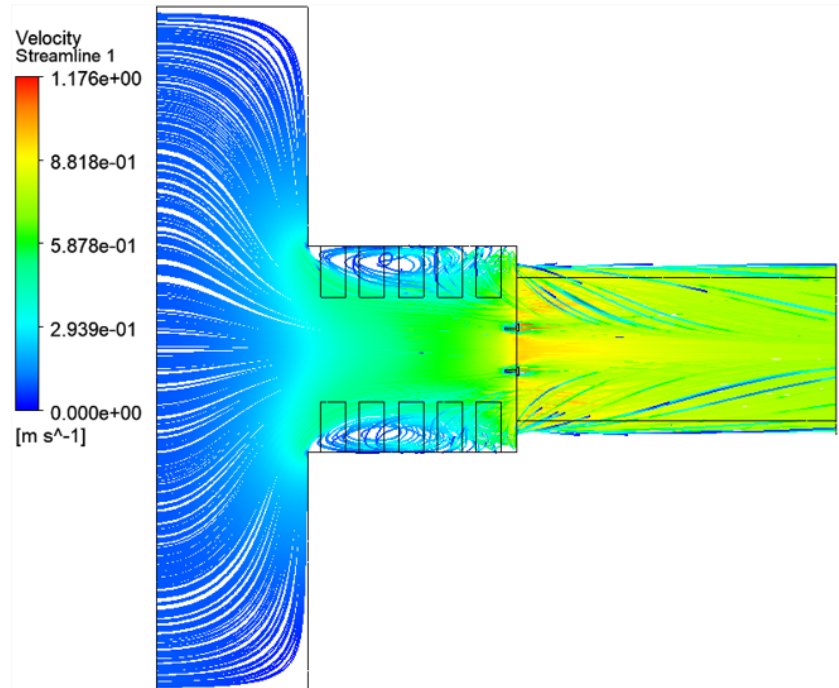


Figure 166: Streamlines for $1688 \text{ m}^3/\text{h}$ in top view

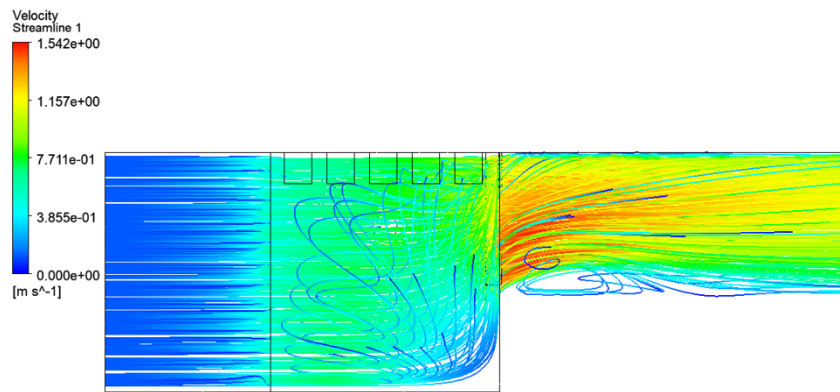


Figure 167: Streamlines for 2250 m^3/h in profile

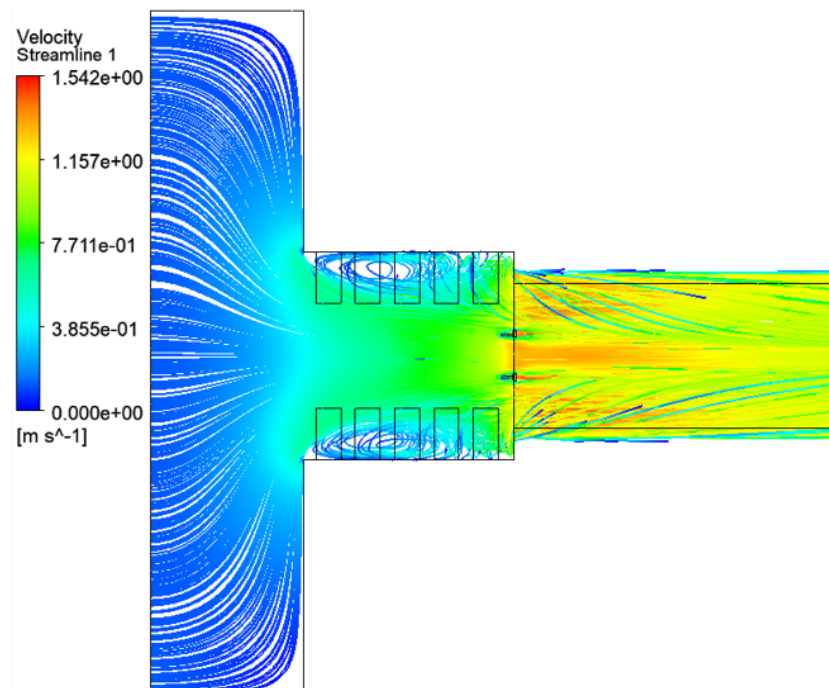


Figure 168: Streamlines for 2250 m^3/h in top view

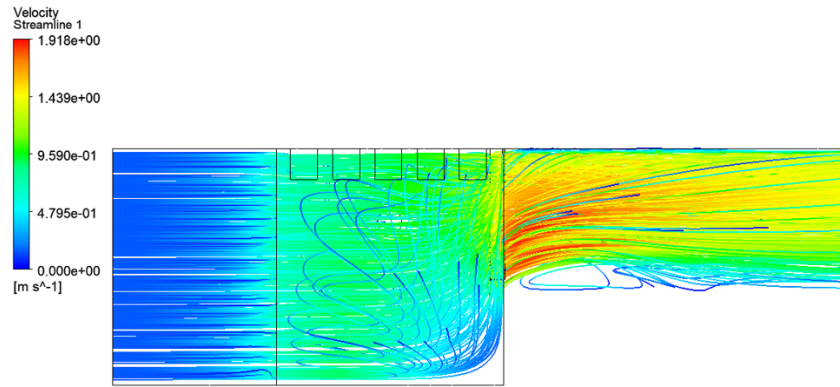


Figure 169: Streamlines for 2800 m^3/h in profile

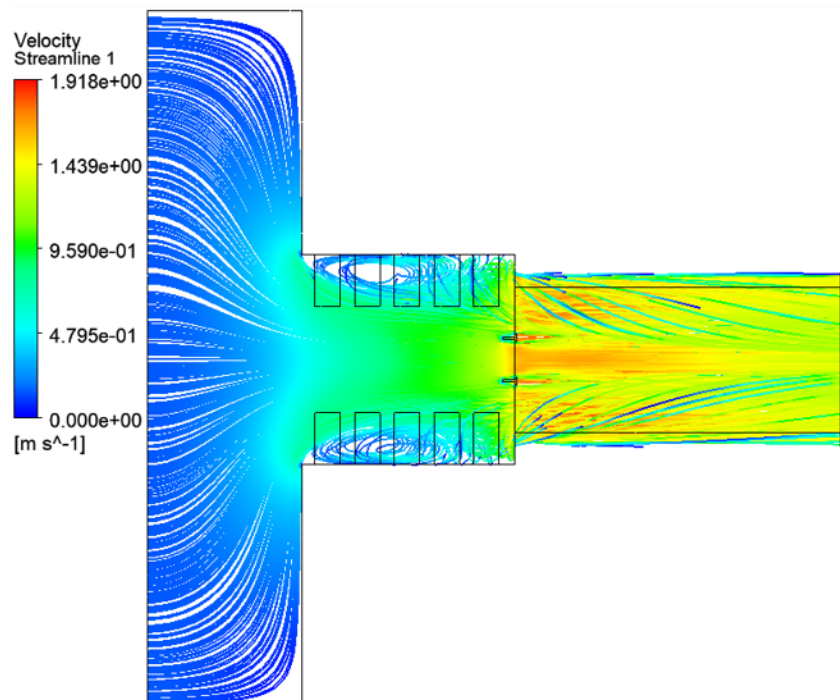


Figure 170: Streamlines for 2800 m^3/h in top view

Simulated flows the Filter B wing walls in Table 11 are presented in Figure 171-176.

