Deliverable report

Calculation programme to optimize system performance

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Report No:

2022:00240 - Unrestricted

Client:

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Report

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KEYWORDS
Pneumatic conveying
Fish feed pellets
Erosion
Microplastic emissions

VERSION
Version1.0

DATE
2022-03-03

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CLIENT(S)
FHF - Fiskeri- og havbruksnæringens forskningsfinansiering

CLIENT'S REFERENCE
Eirik Ruud Sigstadstø, FHF project no. 901658

PROJECT NO.
102024088

NO. OF PAGES/APPENDICES
14+Appendices

SUMMARY
This report is submitted as a deliverable in the MICRORED project, entitled "Reduction of Microplastic Emissions through Optimisation of Feed Pellet Conveying Systems", funded by Fiskeri og Havbruksnæringens forksningsfinansiering (FHF) under the project number 901658. It describes the pneumatic conveying tests carried out with commercial fish feed pellets and a standard PE pipeline in a pilot-scale conveying test rig at SINTEF Tel-Tek. The tests were conducted under a wide range of conveying conditions while collecting data on pressure drop, air volume flow rate and transport rates. The data is used to determine a safe operating window for the transport of fish feed pellets avoiding too low velocities, that could result in clogging of the pipe, and unnecessarily high velocities. The data forms a basis for the development of a calculation programme that has the potential to be used for optimization of air-based feeding systems at fish farms.

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REPORT NO.	ISBN	CLASSIFICATION	CLASSIFICATION THIS PAGE
2022:00240	978-82-14-07556-4	Unrestricted	Unrestricted

Document history

VERSION	DATE	VERSION DESCRIPTION
V1.0	2022-03-01	First version of a report summarizing the results of pneumatic conveying tests conducted in WP1 of MICRORED project

Participating organizations in the project:

1) SINTEF Industry, SINTEF AS (Project Coordinator)
2) SINTEF Ocean AS
3) NORCE AS

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1 Introduction

The fisheries and aquaculture industry contribute to emissions of microplastics into the sea, which may potentially have negative consequences for the marine environment and living organisms. The release of microplastics from the fish feeding pipes has been recognized as one of the contributing factors to the pollution of the sea water, with implications for seafood safety and potentially human health, lowering the consumer confidence in seafood products.

In larger fish farms, the fish feed is typically transported by means of compressed air from the storage point to several fish cages through a network of transportation pipes that are typically made of plastic, mainly HDPE (high-density polyethylene). The use of unnecessarily high air flow volume rates accelerates the pellets to a high velocity, causing hard impacts with the internal wall of the pipe, especially in bends and curved sections, with directional change of pellet conveying path. Depending on the fish feed properties (hardness, shape, size, surface texture), this can result in potential problems with negative economic and environmental consequences:

1) excessive erosion (abrasion) of the pipe surface and faster wear that leads to more frequent replacement of the pipeline;
2) significant breakage of the pellets leading to local pollution and loss of valuable and costly feed; and
3) higher rates of microplastic release into aquaculture facilities and further into the wider environment.

On the other hand, use of too low air velocity may lead to pipe blockages and pellet breakage due to compressive stress. Optimization of feeding system operating parameters is therefore key for ensuring minimal release of microplastics from the feeding pipes, maximising the lifetime of the pipeline and for delivering intact, undamaged pellets to the fish.

Therefore, the main objective of the MICRORED project is to optimise the feed pellet conveying systems, technology and costs in fish farms to minimise microplastic emissions and maximise pipeline lifetime and pellet integrity. The project will also provide recommendations on measures and best practices that the industry can implement to reduce emissions of nano- and microplastics from feeding pipes. This is achieved through the following sub-objectives:

A. To evaluate the effect of air velocity and pipeline configuration (bend radius) on pipe wall erosion for selected fish feed qualities.
B. To quantify the amount of micro- and nanoplastic (MNP) fragments from objective A and characterize their physical properties (size, shape).
C. To map the erosion pattern and evaluate the evolution of erosion with application time.
D. To implement the results in a simulation software for a selected industrial site to demonstrate how the feeding system can be optimized.
E. To disseminate the learning from the project and present the methodology for optimization of the feed pellet conveying systems to the fish farming community.

