Development of Test Rig for Acoustic Chemometer

Master of Science Thesis

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Preface

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Master's Thesis in the Master's programmes:
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Abstract

Acosense AB develops and markets the acoustic chemometer Acospector. It uses acoustic techniques and signal processing to measure fluid properties without influencing the system or the fluid. This enables fluid measurements previously considered impossible and can thus improve process control and raise efficiency.

For development and demonstration of the instrument a test rig was needed. The basic idea of the rig was to create a fluid flow with variable properties through a transparent tube. A number of practical limitations also had to be considered since the rig should be used at trade fairs. This report describes how the rig have been developed, manufactured and tested during the spring 2011.

The design was made using Pahl and Beitz systematic design approach. Several practical tests and prototypes have been done during the development. This report describes the different development steps and alternatives that have been evaluated. A background on the technical principles behind the sensor and the different test rig components is also given.

The result from the project is a test rig that uses an ejector to mix water with plastic particles to slurry. The ejector has been designed and manufactured as a part of the project. The particle concentration as well as the fluid flow can be controlled by the user. It is also possible to add air bubbles in the flow by pushing a button. The rig was successfully used during the SPCI trade fair in May 2011 for demonstration purposes. Suggested further developments are to enhance the interaction with the user and to increase the dependability.

Keywords: Acospector, Acosense, Acoustic Chemometer, Ejector, Test Rig.

Nomenclature

Accelerometer Device that measures acceleration. Used as sensor for the AcoSpector instrument to measure vibrations (sound) in the tube wall.

Bar (unit) Pressure unit commonly used in engineering. 1 Bar = 100 kPa.

Black liquor Fluid that is central in the Kraft process at paper mills. Contains dissolved wood compounds. It is considered hard to measure.

Cavitation Formation of gas bubbles in a fluid when the pressure reaches below the vaporization pressure. This is a common problem on the suction side of pumps and may cause damage to the pump.

Dry solids Mass percentage of a fluid that remains after complete drying. Used e.g. for black liquor.

Emulsion Mixture of two fluids not soluble in each other.

GFRP Glass-fibre reinforced plastics.

Plastic granulate Plastic grains which is the common form to deliver thermoplastics to manufacturing plants.

Solution (liquid) A mixture of two or more substances soluble in each other.

SPCI The Swedish Association of Pulp and Paper Engineers. The SPCI fair is the world's largest pulp and paper event and is held every third year in Stockholm.

Static pressure The pressure that can be measured at a certain point in a fluid.

Suspension A mixture of solid particles and a liquid that is not soluble in each other.

Notations

A Area $[m^2]$

Vmin Minimum velocity $[m/s]$

Q Flow rate $[l/min]$

Qmin Minimum flow rate $[l/min]$

Contents

1 Introduction

Acospector is a noninvasive multi-analysis instrument that can measure several properties in complex fluids simultaneously using acoustic chemometry. The instrument is mounted on the outside of an existing pipe and uses sound and multivariate analysis to predict the properties of the fluid inside the pipe.

This report documents the project of developing a test and demonstration rig for the instrument on behalf of Acosense, the company behind the instrument. All steps from concept design to a fully functional rig that allows trade fair visitors to change a fluid's properties and see how the instrument reacts correspondingly is covered in the report.

1.1 Background

Acoustic chemometric techniques were first used in the late 1980's. Among the first applications were measurements of oil and de-icing fluids in Norway [1]. The technique for measurements on de-icing fluids is still marketed by the Norwegian company Sensorteknikk. [2]

In 1990, Wade presented the article: “Acoustic Emission: Is Industry Listening?” in Chemometrics and Intelligent Laboratory Systems [3]. This was probably one of the first academic works on the subject, and addressed issues that are still important when applying the technology. [1]

Backa, Liljenberg, Åbom and Thegel at ABB developed the technology for active acoustic spectroscopy and patented it in 2002 [4]. The main difference between this solution and the previous ones is that it is active. This means that a sound is emitted into the fluid instead of just "listening" to sound generated by the fluid flow. The acoustic source is controllable which gives more possibilities in the signal processing. The use of a controllable acoustic source also makes it easier to distinguish signal and noise in the measured data. In passive acoustic spectroscopy this may be a problem, since other parts of the process that causes vibrations, e.g. pumps, may disturb the measurement. The active technique is not as sensitive to these disturbances, since the controllable acoustic source enhances filtering of the measurement data.

The technology used at Acosense today is a further development of the patent by Backa et al.[4]. They use a controllable acoustic source and two acoustic sensors, and have developed a unit that handles the measurement data and signal processing.

1.2 Purpose

The purpose of the project is to build a test rig that can emphasize Acosense' Acospector abilities to potential buyers at exhibitions and can be used for development of the instrument. The rig should achieve a fluid flow through a pipe with an attached instrument; this pipe is referred to as "measuring tube" in the report. Since the instrument is very versatile and can measure a wide range of parameters, the rig should emphasize this. The rig should therefore let the user change the properties of a fluid flow. These properties can then be measured.

The test rig will be an important part in the promotion of the product, and should therefore give a trustworthy impression in its design and follow Acosense' graphical profile.

The goal is to have a working test rig that can demonstrate the instrument at the SPCI trade fair in May 2011.

1.3 Delimitations

To develop the instrument is not within the scope of this project. The measurement technology should neither be thoroughly described in the report.

The service life will not be considered since the rig should only be used for shorter demonstrations and tests and not in continuous operation 24/7. The reliability of operation is however important since failures must not occur at exhibitions.

The budget for the project is limited both in money and man-hours.

2 Theory

This chapter presents a technical background for the acoustic chemometer and different components that have been considered for the test rig.

2.1 Acospector

The Acospector consists of four different parts. These are:

- Vibration emitter
- Two accelerometers
- Signal converter
- Data analyser with human-machine interface

The vibration emitter is attached on one side of a pipe and the accelerometers are attached on the opposite side. Other configurations of transmitters and accelerometers are possible depending on the fluid. At the time being the second accelerometer is not used except to collect research data for future improvements of the product. The accelerometers are glued onto the pipe and the vibration transmitter is fixed with a clamp. This makes it possible to use the instrument for almost any tube material. The signal converter can be placed anywhere within 10 meters from the measuring position. The signal converter is connected to the data analyser which converts the measured acoustic data to fluid properties. The data analyser is basically an embedded computer with a human-machine interface to present the measured data. It can also communicate with a control system through a network connection. A basic sketch of the setup is shown in *Figure 2.1.* [5]

The transmitter emits white sound in the range between 0-50 kHz which propagates through the contents of the pipe. Some of the energy is absorbed and some scattered by the fluid and potential particles due to a range of acoustic mechanisms. The measured signals from the accelerometers can be correlated to different fluid properties. These may be particle size, concentration, flow rate, dry solids etc. [6]

The correlations are found by transformation of the signal to the frequency domain and the use of multivariate analysis. Calibration data needs to be collected for a period of time before the instrument can be calibrated and used. This means that the instrument is installed at the site and used to collect data. Samples are then taken for lab tests. The measured values from the lab and the time stamps from the sample collection can then be used to calibrate the instrument. [5]