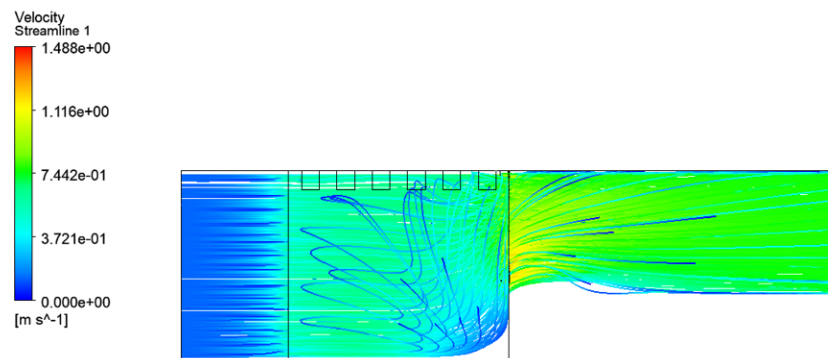


Figure 171: Streamlines for 3000 m^3/h in profile

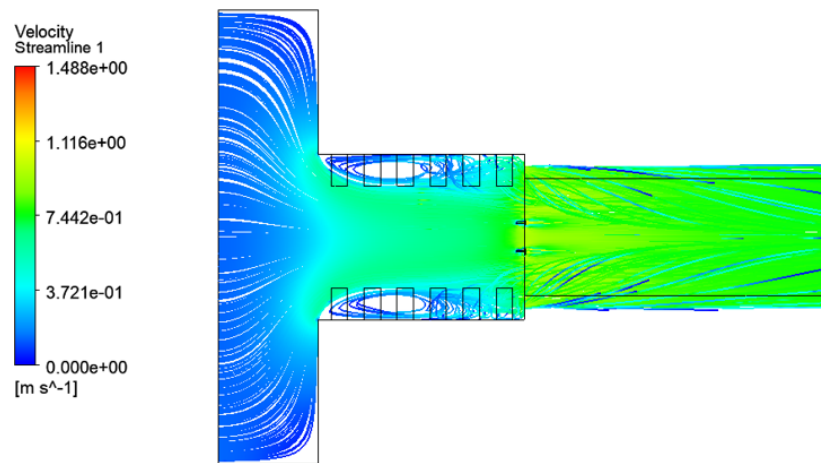


Figure 172: Streamlines for 3000 m^3/h in top view

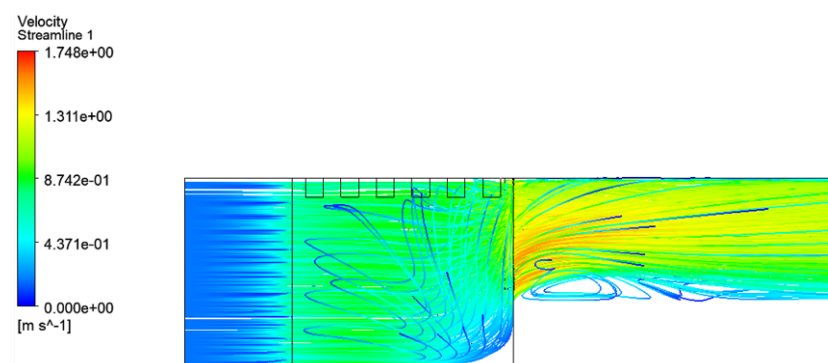


Figure 173: Streamlines for 4000 m^3/h in profile

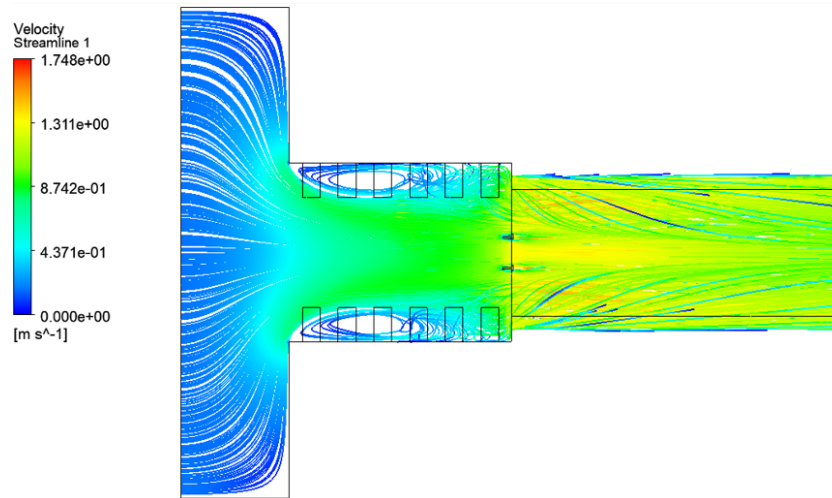


Figure 174: Streamlines for 4000 m^3/h in top view

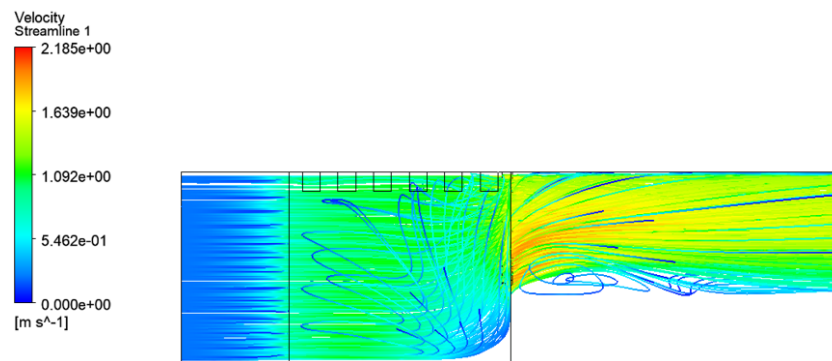


Figure 175: Streamlines for 5000 m^3/h in profile

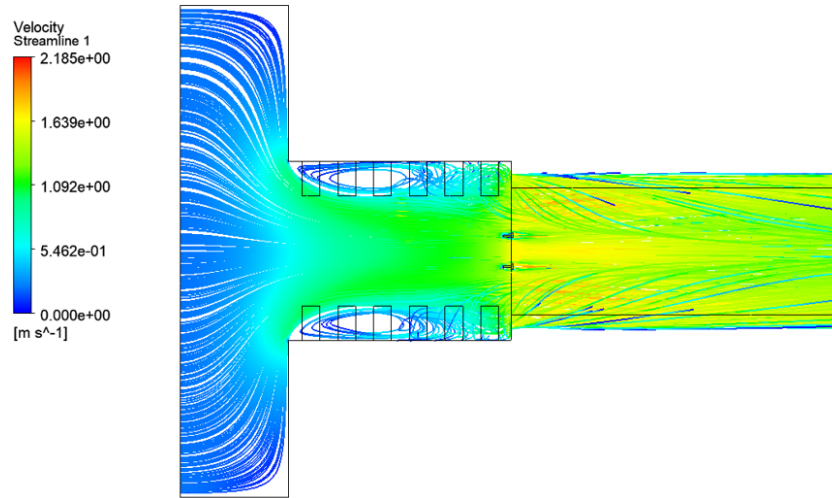


Figure 176: Streamlines for 5000 m^3/h in top view

Simulated flows the Filter A inlet channel in Table 12 are presented in Figure 177-182.