The project work will be divided into 4 WPs, shown schematically in Figure 1.

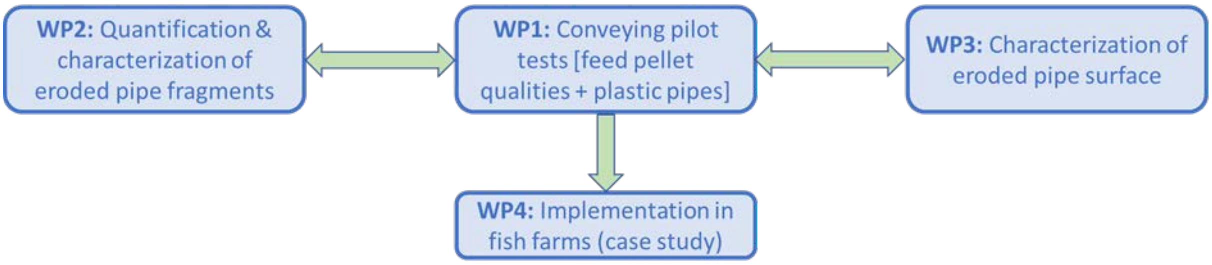


Figure 1: Schematic outlining the work packages in MICRORED and their connections

This report describes some of the results of the pneumatic conveying tests that will be used for the development of a calculation programme for optimization of transport systems.

2 Background

2.1 Pneumatic conveying of feed pellets

Pneumatic conveying is a common technique used to transport feed pellets in fish farms. Generally, pneumatic conveying is a material transportation process, in which bulk particulate materials are moved over horizontal and vertical distances within a piping system with help of an air stream. Using either positive or negative pressure of air or other gases, the material to be transported is forced through pipes and finally separated from the carrier gas and deposited at the desired destination. Since pneumatic systems are completely enclosed, product contamination, material loss and dust emission (thus, environment pollution) are reduced or eliminated. In addition, reduced dimensions, progressive reduction of capital and installation costs, low maintenance costs (due to the small number of moving parts), repeated usage of conveying pipelines, easiness in control and automation are among the favourable advantages of pneumatic conveying over the other traditional methods of particulate material handling.

Although pneumatic conveying has seen increased use in many industrial sectors, there are still many major problems hampering its employment in a wider range of industrial conveying applications. Specially, in dilute-phase transport (with high velocity and low transport rate), high energy consumption, excessive product degradation and system erosion (pipelines, bends etc) are some of the major problems. In an alternative method, in dense-phase conveying (low velocity and high transport rate), unstable plugging, severe pipe vibrations and repeated blockages are experienced frequently. Further, the lack of simple procedures for the selection of an optimal system is a major problem in pneumatic transport system design. These challenges are also relevant for the fish feed transport at fish farms, often resulting in undesirable breakage of fish feed pellets and/or microplastic emissions caused by the wear of the plastic fish feeding pipes.

2.2 Impact erosion

The main objective of the MICRORED project is to investigate the generation of microplastic emissions caused by erosion of the fish feeding pipes. This effect is especially pronounced at high conveying velocities when the pellets experience hard impacts with the surface of the transport pipe walls. The other effect of hard impacts with the surface of the transport pipe walls is pellet degradation, which has been studied elsewhere [1-6]. Pipe leakage in pneumatic conveying systems caused by excessive erosion of the pipe surface obstructs the continuous operation and results in economical (due to downtimes and repairs, exchange of worn-out pipes) and HSE drawbacks. Thus, thorough understanding of the erosion process and its prediction is essential for appropriate control of pneumatic conveying systems and their trouble-free operation. Impact erosion is influenced by many factors such as impact angle, impact velocity, exposure time, temperature, particle properties, etc. [7-9]. One common observation of those studies is that the erosion rate increases exponentially as a function of the conveying air velocity, the angle of impact and concentration of particles in a pipeline, etc.