The signal processing unit has a built-in web server which makes it possible to monitor the measurements from any computer connected to the same network as the measurement device. It is also equipped with outputs that can be programmed to control other equipment such as valves and pumps. A product specification for the Acospector can be found in *Appendix A*. [5]

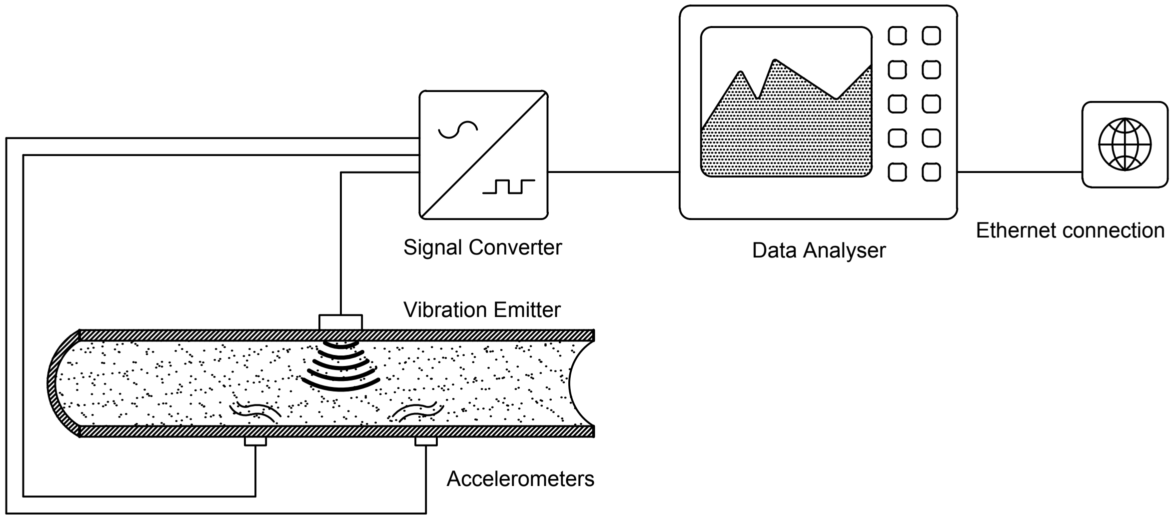


Figure 2.1: *A basic sketch of the Acospector setup. There are two accelerometers under the pipe, one vibration emitter on top of it, a signal converter and a data analyser.*

Readers interested to know more about the theory behind the instrument is referred to "Chemometric and signal processing methods for real time monitoring and modelling using acoustic sensors" [1] and "Analys av Svartlut med Aktiv Akustisk Spektometri" (Swedish) [6].

2.1.1 Acospector and Sustainable Development

One of the worst things to handle for a control system is slow measurements (lag). This makes it very hard to optimize the system performance and creates a need for big safety margins. [7] An example of this is the handling of black liquor that is a rest product from paper pulp production. The black liquor is burned in a recovery boiler which recovers the chemicals and generates steam for the process. The higher dry solids level of the black liquor, the higher efficiency in the combustion [8]. A problem is however that a too high dry solids level will cause problems in the process. In combination with the slow measurement methods, this implies that big safety margins are needed which means waste. According to Acosense the efficiency of a recovery boiler (used in pulping) can be increased by 1-5% with better measurement and control. [9]

The aim with the Acospector instrument is to use it for hard-to-measure liquids. In some cases (e.g. black liquor measurements in the paper pulp industry) there are no previous methods to do the measurements apart from lab tests. Then the instrument can enable the use of a control system, which results in a more stable process and reduced waste. In the example with black liquor, the lag in the measurements can be lowered, which enables reduced safety margins and losses. [10]

This kind of measurement possibility can be an important part in the sustainable development. Processes can be optimized, which may for instance save energy and reduce emissions. This is important in the environmental perspective. Sustainable development includes economic and social sustainability as well. In-line process measurements can contribute also in these areas e.g. by reducing costs and minimizing the risks linked to manual sample collection in harsh environments.

2.2 Pump types

Most pumps can be classified into one of two main classes; velocity pumps or volumetric displacement pumps. A bit generalized it can be said that velocity pumps give relatively high flow at low pressure while displacement pumps give low flow at high pressure. Higher viscosity requires higher pressure to keep the same flow. Thus is the viscosity of the fluid often an important factor in the selection of pump type.[11]

2.2.1 Velocity pumps

Velocity pumps add kinetic energy to the fluid by the use of an impeller rotating at high speed. One of the most common pump types is the centrifugal pump, where the fluid enters the pump housing near the center of an impeller, which throws the fluid outwards. A typical centrifugal pump is shown in *Figure 2.2*. These pumps are widely used since they are simple and operate quiet. They do not require inlet and outlet valves, which makes them robust and inexpensive. Typical uses for centrifugal pumps are circulation pumps in heating systems and water pumps for irrigation. Unlike displacement pumps, velocity pumps can generally operate against a closed outlet valve without failure. A drawback is that the suction will easily be broken by cavitation when a liquid contains vapor. Thus, they are not well suited for operation with negative pressure on the inlet side. A way to overcome this is to add an ejector, either in the end of the suction line or inside the pump. The working principle of an ejector is further described in *Section 2.2.3* below. [11]

Generally, centrifugal pumps are made only for pumping pure liquids. Since the clearances inside the pump are small, contaminated liquids may cause clogging [12]. There are however centrifugal pumps that can be used to pump fluid containing solid particles. One example of this is drain pumps used e.g. at construction sites. These have an open pump wheel (impeller), and can thus handle rather big particles without failure [13]. Different impeller designs are shown in *Figure 2.3*.

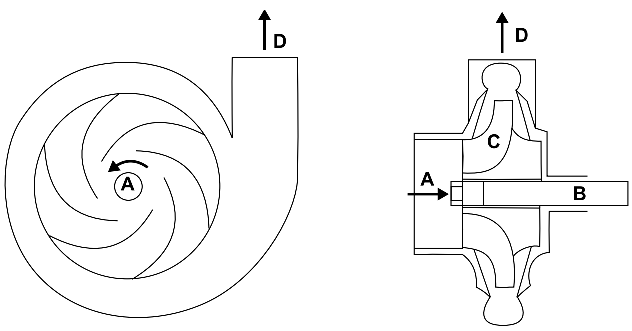
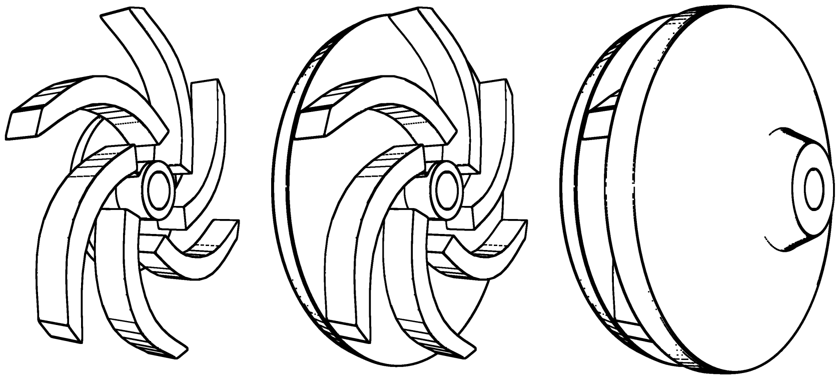