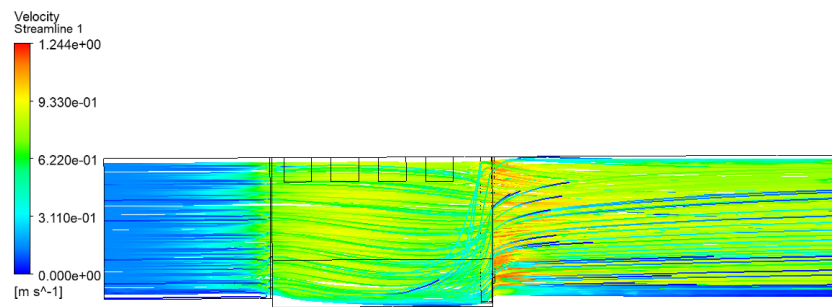


Figure 177: Streamlines for 1688 m^3/h in profile

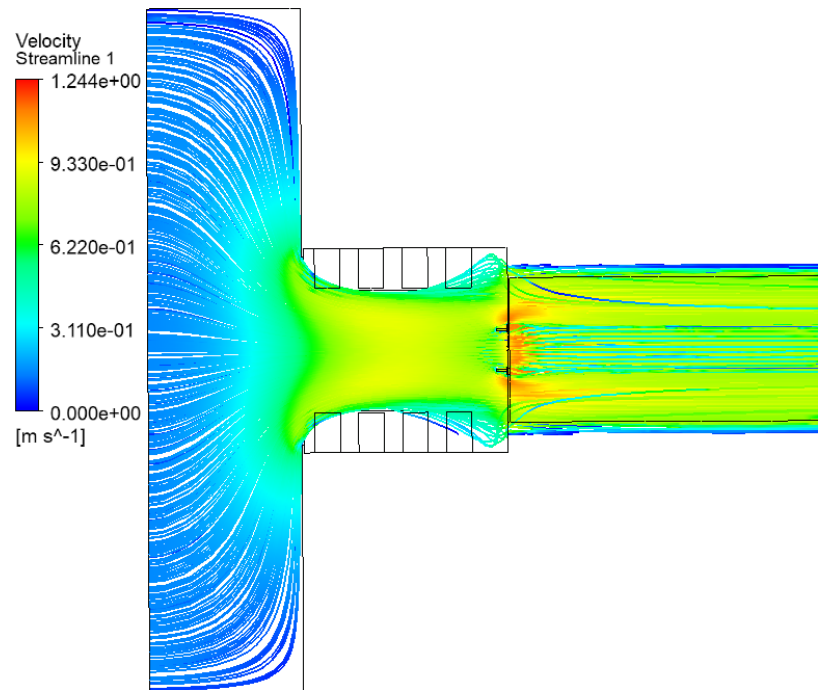


Figure 178: Streamlines for 1688 m^3/h in top view

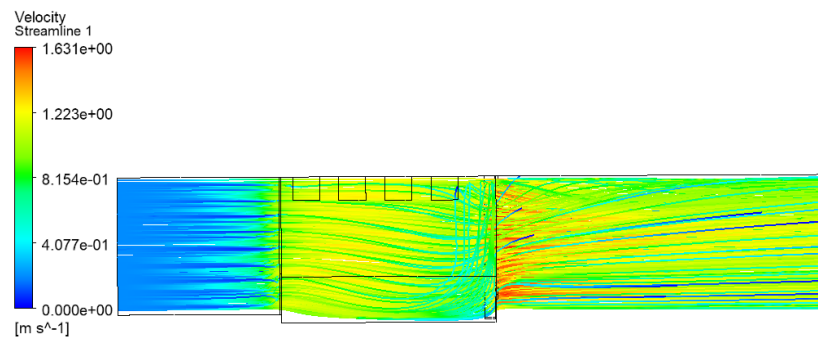


Figure 179: Streamlines for 2250 m^3/h in profile

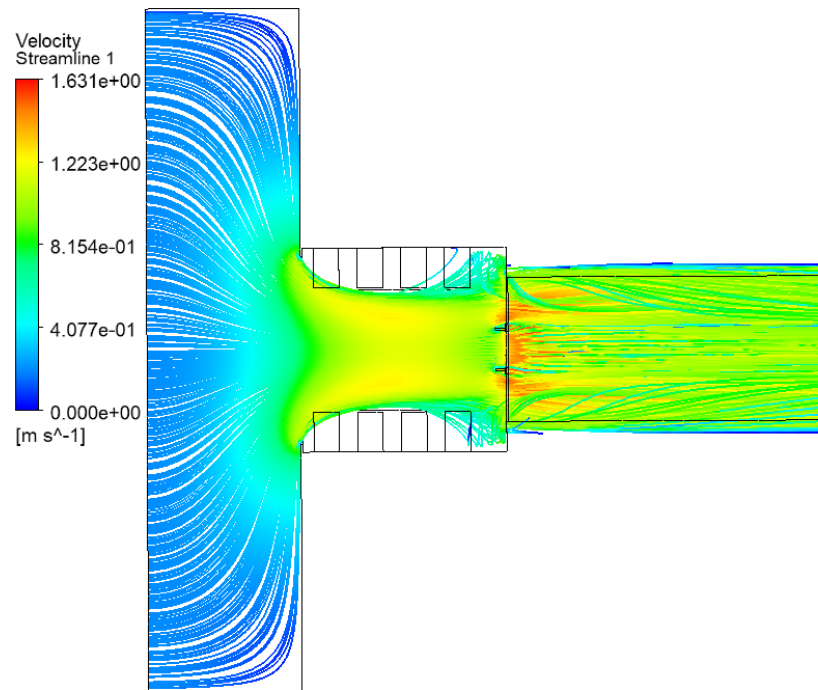