As a remedy to minimise the impact erosion in transport pipes, the conveying systems are designed with low conveying velocity. However, systems designed with extremely low conveying velocities or extremely high solid flow rates are subject to erratic operation due to solids deposition or they may become completely inoperable because of pipeline blocking. In general, minimum-conveying velocity can be defined as the safe gas velocity for transporting of pellets. If this gas velocity is used at the beginning (feed point) of the pneumatic conveying system, the gas velocity will increase along the pipeline due to the due to expansion of conveying gas, i.e., density decrease, so the rest of the pipeline should be operating well above this starting velocity, if the pipeline has a constant pipe diameter. By keeping the gas velocity above the minimum conveying velocity in all sections of the pipeline, it can be ensured that no deposition of pellets (saltation), which leads to pipeline blockage, occur in the system.

2.3 Conveying system optimisation

To ensure reliable operation of a pneumatic conveying system, at least two parameters have to be determined accurately in its design stage. These are:

- the pressure head required to have a predetermined solid transport rate along a known pipeline length of given pipe diameter
- the optimised air velocity to have a safe transport without pipe blockages and undesirable product degradations/ pipe erosions

Consequently, plant designers have been trying to figure out a straightforward, easy and reliable method to determine these parameters using physical and geometrical characteristics of the conveying pipeline and properties of bulk material to be transported.

Operation of a conveying system depends on the strong interaction between the following parameters:

- properties of conveying materials
- available pressure head
- transport air volume flow rate
- product transport rate
- features of conveying pipeline

The following figure (Figure 2) shows the relationship in graphical form.

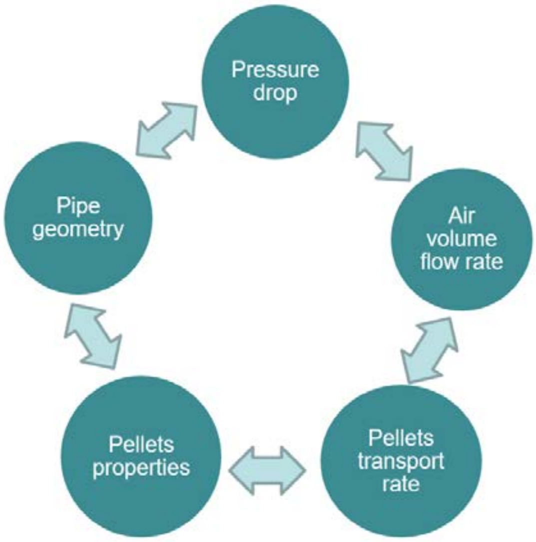


Figure 2: Diagram showing the main influential parameters to reliable operation of a feed pellet conveying system

It is important to understand the inter-relation between the above parameters for reliable operation (i.e., without pipeline blocking, achieving required transport rate, etc), and optimisation of systems (i.e., minimising erosion, pellets degradation, minimising energy consumption, etc). Though there are design equations based on mathematical and statistical models to use in designing conveying systems [10-15], their reliability is challenged in many situations.

SINTEF Tel-Tek (former Tel-Tek) has developed a scaling up technique for system design [10]. The approach used in this technique is based on a characterisation method of different pipeline components together with a selected conveyed material (in this specific case fish feed pellets), so that it can cope with very dynamic changes happening in a conveying pipeline under a wide range of transport conditions. In this approach, a representative sample of a product, which is to be conveyed in the industrial plant, is tested in a laboratory scale pneumatic conveying test rig (pilot plant) over a wide range of operating conditions. The product mass flow rates, air volume flow rates and resulting pressure drops are measured. Additionally, the minimum conveying conditions and blocking limits are also observed. This approach has the advantage that real test data on the product to be conveyed in the proposed system is used for the design process. Thus, it gives a high reliability level about the effects of product type. This is very important because it provides useful information on the conveyability of product. On the other hand, this approach gives good results for the determination of specified conveying limits like minimum conveying velocity, pressure minimum conveying, etc.