Figure 2.2: *(A) inlet, (B) motor shaft , (C) impeller, (D) outlet. When the impeller rotates it throws the fluid outwards and through the outlet. This causes a underpressure at the inlet and new fluid is sucked into the chamber.*



(a) *Open impeller* **(b)** *Semi-open impeller* **(c)** *Closed impeller*

Figure 2.3: *Principle sketch of impeller variants. The closed impeller is highly efficient in moving fluids, but can not handle fluids containing solid particles. The open impeller can on the other hand handle fluids containing solid particles, but is not as efficient in moving fluids. The semi-open impeller lies somewhere in between in performance.*

2.2.2 Displacement pumps

Characterizing for displacement pumps is that they pump a certain amount of fluid for each stroke or revolution. They can be further divided into reciprocating and rotary pumps. Examples of reciprocating pumps are piston and diaphragm pumps. These have the advantage that they pump the same volume independent of pressure, viscosity etc. The flow is generally pulsating or fluctuating, since the pumps build upon a reciprocating movement. [11]

Piston pumps have a piston that pumps the fluid. Check valves are mounted on the in- and outlet to control the flow direction.[11]

Diaphragm pumps have a flexible membrane instead of a piston. The motor gives the membrane a pulsating movement that pumps the fluid. As piston pumps, they have check valves to control the in- and outlet. These pumps can be used for corrosive fluids or fluids containing solid particles, since the liquid is never in contact with any sealing surfaces. They can also be run dry for a relatively long time without failure. [11] In *Figure 2.4* the conceptual function of a diaphragm pump is described.

A peristaltic pump is a rotary displacement pump, and the most common type of peristaltic pumps is the hose pump[14, p. 85]. A hose is placed inside a circular pump housing. A rotor with rollers or sliding shoes is then used to compress the hose in a rotating movement. As the roller compresses the hose, an enclosed pumping chamber is formed. The rotating movement forces the medium towards the outlet port. As the hose expands when the roller has passed, a suction is formed that move new medium into the hose. *Figure 2.5* shows the principle of a hose pump. The only part of the pump that is in contact with the medium is the hose, which makes it easy to choose a material that is suited for

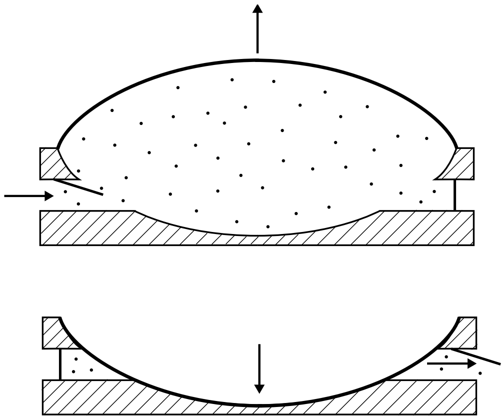


Figure 2.4: *Conceptual function of a diaphragm pump. In the top image the membrane is filled with a fluid from the inlet to the left. In the second image the water in the membrane is pressed out through the outlet to the right.*

the medium in question. These pumps can be used to pump aggressive, abrasive or sterile media. The peristaltic pumps can also handle solid-laden media. The disadvantages with these pumps are their low efficiency and the non-uniform (pulsating) flow. [15]

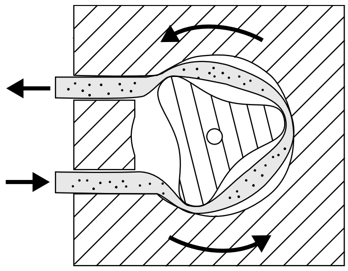


Figure 2.5: *Conceptual function of a hose pump. The rotor compresses the hose in a rotating movement that forces the fluid to the outlet.*

2.2.3 Ejector pumps

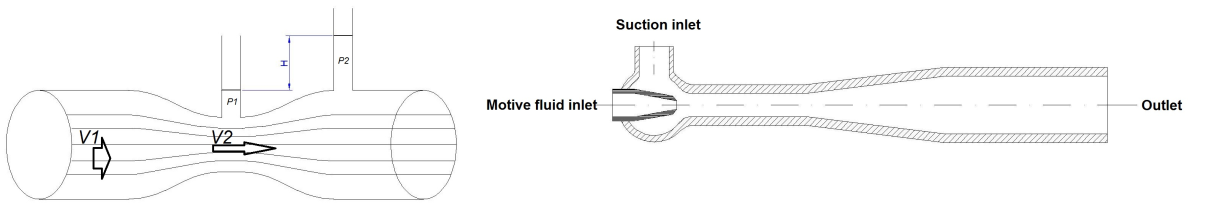
An ejector pump uses the Venturi principle named after the Italian physicist Giovanni Battista Venturi (1746-1822) [16].

It can be used to pump liquids, gases or grains of solids without any moving mechanical parts. The driving energy comes from another flow, which can be a liquid or gas. This is called the *motive medium.* As can be seen in *Table 2.1* there are different combinations of pumped and motive medium. Each combination has its own name according to DIN 24290. [14, p. 92]

The Venturi principle builds upon the law of concentration of mass. It is often demonstrated using a so-called Venturi tube, see *Figure 2.6a.* When a fluid flow is forced through a narrow section in a tube the speed increases. To satisfy the conservation of energy, the static pressure decreases. Thus a pressure difference results between the narrow and wide part of the tube. This is used in a wide variety of applications, from carburetors in gasoline engines to flow meters in the process industry. [18] *Figure 2.6b* shows how a simple ejector pump is designed.

Table 2.1: *Ejector pump naming convention. [17]*

Suction medium \ Driving medium		Gas jet pump	Steam jet pump	Liquid jet pump
Jet gas pump	Jet ventilator	Gas jet ventilator	Steam jet ventilator	Liquid jet ventilator
	Jet compressor	Gas jet compressor	Steam jet compressor	Liquid jet compressor
	Jet vacuum pump	Gas jet vacuum pump	Steam jet vacuum pump	Liquid jet vacuum pump
Jet liquid pump		Gas jet liquid pump	Steam jet liquid pumps	Liquid jet liquid pump
Jet solid pump		Gas jet solid pump	Steam jet solid pump	Liquid jet solid pump



(a) *Venturi tube* **(b)** *Venturi pump*

Figure 2.6: *Venturi tube and venturi pump (ejector pump). When the fluid is forced through a narrow pipe it increases its speed, and the pressure is reduced. This underpressure is utilized in an ejector pump to drag along a suction medium.*

The pressure decrease generates a suction flow which can be used to pump a medium. A high flow rate can be pumped at a relatively low pressure by using a motive fluid with higher pressure and lower flow rate. [14, p. 93-94]

These pumps are preferably used for applications where a mixture of the two mediums is wanted. They can for example be used to mix a fluid or gas with additives. The additives could also be in another phase than the motive medium. [14, p. 93-94]

The main advantage with these pumps is that they have no moving parts. This makes them very robust. Thus they can be used to pump e.g. slurries with wearing particles. A drawback is that the efficiency is rather low compared to other alternatives if mixing of the mediums are not needed. [14, p. 93-94]

2.3 Valves and Valve Actuator types

There are four main reasons to use valves in a fluid system; to keep a constant flow direction, to stop flow, to control flow rate, or to control flow direction. Depending on what function is needed from the valve there are a number of valve types to choose from. The interested reader can find more information on basic valve types on the Valve Manufacturers Association of America website [19].