Figure 180: Streamlines for 2250 m^3/h in top view

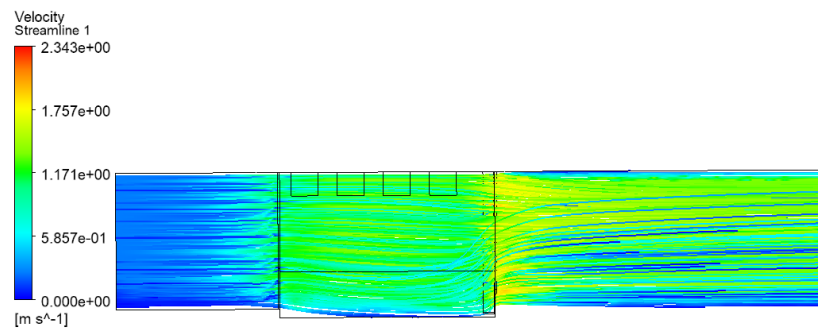


Figure 181: Streamlines for 2800 m^3/h in profile

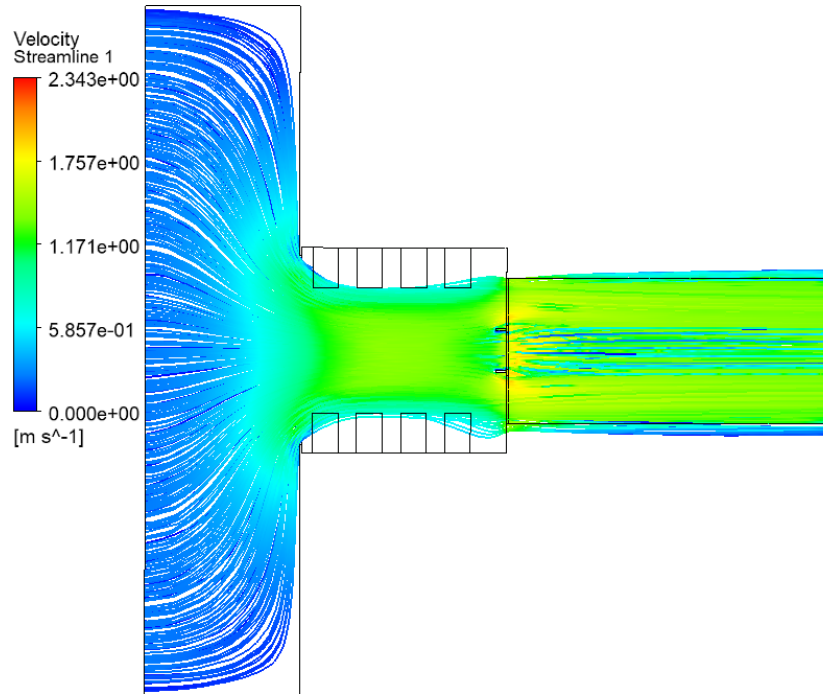


Figure 182: Streamlines for 2800 m^3/h in top view

Simulated flows of the Filter B inlet channel in Table 13 are presented in Figure 183-188.