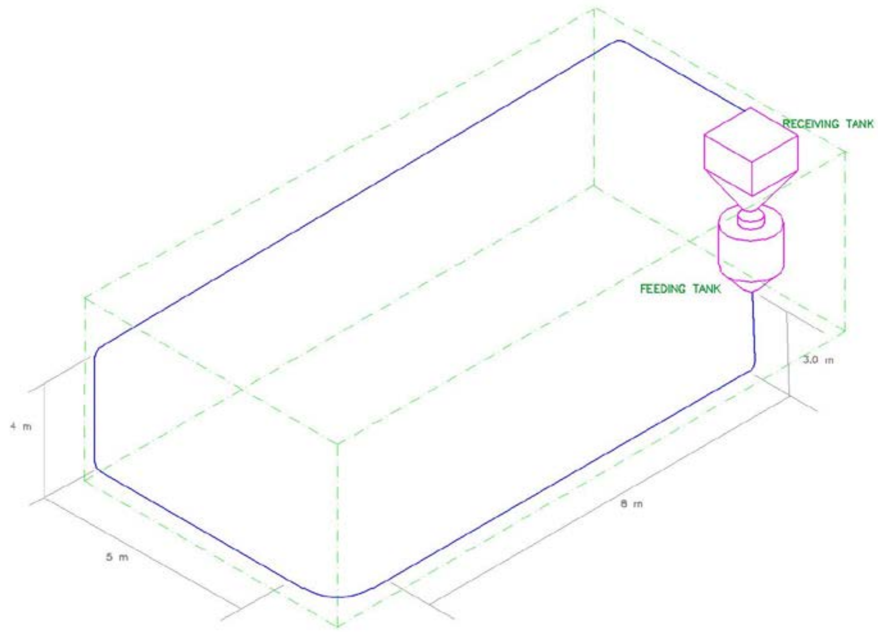
Under the present investigation, a similar procedure based on pilot testing of fish feed pellets in a conveying test rig using a real PE pipe was used to collect data to be further used for the development of the calculation programme that can be used for optimization of pneumatic transport fish feeding systems.

3 Materials and methods

3.1 Conveying test rig

The pilot scale test rig was setup at Powder Hall in SINTEF Tel-Tek (STT) mimicking a transport system at a fish farm. A schematic diagram of the rig configuration is shown in the Figure 3.