2.3.1 Valve Actuators

There are some common actuation methods to control a valve available. The simplest method is manual valves which are regulated by turning knobs using manpower. These can however be rather unpractical when the valves are very large, placed in hostile environment, fast operation is required or automated regulation is desired.[20]

When an automatic or remote controlled valve is desired there are three main actuator types to choose from, hydraulic/pneumatic, electric motor or solenoid.

Hydraulic/Pneumatic valve actuators use fluid or air pressure to provide thrust to a piston that closes the gate in a gate valve. The thrust could also be converted to mechanical rotation to operate on rotational powered valves such as ball or butterfly valves. The valves usually contain few mechanical parts and can be designed such that they are normally open/closed and thereby open/close under emergency circumstances.[20]

The torque from an electric motor is used to operate multi-turn valves such as gate and globe valves, or together with a gear box operate quarter-turn valves such as ball-valves. [19] The running time, i.e. the time to go from totally open to totally closed and vice versa, is commonly 15 seconds or more [21]. This makes them unsuitable for processes where fast flow regulation is required.

Solenoid valves use the thrust from electromagnets to move a piston which in turn open/close the flow passage. With no current through the solenoid, the valve can either be normally open or normally closed depending on construction. They are commonly used for small flows and when fast operation is needed. Most solenoid valves are however sensitive to contamination, and are therefore not suitable for fluids containing particles. The solenoid valve will also consume energy as long as it is in operation which can be a drawback in applications where the valve should be activated for long periods of time. [22, 23]

Solenoid valves can also be divided into direct-acting and servo-operated. The solenoid in a servo-operated valve only controls a pilot system that uses the fluid or gas pressure to open the valve. Thus it needs a certain pressure difference over the valve in order to operate. In applications where this is not possible, e.g. vacuum systems, direct acting valves can be used instead. [24]

2.3.2 Mixing Valve

A mixing valve is used to combine two flows, e. g. with different temperature, to one flow. The most common example is water taps where the hot and cold water is delivered in separate tubes and the output temperature can be controlled. Another application is to control the temperature in heating systems, where the heat source has a constant working temperature while the temperature in the system should be controllable. A manufacturer of such valves is ESBE. Their valves build upon a rather simple principle described in *Figure 2.7*. They can also be used for diverting, which is the case shown in the figure.

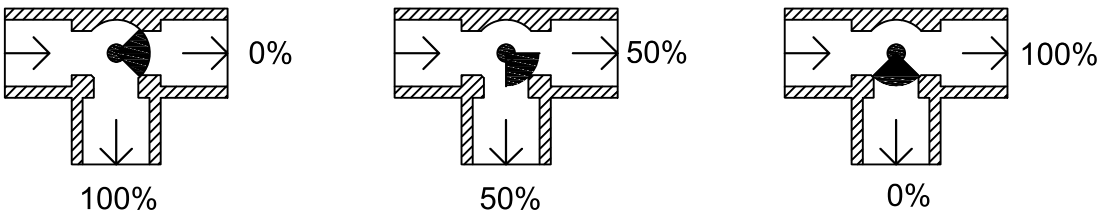


Figure 2.7: *Mixing valve used for diverting.*

2.4 Fluids - general

A fluid is a material in liquid- or gas-phase. By definition it deform continuously when subjected to stress. The continuous movement of the material is denoted flow, which is a characteristic property of fluids. Another important property is the viscosity, which is the resistance to change in shape, or the "internal friction" in the fluid. [25, 26]

It is a well-known fact that a fluid can be blended with other liquid or solid matter. The resulting mixture can be homogenous; containing only one phase, or heterogeneous; containing more than one phase. Three basic types of mixtures are described below: [27]

- Solution: A homogenous mixture between two or more substances. The substances cannot be distinguished. Example: Salt in water.
- Suspension: A heterogeneous mixture of solid particles in a liquid. The two substances can be distinguished (at least under a microscope), and will settle if left undisturbed. Example: Sand in water.
- Emulsion: A heterogeneous mixture of two unblendable substances. One of the substances is dispersed as droplets in the other. Emulsions are unstable and will not sustain if left undisturbed, but adding of e.g. emulsifiers can make them fairly stable. Example: Oil in water.

3 Systematic Design

Pahl et al. describes a systematic way to work with development projects in their book Engineering Design: A Systematic Approach [28]. Some of their methods and principles were adopted in the development process of the test rig. A brief summary of the most important parts are given in the following chapter.

3.1 Development Process

The development process can be divided into a number of steps as shown in *Figure 3.1.*The main purposes of a systematic development work are:

- Optimisation of principle
- Optimisation of layout
- Optimisation of production

Figure 3.1 shows how these purposes are fulfilled in sequence but with a certain overlap. In that way the development work can be focused on the most important purpose for the moment. The process is also divided in a number of main phases. In practice it is not suitable to draw sharp borderlines between the phases. For example some embodiment may be needed when the concept is elaborated. Rework of a preceding step may also be needed. The division into different phases is however helpful for a structured process.

3.1.1 Task clarification

When the product development is started, the first step is to clarify the details of the task. This is important in order to find and quantify constraints and requirements for the product. The result from the task clarification is a design specification that can be continuously updated and used during the development project. The specification is basically a list of all known requirements on the finished product. It is also common that wishes are included in the list which, in contrast to requirements, does not necessarily have to be fulfilled. The requirements are used for selection, to eliminate solutions that do not fulfill them. Wishes are instead used for evaluation, which is used to distinguish solutions that already fulfill the demands. The requirements can be further divided into:

- **Qualitative** – Requirements describing special properties, such as waterproof, corrosion resistant or ergonomic.
- **Quantitative** – Requirements described by numbers, such as power rating, length or flow rate.