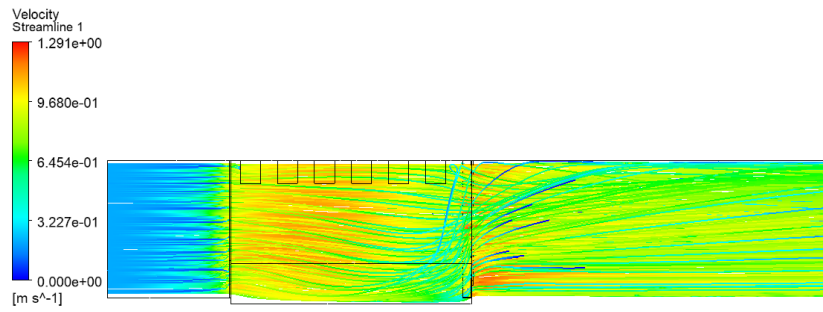


Figure 183: Streamlines for 3000 m^3/h in profile

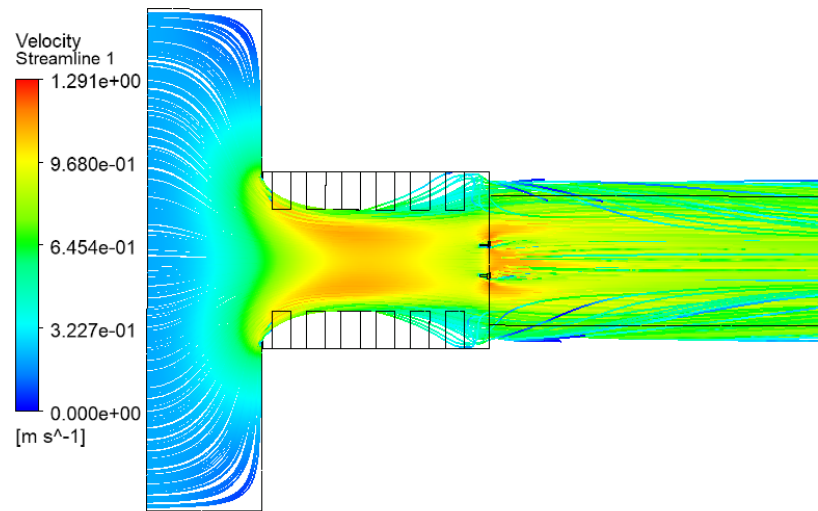


Figure 184: Streamlines for 3000 m^3/h in top view

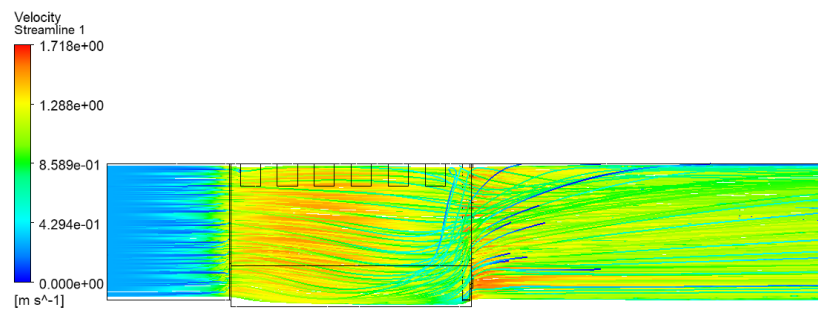


Figure 185: Streamlines for 4000 m^3/h in profile

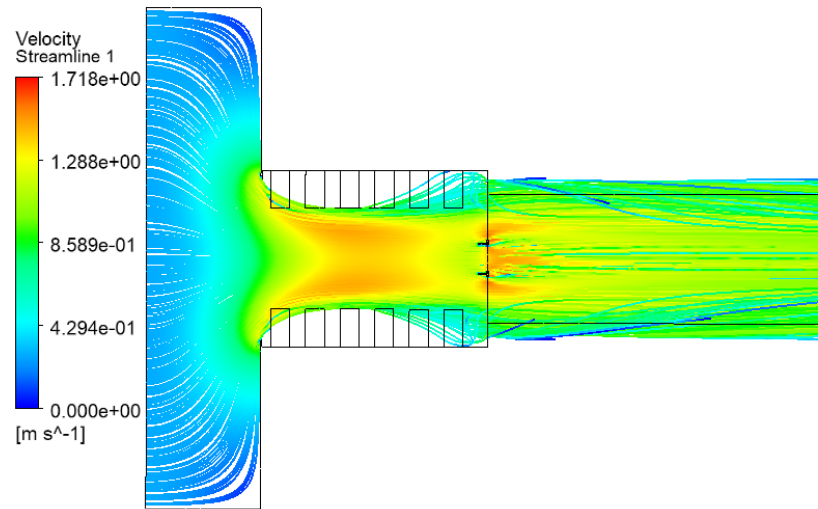


Figure 186: Streamlines for 4000 m^3/h in top view

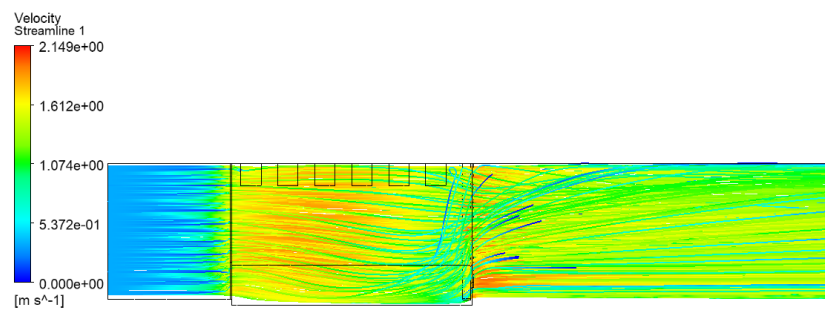


Figure 187: Streamlines for 5000 m^3/h in profile

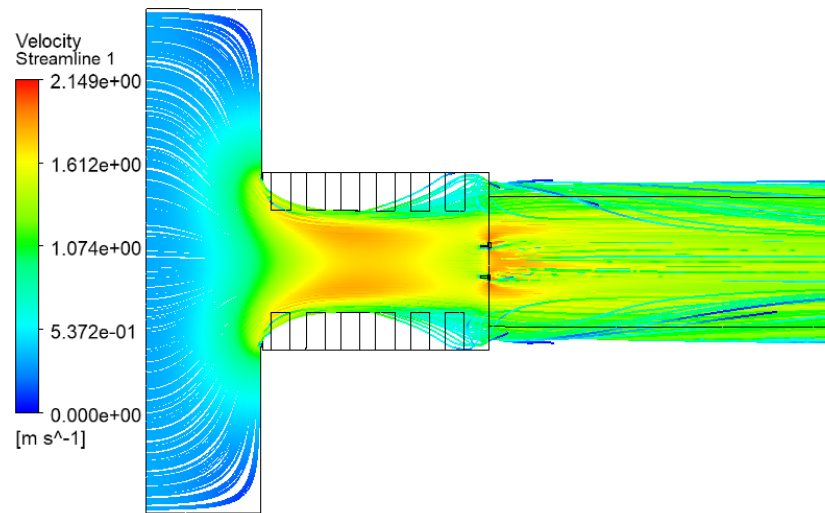


Figure 188: Streamlines for 5000 m^3/h in top view

C Mesh Study for Concept Generation

Concept 1			
Body Sizing	160	80	40
Element	112377	161931	648457
Max velocity	1.31619	1.3732	1.34333
% difference		-4.331441509	2.175211186
Mean Vel			0.935277
Concept 2			
Body Sizing	160	80	40
Element	87351	134713	637202
Max velocity	1.26375	1.29209	1.31874
% difference		-2.242532146	-2.062549822
Mean Vel			0.959292
Concept 3			
Body Sizing	160	80	40
Element	146450	194406	664567
Max velocity	1.25023	1.31202	1.30567
% difference		-4.942290619	0.4839865246
Mean Vel			0.918403
Concept 4			
Body Sizing	160	80	40
Element	84903	141606	634715
Hastighet	1.28225	1.21676	1.2359
%-Skillnad		5.107428349	-1.573030014
Mean Vel			0.89
Concept 5			
Body Sizing	160	80	40
Element	146016	186417	646337
Max velocity	1.22847	1.2473	1.24097
% difference		-1.532800964	0.5074961918
Mean Vel			0.86324
Concept 6			
Body Sizing	160	80	40
Element	56830	110176	624643
Max velocity	1.08686	1.13509	1.1434
% difference		-4.437554055	-0.7321005383
Mean Vel			0.843936
Concept 7			
Body Sizing	160	80	40
Element	111835	159940	643166
Max velocity	1.23867	1.25975	1.2259

% difference		-1.701825345	2.68704108
Mean Vel			0.91672
Concept 8			
Body Sizing	160	80	40
Element	45963	96373	584987
Max velocity	1.32347	1.24942	1.27629
% difference		5.595140049	-2.150597877
Mean Vel			0.904646
Concept 9			
Body Sizing	160	80	40
Element	96063	145348	624147
Max velocity	1.20468	1.19715	1.22952
% difference		0.6250622572	-2.703921814
Mean Vel			0.899781
Concept 10			
Body Sizing	160	80	40
Element	47076	97910	596895
Max velocity	1.3109	1.29686	1.32304
% difference		1.07101991	-2.018722144
Mean Vel			0.910666
Concept 11			
Body Sizing	160	80	40
Element	45942	95543	581812
Max velocity	1.29075	1.31313	1.27884
% difference		-1.733875654	2.611317996
Mean Vel			0.903117