A



B

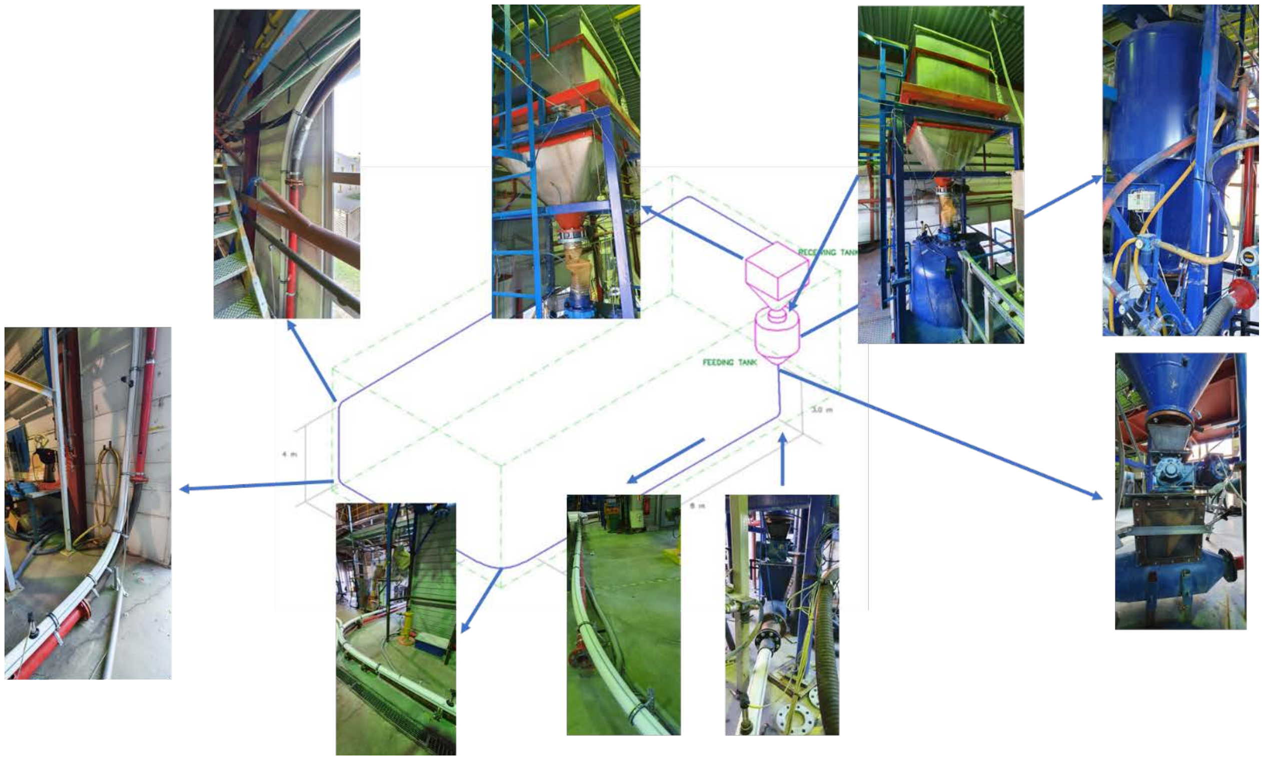


Figure 3: Schematic view of the conveying test rig (A), pictures showing different parts of the test rig and equipment (B)

The test rig mainly consists of a discharge tank of 2.5 m^3 capacity, a receiving tank, which is mounted on a special arrangement of load cells to monitor the weight accumulation during the experimentations. The pipeline material was kindly provided by Hallingplast. It is a standard PE pipe, with an internal diameter of 75 mm and approximately 40 m in length. The feeding from discharge tank to conveying pipeline is arranged through a rotary valve. The conveying line forms a closed loop pneumatic transport circuit by placing the receiving tank on top of the blow tank so that the pellets under testing can be repeatedly transported without taking them out of the test rig (Figure 3B).

The air supply was received from a combination of a screw type air compressor and a drier/air cooler. The pressure and volume flow rate of supply air could be controlled by a regulator. Number of different measuring instruments like pressure transducers, flow transducers are also mounted on the transport line in order to achieve the desired measurements. The transport rig is equipped with facilities for continuous online data logging and visualising of data like air pressure at various locations, material transport rate etc, on a real time basis. The data acquisition and analysis are undertaken with the help of a software program of the LabVIEW® package.

3.2 Feed pellet characteristics

The pellet quality named 'Protec' was bought from Skretting. Their characteristics are given below:

Table 1: Characteristics of tested fish feed pellets

Pellet quality	Height (mm)		Diameter (mm)		Pellet Density (kg/m3)
	max	min	max	min	
Protec	10,0	9,1	10,1	9,0	1,18

3.3 Test procedure

The first step of testing was filling up the supply tank with test pellets of approximately 200kg. After regulating the desired air volume flow rate by adjusting the regulator on the main air supply, the conveying of pellets was started by starting the rotary valve at the bottom of the feeder tank and the data acquisition programme was simultaneously started. The recording of all signals was inspected during the test run. The end of the conveying cycle could be determined by checking the amount of pellet collected in the receiving tank and also by monitoring the pressure signals on the conveying line. Then, the rotary valve was closed, and the data logging programme was also stopped at the same time. The pipeline was then supplied some additional compressed air to clean any residual materials deposited inside the pipeline. After that, the feeder tank was opened to de-pressurise and pellets were then taken down to the feeder tank from the receiving tank for the next test run. Changes in pellets size and size distribution were monitored continuously to trace any significant pellets degradation, during conveying tests.