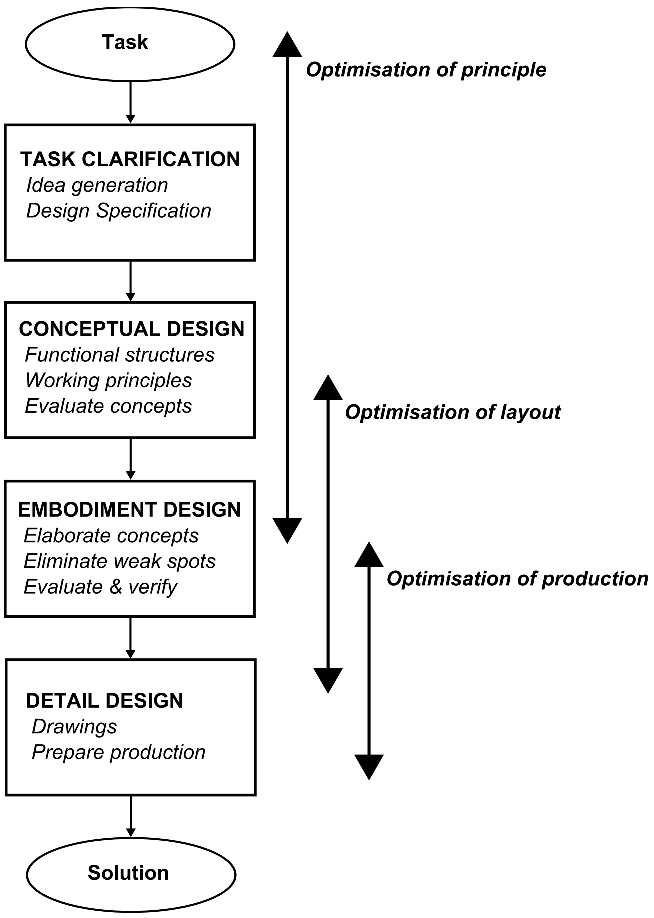


Figure 3.1: *Product development process. Different purposes are fulfilled during different phases in the process. (After Pahl et al. [28])*

If possible the requirements should be quantified. They should also be written as clearly as possible to avoid misinterpretation. For example it is preferable to require a maximum weight instead of a "light" product.

3.1.2 Conceptual design

When the task is clarified, the next step is to find a principal solution or concept that fulfills the specification. This is achieved by finding working principles which can be combined into a working structure. This work often includes much concretization since material selection, preliminary drawings and technical details often needs to be evaluated in order to find a working concept. Sometimes several concepts will be generated and delivered to the next step in the process.

A function structure is developed by defining the main functions of the product. It can then be broken down into subfunctions. The function structure should describe the function of the product in a solution-independent way. The main reason is that the problem should be solved without any other input than the desirable function. As an example, the task should not be to develop a pump; it should be to develop a way to transfer a liquid from A to B. This is referred to as "finding the crux of the task". [28, p. 161-164]

Morphological matrix The overall solution is determined by combining the working principles into a working structure (synthesis). A systematic way to represent the different combinations of solutions is a morphological matrix.

A morphological matrix is done by inserting the different subfunctions as rows in a matrix. Solutions for each subfunction are then inserted in the respective row. The morphological matrix will represent all possible solution combinations for the product. Each combination of solutions to subfunctions is referred to as a working structure, and each working structure should be a possible solution to achieve the main function.

When using combinatorial methods it is important to keep in mind that all combinations may not be good solutions. The geometrical and technical compatibility have to be settled by the designer. The favorable solutions are only a small portion of the theoretically possible combinations.

The conceptual design can be represented in many different ways, mainly depending on the type of product. If the concept is a combination of standard components or building blocks, a block diagram may be sufficient, while a drawing may be needed if the concept is based on a completely new idea.

The conceptual design phase decides the principles of the final product without concerning technical details. Thus it is a very important step in the process, since it has a very big impact on the final product. If the working principles of the concept are not good enough, the embodiment design of the product will be hard or even impossible to perform.

The final part of the conceptual design is to evaluate the different concepts. This is done by eliminating the concepts that does not fulfill all requirements in the design specification. The wishes in the specification can also be useful in the selection of the most promising concepts. A decision matrix can be used to facilitate this process. It is used in order to put up criteria which can be evaluated for each concept. By adding weights to the different criteria, a grading can be achieved in a systematic fashion. There may be several concepts that seem equally good. The final decision can then often be facilitated after some more concretization in the embodiment design phase.

3.1.3 Embodiment design

The embodiment design should take the project from a concept to a layout. A detailed design that fulfills the technical and economical criteria should be achieved by developing the principles further. The different concepts are elaborated and compared at a higher level. In that way weak spots can be eliminated and a winning layout can be selected. This definitive layout can then be used to assess different properties and verify that the product can fulfill the requirements. The reader interested in a thorough description of the embodiment design phase is referred to chapter 7 in Pahl et al. [28]

3.1.4 Detail design

In the detail design phase, all details of the product should be specified and it should be prepared for production. All dimensions, tolerances and surface properties have to be decided. The materials and production processes is to be selected. Final drawings and other production documentation should also be made. Of course changes may be done to the concept in order to enhance production or minimize costs. Corrections needed in the design may also be found when the details are further processed. Thus improvements and rework of the preceding steps are often needed. After the detail design is finished, the product should be ready for production.

4 Product Specification

The first step in this project was to discuss what the purpose of the test rig were, and what expectations and requirements Acosense had on it. This was done in a meeting with the CEO David Brohall where he described his thoughts about the rig.

4.1 Task clarification

From the discussion with Acosense a problem description that defined the project were made. Since the discussion mainly treated solutions to different problems, a conversion to a problem oriented specification was conducted. This is an important step in understanding the problem, since focusing on solutions too early in the process may lead to missed opportunities [28, p. 161-164].

A product design specification was written that listed and quantified the requirements on the rig. A list of desirable properties (wishes) was also done to describe features of the product that should not necessarily be fulfilled, but that might be useful as decision basis when two solutions stand against each other. These specifications were discussed and agreed upon with Acosense.

When the requirements were settled the problem were divided into two partial problems. The first was to find a fluid and a system to handle it and the second was to develop a suitable body for the test rig. The fluid part was mainly about finding technical solutions, while the body included more of design and aesthetical issues. Both were considered important by Acosense, since the rig would be an essential part of a customer's first impression of them at trade fairs.

4.2 Requirements and wishes

The following requirements for the product were decided:

- The rig must be small enough to be fitted on a standard EURO pallet (80 x 120 cm), so that it can be easily shipped to trade fairs.
- The rig should be movable with a hand pallet truck.
- The rig should be able to vary some property of the fluid when the user gives a signal.
- The fluid characteristic should change notably in 10 s from the signal.
- The fluid that is used may not be caustic or emit hazardous vapor, since unsupervised trade fair visitors will handle the demonstration rig.
- The fluid should be based on water or other easily accessed and discarded fluid to ease the handling during exhibitions.

- The rig must be reliable and work without any maintenance during a full trade fair day, and require maximum 15 min of maintenance before/after each trade fair day.
- Energy supply 230 V, 10 A, 1-ph.
- One should be able to keep a dialogue while operating the rig without raising the voice.

A number of wishes were also stated:

- Aesthetics – good design that fits into the showcase at trade fairs.
- Visually clear system that makes it simple to follow the process.
- Spillage container that holds the fluid in case of a leakage.
- Simple preparation for shipping.
- The fluid characteristic should change notably in 5 s from the signal.