Concept 12			
Body Sizing	160	80	40
Element	152503	190052	662426
Max velocity	1.08631	1.10374	1.09461
% difference		-1.604514365	0.8271875623
Mean Vel			0.891734
Concept 13			
Body Sizing	160	80	40
Element	45369	91679	552599
Max velocity	1.27847	1.25837	1.21514
% difference		1.57219176	3.435396584
Mean Vel			0.900458
Concept 14			

Body Sizing	160	80	40
Element	50755	92964	539995
Max velocity	1.31424	1.29535	
% difference		1.437332603	100
Mean Vel			0.927815
Concept 15			
Body Sizing	160	80	40
Element	63126	105070	572566
Max velocity	1.24337	1.23684	
% difference		0.5251855843	100
Mean Vel			0.898526
Concept 16			
Body Sizing	160	80	40
Element	175916	217060	683511
Max velocity	1.26095	1.31854	1.32222
% difference		-4.567191403	-0.2790965765
Mean Vel			0.889377
Concept 17			
Body Sizing	160	80	40
Element	397354	431945	866418
Max velocity	1.2769	1.26354	1.26145
% difference		1.046283969	0.1654082973
Mean Vel			0.874785
Concept 18			
Body Sizing	160	80	40
Element	144488	192078	669974
Max velocity	1.27921	1.28844	1.33852
% difference		-0.7215390749	-3.886870945
Mean Vel			0.909727
Concept 19			
Body Sizing	160	80	40
Element	281776	317828	757082
Max velocity	1.25144	1.25963	1.2915
% difference		-0.6544460781	-2.530108048
Mean Vel			0.898136
Concept 20			
Body Sizing	160	80	40
Element	63951	106210	586552
Max velocity	1.18906	1.18101	1.24682
% difference		0.6770053656	-5.572349091

Mean Vel			0.872122
Concept 21			
Body Sizing	160	80	40
Element	44287	91284	544807
Max velocity	1.43867	1.4387	1.35532
% difference		-0.002085259302	5.795509835
Mean Vel			0.931463
Concept 22			
Body Sizing	160	80	40
Element	54726	98511	573213
Max velocity	1.27706	1.28554	
% difference		-0.6640251828	100
Mean Vel			0.897233
Concept 23			
Body Sizing	160	80	40
Element	161806	196600	627560
Max velocity	1.4735	1.45678	1.45239
% difference		1.134713268	0.3013495518
Mean Vel			1.10066
Concept 24			
Body Sizing	160	80	40
Element	130634	163903	627481
Max velocity	1.21254	1.14452	1.1489
% difference		5.609711845	-0.3826931814
Mean Vel			0.908298
Concept 25			
Body Sizing	160	80	40
Element	51068	108056	667383
Max velocity	1.16832	1.15921	1.16301
% difference		0.7797521227	-0.3278094564
Mean Vel			0.859945

D Final Concept - Different flows

Simulated flows of the final Channel + Filter A adapter reported in Table 23 are presented in Figure 189-194.