The different signals recorded during the tests were then analysed and the stable conveying regions were identified by inspecting the signal curves with respect to time scale. A screenshot of typical signal curves is shown in Figure 4**.**

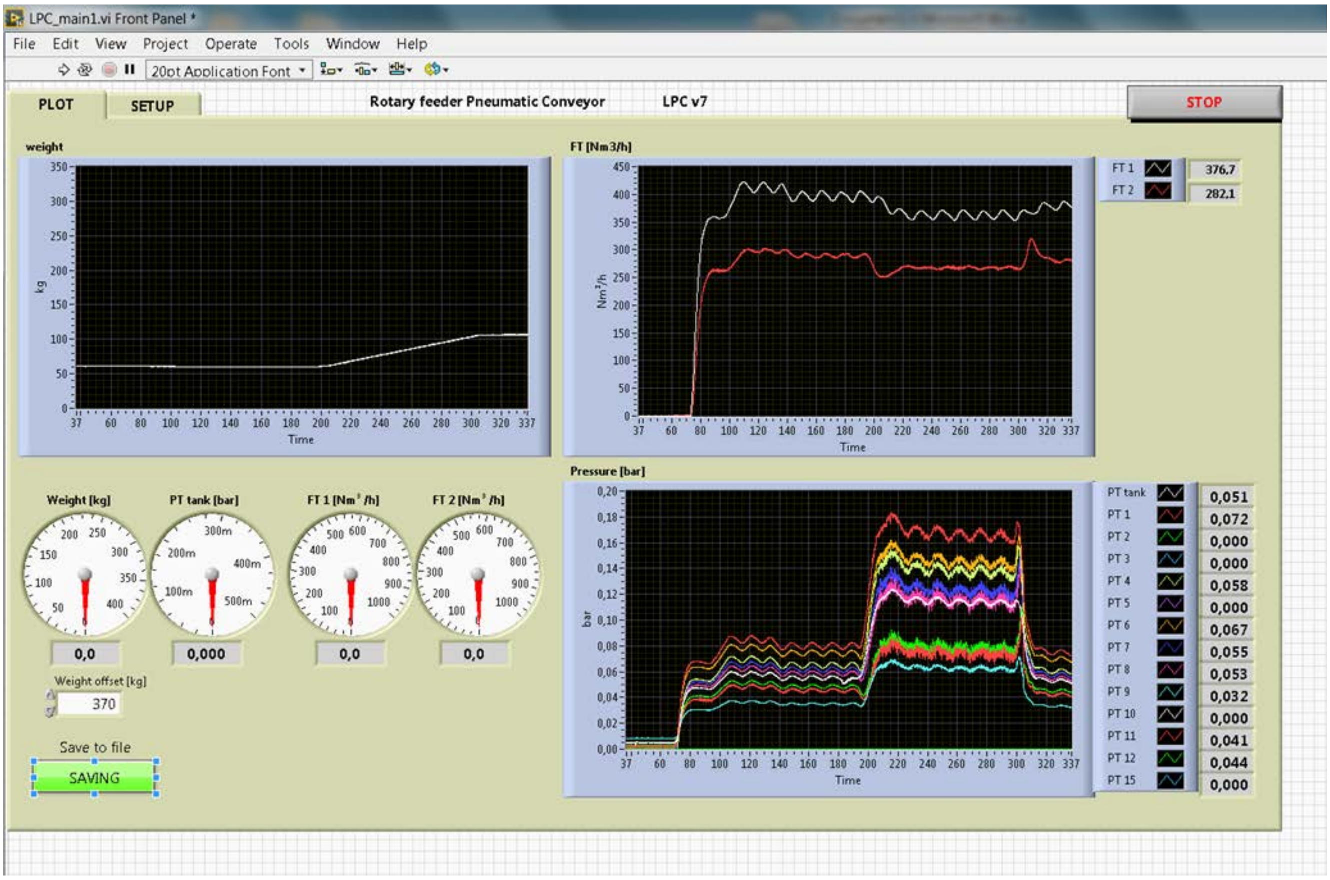


Figure 4: Recorded signal curves during a typical test run

As seen in the above figures, quite stable conveying could be seen during the conveying trials. It was noticed that when the air volume flow rate remains stable during a considerably long-time interval, the pressure signals also show a quite stable behaviour.

For the analysis and calculation purposes, the stable region with respect to pressure, weight collection and air volume flow signals were selected. The time averaged values of different signals were recorded with help of the data analysis software package. Basically, the supply air pressure, the air volume flow rate, solid flow rate and pressure values at discrete positions of the conveying line were recorded as the output results of the experiments. Special attempts were made to determine the lowest conveying velocity, without getting the conveying line blocked.