5 Conceptual Design

To find a good concept for the test rig there was a natural order in which the different parts and functions should be evaluated. It started with the selection of fluid and after that the fluid system could be designed. In parallel with this the concept for the test rig body were elaborated as an own subfunction. Together this resulted in a concept that could be delivered to the embodiment and detail design phases.

5.1 Fluid system

The aim with the fluid system is to achieve a flow through a pipe where the measurement device can be placed. This pipe is called the measuring tube, and should be made of transparent material to make it possible for the user to see the fluid that is measured. The properties that are measured should also be possible to change, and it should be easy to see the difference in the measuring tube. This change is the main challenge for the fluid system.

5.1.1 Selection of fluid for the rig

The decision that has largest impact on the fluid system is which fluid that should be used in the test rig. In the conceptual design phase, three main alternative fluids were discussed. The three alternatives are of different blending types (see *Section 2.4*). The different available alternatives and their performance in different aspects are summarized in *Table 5.1.*

Table 5.1: *Decision matrix Alternative 1: Two different fluids, Alternative 2: Particles in water, Alternative 3: Oil and water.*

Evaluation criterion	Weight	Ideal		Alt. 1		Alt. 2		Alt. 3	
		Grade	Sum	Grade	Sum	Grade	Sum	Grade	Sum
Easily accessible fluid	5	5	25	4	20	5	25	4	20
Easily discarded fluid	5	5	25	5	25	5	25	1	5
Wide measuring range	3	5	15	4	12	3	9	3	9
Low maintenance	4	5	20	4	16	4	16	4	16
Visual feedback	4	5	20	5	20	4	16	4	16
Multiple measurable parameters	2	5	10	1	2	4	8	4	8
Simple system	4	5	20	2	8	4	16	4	16
Total			135		103		115		90
Total / Tmax			1.0		0.76		0.85		0.67

Alternative 1: Two different solutions kept in separate tanks Two different liquids can be used together with valves to control which of them that is pumped through the measuring tube for the moment. The advantage with this is that a big difference

can be achieved between the two fluids. A drawback is that some amount of the fluids will always stay in the tube while changing from one liquid to the other, which leads to a mixing of the liquids. The control system will also be somewhat more complicated compared to the other cases described below.

Alternative 2: Suspension of particles in water By adding and separating particles, a variation of fluid properties can be achieved. The concentration of particles can be measured by the instrument. To separate the particles from the fluid, a weir plate can be used in the tank. The particles will then accumulate at one side of the plate and pure water on the other; given the particles has higher density than the water. The fluid can be emptied from the tank while the particles are kept when shipping the unit. Another advantage is that fluids containing particles are generally hard to measure using conventional instruments (e.g. flow meters). This makes it especially interesting from a demonstration perspective; it shows one of the instrument's competitive advantages. A drawback is that the particles demand more robust pumps and valves. There are components suited for this kind of applications, but they are generally bulky and more expensive than types for pure fluids.

Alternative 3: Emulsion of oil in water Tests were made in an early stage of the project with cooking oil and water. It was concluded that they could be mixed to a rather homogenous blending, and separated sufficiently fast. This could be used to pump three different phases through the measuring tube: water, blending or oil. The visual effect could also be good, since there are coloring agents that affect water but not oil. The fluid system used can be rather simple since this fluid can easily be pumped. A disadvantage is that oil cannot be emptied into the drain system; not even cooking oil [29]. This makes it less simple to empty the rig and prepare it for shipping.

Selected alternative After evaluation of these three concepts it was decided to use particles in water. The reason was mainly that a two-phase system was preferable as measuring object and that the emulsion did not satisfy the requirement of easily discarded fluid. The particles-in-water solution could also be achieved with a rather simple system compared to the two-fluid solution. The next step of the conceptual design was to find suitable particles and systems to handle the particle suspension.

5.1.2 Selection of particles

To be suitable for use in the test rig, there were a number of desirable properties for the particles:

- Density close to water to easily be transported in the fluid, but sufficiently different in order to be easily separated e.g. by sedimentation.
- Sufficient size to be easy to see when it passes the measuring tube and easy to filter out from the fluid when needed.

- Non-wearing in order not to scratch the inside of the transparent measuring tube.
- Easily accessible to a low price.

In order to fulfil the density and non-wearing criteria, plastics is the natural choice. Since sedimentation seemed to be an easy way to separate the particles from the fluid, a plastic material with somewhat higher density than water was desirable. Thermoplastics as raw material for the manufacturing industry are delivered as granulate (approximately 5 mm in diameter). Since this is a large volume product with minimal processing, it is probably the most inexpensive plastic particles. After a sedimentation test it was decided to use PVC granulate with a density of 1.4 kg/l in the test rig.

5.1.3 Selection of pump system

The selection of pump system was started by browsing the market for handling of solid-laden fluids. Many solutions exist, but most of them are larger in scale than needed in this case. For instance there are large pumps for pumping wastewater which can handle solid particles without problems. The flow rate in the system is determined by the needed speed in the tubes to make sure the particles will not stop. The needed flow were estimated to 30-50 liters/minute. After contact with suppliers of different product types, three different concepts were designed. These are further described below. A strength diagram that summarizes the three alternatives can be found in *Table 5.2*.

Table 5.2: *Decision matrix. Alternative 1: Hose pump and centrifugal pump, Alternative 2: Solids handling centrifugal pump, Alternative 3: Ejector and centrifugal pump. Even though there is not a significant winner, the matrix summarizes the properties for the different concepts and is useful as decision basis.*

Evaluation criterion	Weight	Ideal		Alt. 1		Alt. 2		Alt. 3	
		Grade	Sum	Grade	Sum	Grade	Sum	Grade	Sum
Compact	5	5	25	1	5	4	20	3	15
Fluid variation speed	3	5	15	4	12	4	12	4	12
Low noise	4	5	20	4	16	3	12	4	16
Easy-to-understand principle	3	5	15	3	9	4	12	3	9
Usability for tests with other fluids	3	5	15	5	15	3	9	3	9
Max particle concentration	4	5	20	5	20	2	8	3	12
Reliability	5	5	25	4	20	2	10	3	15
Low cost	5	5	25	1	5	3	15	4	20
Total			160		102		98		108
Total / Tmax			1.0		0.64		0.61		0.68

Alternative 1: Hose pump and centrifugal pump A hose pump can be used to pump slurry with high concentration of solid particles. Since these pumps works at

a low rotary speed, a large pump will be needed to achieve the wanted flow rate. A possible solution is to use it in combination with a simple centrifugal pump for pure water. The output from the two pumps is mixed, and by adjusting the flow rate from the two pumps respectively the concentration of solids in the water can be controlled. The main advantage with this design is that a very high concentration of particles can be achieved in the measuring tube. The downside is that two pumps make more noise than one pump.