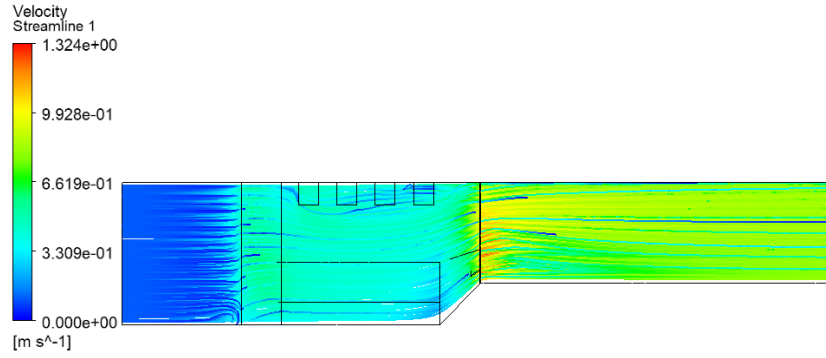


Figure 189: Streamlines for 1688 m^3/h in profile

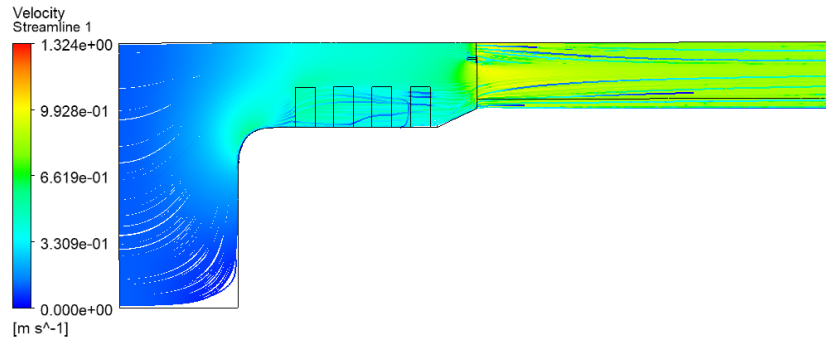


Figure 190: Streamlines for 1688 m^3/h in top view

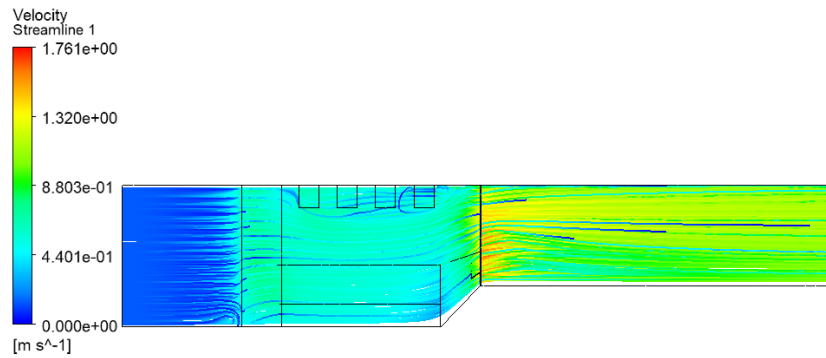


Figure 191: Streamlines for 2250 m^3/h in profile

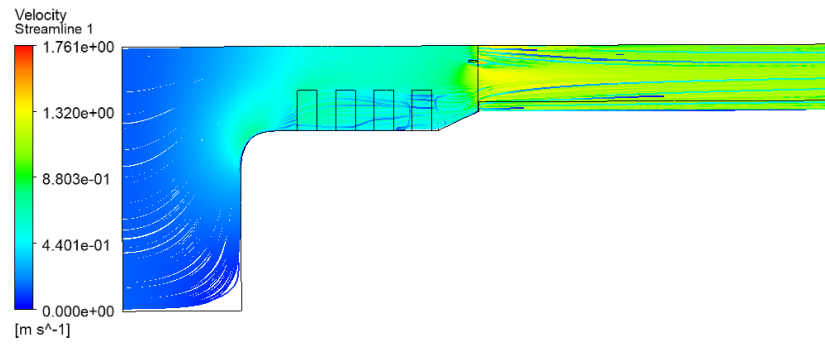


Figure 192: Streamlines for 2250 m^3/h in top view

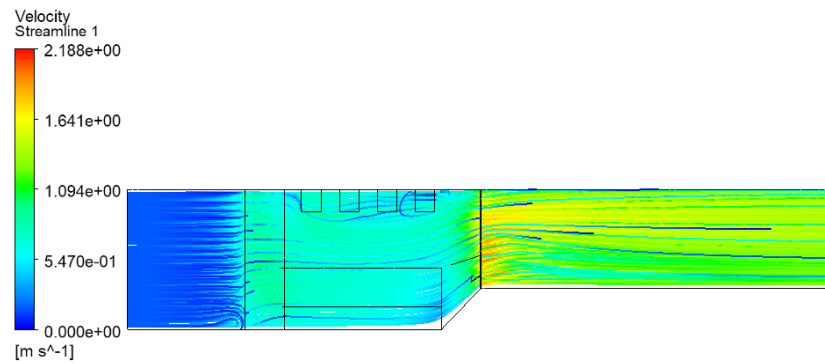


Figure 193: Streamlines for 2800 m^3/h in profile

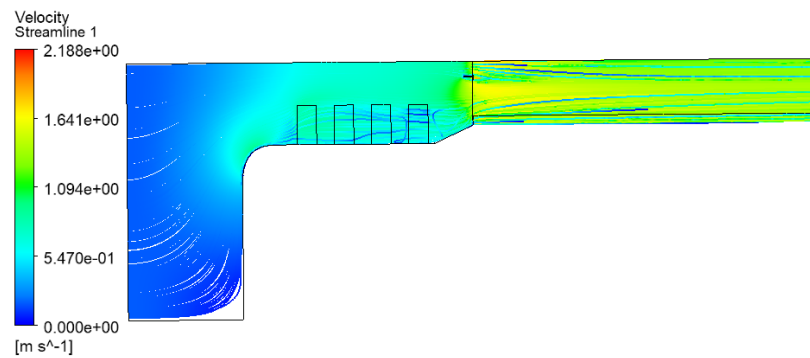


Figure 194: Streamlines for 2800 m^3/h in top view

Simulated flows of the final Channel + Filter B adapter reported in Table 22 are presented in Figure 195-200.