4 Results and discussion

Based on the measurement of pressure, air volume flow rate, pellets transport rate, etc., the main parameters (pellets velocity, pressure drop, suspension density of gas-pellet mixture, etc.) across the selected pipe sections required for the calculation program were determined.

The graph of pellets transport rate against air volume flow rate is shown in the Figure 5.

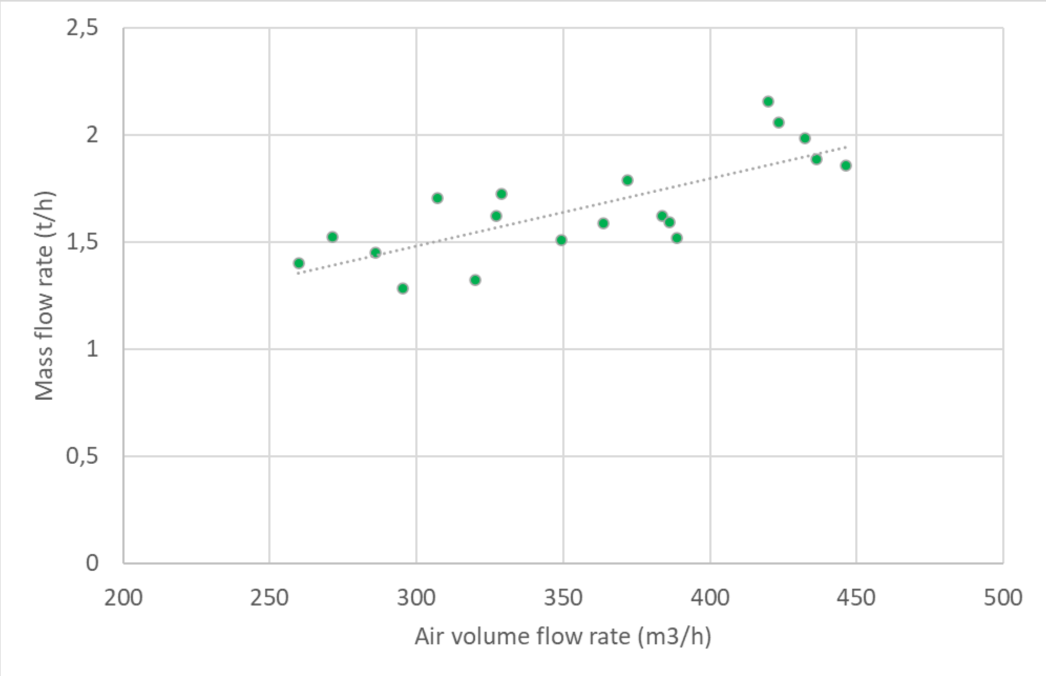


Figure 5: Graph of pellets mass transport rate vs air volume flow rate

Throughout the test series, the average transport velocities were within the range of 15- 24 m/s, while the transport rates of pellets were varying between approximately 1.5 and 2.2 t/h . The test measurements were used to formulate the calculation program. The relevant process is explained in detail in the scientific article by the authors [16].

5 Calculation programme

The calculation program based on the scale-up model has been successfully used in transport system design and optimization in previous R&D works with the feed pellet handling sector [6]. The calculation/simulation software can be used to design a reliable conveying system and optimize its performance in terms of conveying parameters and addressing issues of pellet degradation, improving transport rate and minimizing energy consumption in pellet conveying. A screenshot of a typical calculation/simulation software is shown in Figure 6.