Alternative 2: Solids handling centrifugal pump Centrifugal pumps with open pump wheels can be used to handle fluids containing solid particles, see *Section 2.2*. The concentration of solids can then be set by a mixing valve at the suction side of the pump. The main advantage with this design is its simplicity. One problem is however to find a mixing valve that can handle solid-laden fluids. A drawback compared to alternative 1 is also that a high concentration of particles cannot be achieved.

Alternative 3: Ejector and centrifugal pump An ejector can be used to mix solids into a fluid. In that way the electric pump will only have to handle pure water. By adjusting which portion of the fluid that should pass the ejector, different concentrations can be achieved. This can be done by using a mixing valve. An advantage is that the only component that will have to handle particles is the ejector. The ejectors for pumping solids are however rather bulky and expensive, since they are made to handle wearing particles as sand or gravel. This solution will neither be able to achieve the high particle concentrations of alternative 1.

Selected Alternative Alternative 3 was selected since it was a relatively compact solution to achieve the main functions. An important factor was also that the number of components (valves, pumps) that needed to handle particles could be kept to a minimum. This was considered important for reliable operation.

5.1.4 Selection of air bubbles system

It was desired that it should be possible to add air in the flow on a signal from the user as a disturbance for the measurement instrument. To make air enter the flow the pressure needs to be lower on the inside of the inlet than on the outside. This can be ensured either by increasing the pressure on the outside of the tube, or by lowering it on the inside.

Alternative 1: Ejector Just as in the case with the particles an ejector can be used to lower the pressure in the tube and in that way create an under-pressure to suck air into the tube. The inlet can be controlled using a solenoid valve.

Alternative 2: Compressor By including a compressor in the rig an over-pressure can be achieved on the inlet to blow air into the tube. The major downside is that compressors usually make a lot of noise when working. There are however compressors available (at a higher price) that operates more quiet and should work for this application.

Alternative 3: Gas tube A gas tube could be mounted on the air inlet and use overpressure to blow air into the system. The downside of this solution is that the gas tube might run out of gas during an exhibition and replacing it is cumbersome.

Selected Alternative Alternative 1 was chosen due to simplicity, low noise and no maintenance.

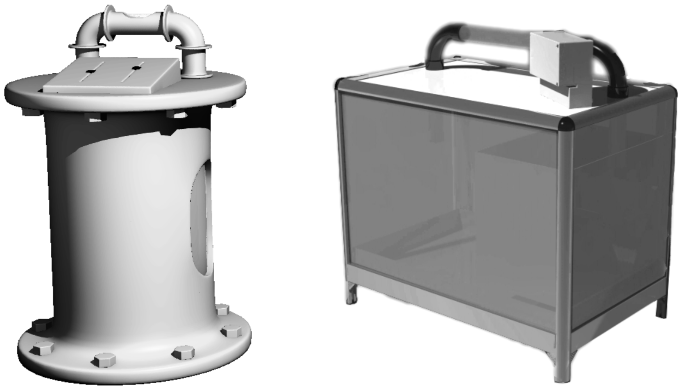
5.2 Selection of materials and shape for the body

The design and aesthetics of the test rig is of great importance since it is meant to attract the interest of potential customers at trade fairs. On the other hand it should not take the attention from the product being promoted. It must also be robust, both to reinforce the feeling that the promoted product is of high quality, and to withstand rough handling during transportation.

Two main concepts were evaluated during the conceptual design. The different alternatives were modeled in 3D to be able to evaluate the design. See *Figure 5.1*. The properties of the respective design are summarized in *Table 5.3*.

Table 5.3: *Morphological matrix with solutions to the subfunctions of the body. Solutions marked with the same symbol is combined to one system. The aluminum body is the one marked with ♣while the "tube" is marked with ♠.*

Function	Solution			
Visualize	Visible tank and measuring pipe ♣♠	Visible measuring pipe	All visible system	
Movable	Hand pallet truck ♣♠	Pivot wheels		
Service access	Door at one side ♣	Openable table top ♠	All sides openable	
Frame	Aluminum T-slot beams, rectangular	Aluminum T-slot beams, rounded ♣	Welded steel beam structure	Free-form GFRP ♠



(a) *"Tube" rig* **(b)** *Aluminum beam rig*

Figure 5.1: *Rig concepts.*

Alternative 1: "The tube" This was a design-oriented solution where the rig should mimic a flanged tube standing on one of the flanges. One way to achieve this should be to make it out of glass-fiber reinforced polyester (the typical material used e.g. for leisure boats and car roof boxes). The "tube" was considered very attractive from a design perspective. It was also the most demanding solution to manufacture. A mold would have to be made, which is very time consuming if a high surface finish of the product should be achieved. A metal frame would also be needed inside the tube to allow mounting of pump and water tank.

Alternative 2: Body of aluminum beams Aluminum beams for this kind of applications are possible to buy cut-to-length and simple to assemble. They are available with sharp edges or with a rounded profile for different applications. The angular design of the aluminum body take better advantage of the given size limits and hence gives more space inside the rig compared to the tube. Another advantage with the aluminum body is the possibility to put text and pictures on the flat surfaces that can simply be changed when needed. The obvious downside is the limited design freedom which affects the possibility to achieve a unique look.

Selected alternative In the end aluminum profiles were chosen thanks to easy assembly. This made it possible to focus on the function of the rig, which was considered to be more important. The aluminum structure is also giving better access to the fluid system and can more easily be rebuilt if needed in the future.

Transparent plastic panels were chosen to be used between the aluminum profiles so that the water tank would be visible from the outside of the rig. To prevent the fluid system from taking the attention from the promoted product a sticker with logotype, information about the product and a "window" for the water tank can be placed on the panel. The information and graphics on the sides can be easily exchanged and adapted for future needs.

6 Embodiment and Detail design

The most promising solutions from the conceptual design phase were concretized and suppliers for the different components were contacted in order to verify that the concept solutions would be possible to manufacture and use. The cost was also evaluated and an approximate budget was written to be used as a decision base. Components were then selected for all different functions and combined according to the selected concept. The detail design was done in parallel since this is a one-of-a-kind product with limited need for detailed production documents.

6.1 Fluid system

The selected concept for the fluid system basically include an ejector, a pump and a couple of valves. This section describes how these components were dimensioned and selected.

6.1.1 Ejector

Different suppliers were contacted in order to find an ejector that could be used to mix the plastic particles into the water flow. It turned out that the ejectors suitable for particles in that size were rather large and made out of steel. Smaller ejectors of brass or plastics were available, but these had a too small mixing tube to be able to handle the particle size in question. The steel ejectors had probably worked well, but became very expensive since a requirement was a corrosion-free system (stainless steel). Thus it was decided to manufacture an own, better suited, ejector. This were considered to be possible since the ejector is working under advantageous conditions in this application; soft particles with low density. The counter-pressure at the ejector outlet is also low.