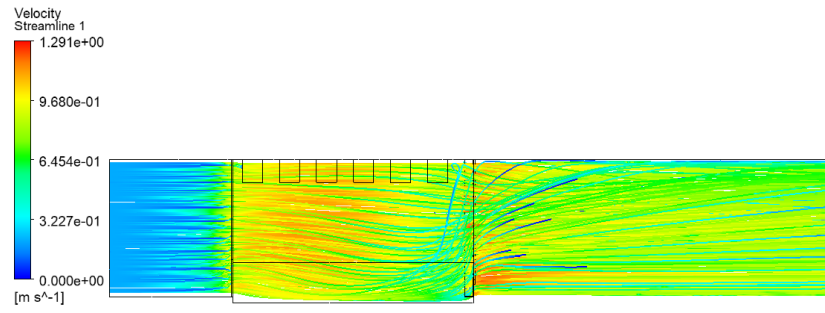


Figure 195: Streamlines for 3000 m^3/h in profile

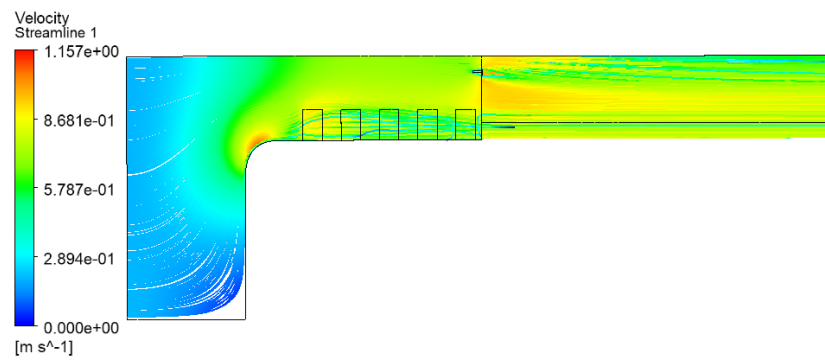


Figure 196: Streamlines for 3000 m^3/h in top view

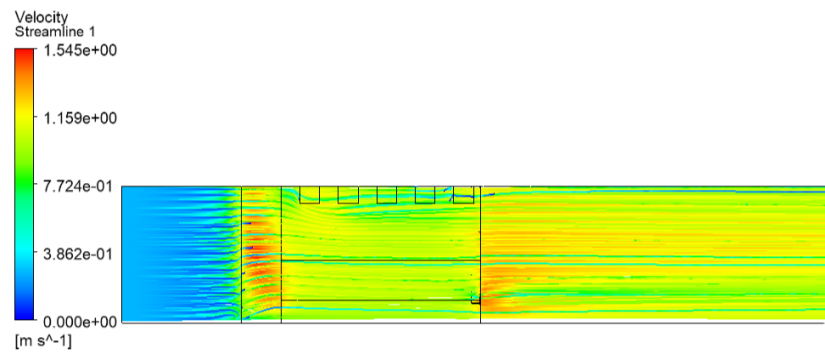


Figure 197: Streamlines for 4000 m^3/h in profile

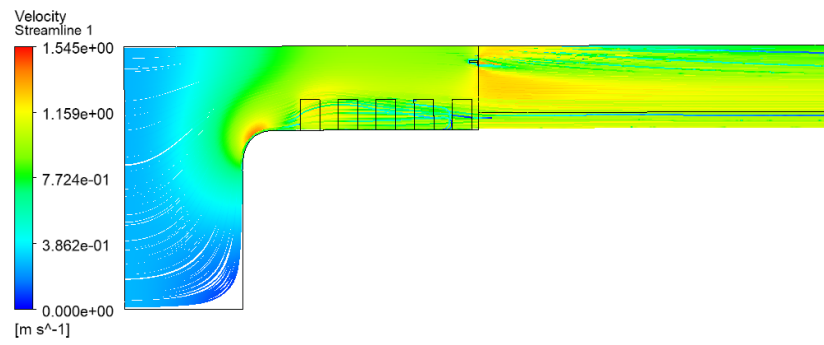


Figure 198: Streamlines for 4000 m^3/h in top view

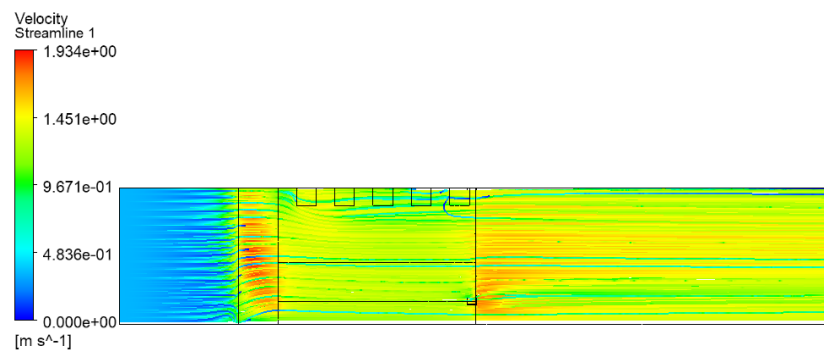


Figure 199: Streamlines for 5000 m^3/h in profile

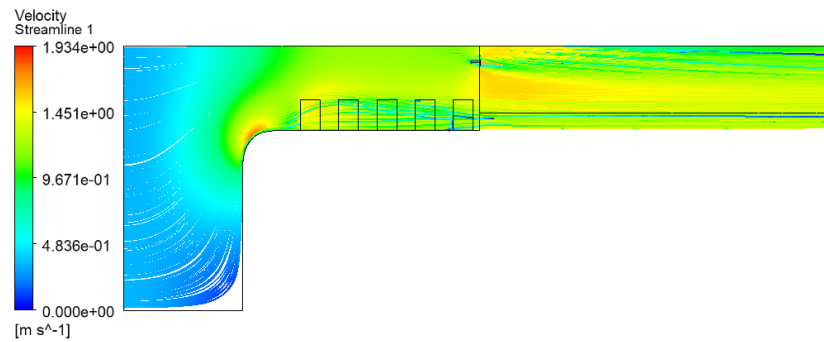


Figure 200: Streamlines for 5000 m^3/h in top view