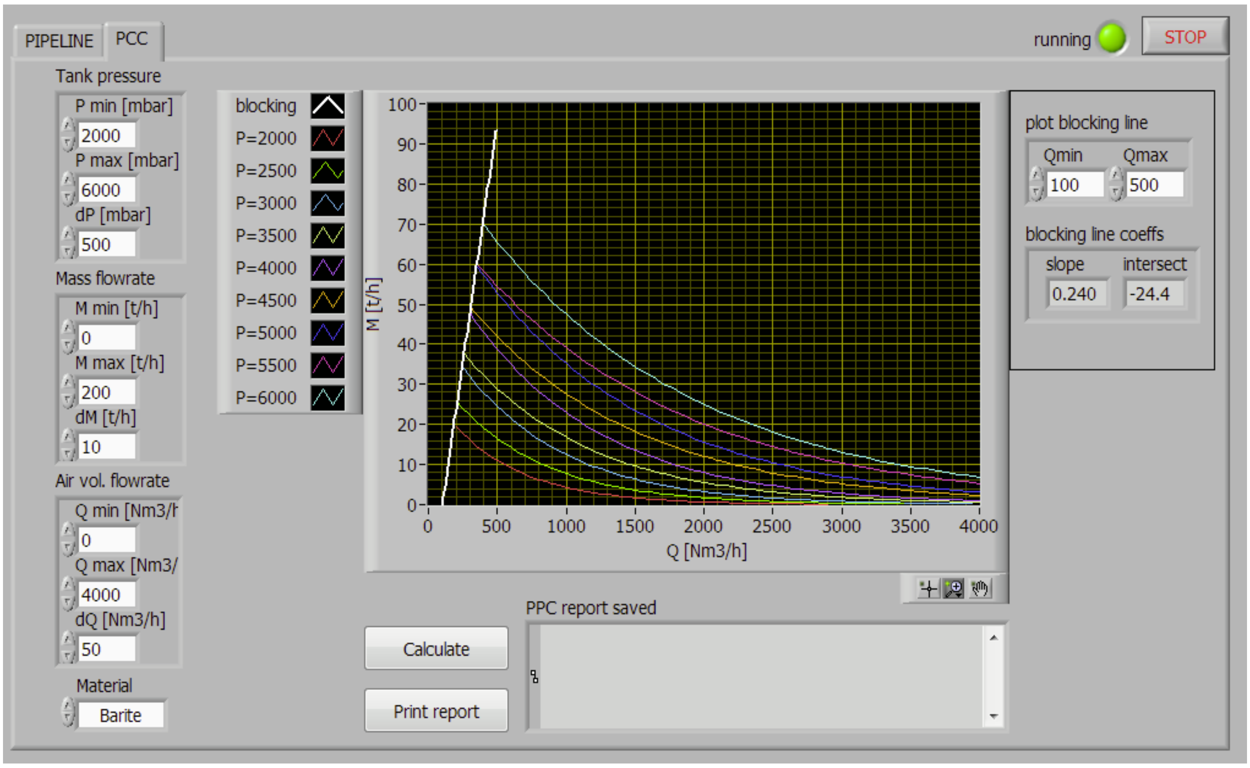


Figure 6: Screenshot of the calculation/simulation software showing the characteristic curves that can be used as a digital twin of an industrial scale conveying rig

The program consists of 3 main parts:

- Input parameters on pressure and volume flow rate of supply air
- Required transport capacity of pellets, and
- Pipeline geometry (diameter, length, bend radii, etc.)

The optimal conveying conditions in terms of air volume flow rate and supply pressure can be determined through an iterative process for a given pipeline configuration.

The test data collected during the present study is incorporated into the simulation/calculation software to optimize the conveying rig in the selected fish farm under Work Package 4. The present approach will be used in recognizing the erosion-vulnerable pipe sections and minimizing the possible erosion due to pellet impact.

The simulation/calculation program can be used as a 'Digital Twin' of the pellet transport system. The approach can further be extended into a sort of feedback controlled conveying system by introducing suitable sensors into the industrial plants.

6 Summary

This report describes some of the results of the pneumatic conveying tests carried out by SINTEF Tel-Tek in a pilot-scale pneumatic conveying test rig with a commercial fish feed and a standard PE pipe. The tests were conducted under a wide range of conveying conditions while collecting data on pressure drop, air volume flow rate and transport capacity. The results show that in the range of conveying air velocities from 15 to 24 m/s the transport rate of pellets varies from 1.5 to 2.2 t/h. The data obtained from the tests will be used to develop a calculation programme that has the potential to be used for optimization of air-based fish feeding systems at fish farms.

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