An ejector design suited for the handling of solid particles was found in Hammoud & Abdel Naby [30]. A simple prototype with similar dimensions was manufactured using standard tube fittings and turned steel components. A photograph of the prototype can be found in *Appendix B*. As the prototype worked quite well, it was decided that an own ejector made out of PVC plastics should be designed and used in the rig. This design was made using standard PVC fittings where suitable. It was decided to use brass for the motive nozzle and PVC for mixing tube and diffuser. Brass was selected for wear resistance in the nozzle, while the other components were made of PVC since it is a cost effective material for larger components. The components were designed to be manufactured by turning. An advantage with the selected materials is that they are corrosion resistant and has good machinability compared to e.g. stainless steel.

By using standard PVC-fittings to a large extent only few components had to be manufactured. In that way cost and time were minimized.

The performance of the ejector is depending on the ratio between inlet and outlet pressure. If the pressure ratio is known, the ratio between the motive and suction flow can be found in tables (for a specific ejector design)[31, 32]. *Table 6.1* show which suction and motive flow that results at a certain in- and outlet pressure for a specific ejector. It was decided that a suction flow equal to the motive flow should be sufficient for the ejector in the rig (based on desirable max. concentration). From *Table 6.1* it can be concluded that an inlet pressure at least 2.5 bar higher than the outlet pressure is needed for a sufficient efficiency in the ejector (See the marked values of the table).

Table 6.1: *Excerpt from performance table for a 1" ejector with no suction height. [31]*

	Motive pressure [bar]	0.7	1.4	2.1	2.8	3.5	4.2
Counterpressure	Fluid Volume[m^3/h]						
0	Suction	1.33	1.83	2.15	2.38	2.63	2.73
	Drive	0.8	1.15	1.4	1.6	1.8	1.97
0.34	Suction		0.3	0.93	1.37	1.82	2.27
	Drive		1.13	1.38	1.58	1.78	1.97
0.69	Suction			0.07	0.52	1.08	1.47
	Drive			1.35	1.57	1.75	1.92
1.03	Suction					0.28	0.77
	Drive					1.75	1.92
1.38	Suction						0.07
	Drive						1.88

6.1.2 Water pump

The pump was dimensioned using a combination of practical tests and calculations. A certain speed is needed in the tubes to avoid sedimentation of the particles. A test showed that no sedimentation occurred in a fluid flow of 25 l/min in a tube with inner diameter 3 8mm. This gives the following speed:

$$Vmin = \frac{Q}{A} = \frac{25/60}{(0.38/2)^2 \times \pi \times 10} = 0.367[m/s] \tag{1}$$

The largest tube diameter in the test rig is the measuring tube with inner diameter 50 mm. To achieve the same speed in this tube the following flow is needed:

$$Qpump = Vmin \times A = 0.367 \times (0.5/2)^2 \times \pi \times 60 \times 10 = 43.2[l/min] \tag{2}$$

The needed pressure in the system is determined by the ejector. The pressure difference over the ejector were approximated to 2.5 bar in *Section 6.1.1.* In the test rig, the pressure drop in the fluid system from the ejector to the tank is low. Thus it was decided that a pump pressure of 3 bar should be sufficient.

Pumps with these properties are commonly used as well pumps and for irrigation purposes. Most common is centrifugal pumps. Where a corrosion-free pump is needed, they are available with a pump housing of stainless steel. Similar pumps were found at a number of suppliers. A data sheet for the pump used in the test rig can be found in *Appendix D.*

6.1.3 Air bubbles

A desirable feature of the rig was the ability to insert air bubbles into the flow as a disturbance for the measurement system. Different methods for this were evaluated during the conceptual design phase, and it was concluded that the simplest way was to use the ejector. As described in *Section 2.2.3* the lowest pressure inside the ejector is found in the mixing tube. By adding an inlet for air in this part of the ejector, it should be possible to insert air bubbles in the flow. A test was done by drilling a hole in the mixing tube of the ejector prototype that was used for the particles. This worked out well; it was possible to insert particles and air using the same ejector. This concept was denoted "double-ejector" in the following work. A drawing of the ejector is found in *Appendix G*.

The insertion of air bubbles should preferably be independent of the particle concentration. Thus it was also needed to insert air bubbles into the water flow that bypasses the ejector when the particle concentration setting is low. This was solved using another ejector on this line with the only purpose to insert air bubbles. In that way approximately the same amount of air bubbles can be achieved regardless the particle concentration.

To control the insertion of air bubbles a solenoid valve was used to open the air suction line to the two ejectors at an electric signal. To make sure that the flow is not reversed at any circumstances, check valves were inserted at the suction inlet of the ejectors. Since the solenoid valve should work with negative pressure, a direct acting valve was selected (See *Section 2.3*).

6.1.4 Valves (Flow and particle control valves)

When valves for controlling the flow rate and the particle concentration in the system should be selected, the main challenges were to find a compact and inexpensive valve type. It should also be possible to control with an electric actuator. Since this system will react immediately upon changes, it was desirable with a fast actuator. This turned out to be hard to find, since this kind of valves are most often used in processes with a large time constant, as for example heating systems. The fastest electric actuator that was found had a running time of 15 seconds. Since the user of the system, e.g. a fair visitor expects a much faster reaction it was decided to use an actuator with manual override. In that way the system can be controlled manually in a fast manner. When the rig is in automatic mode the valve setting will change slower, but that is not considered to be a problem.

The chosen valve type was a mixing valve from ESBE AB that is commonly used for heating systems. It is a simple valve type that has sufficient performance for this application. The system includes two such valves, both connected as diverters. The first is used to set the flow in the system and determines which amount of the flow from the pump that should be put into the system. The second determines which amount of the flow that should be sent through the particle ejector. A description of the technical principle can be found in *Section 2.3*. The valves are equipped with electrical actuators with a running time of 15 seconds that can take common industrial analog signals as input. See *Appendix E and F* for technical details on valves and actuators.

6.1.5 Tube system

The requirements for the tubing in the rig were that it should be corrosion-free and simple to assemble. A common pipe material in the chemical industry is PVC thanks to low cost and good chemical resistance. PVC tubing and fittings are available in different dimensions and pressure classes. The fittings are assembled by gluing. There are also threaded fittings available, which can be used for connection to standard valves, pumps etc. [21]

This material was selected for the rig since it was an easy way to achieve a robust and corrosion-free system. Another advantage was that compatible transparent pipes were available and could be used for the measuring tube.

A combined water- and particle-tank were manufactured of stainless steel. The water and particles are kept separated by a wall inside the tank. A transparent acrylic plate was used as wall on one side of the tank to display the contents of the tank to the rig users. A drawing of the tank can be found in *Appendix H*.

6.2 Body

In the conceptual design phase it was decided to use a body made of aluminum profiles for the rig. A material specification was written for three different suppliers of aluminum profiles. The rounded profiles were approximately 20% more expensive than square profiles, but these profiles were regarded more attractive from a design perspective. Even if the design is not the main function of this product, it is still an important feature. Thus it was decided to use an aluminum body with rounded edges. This solution was modeled in a 3D-CAD software to verify that the parts would fit and that there was enough space for the equipment needed for the fluid system. After that, the necessary changes could be made to the offer from the supplier, and an order was placed.

A spillage container made out of steel was manufactured and placed at the bottom of the body. The container was made large enough to contain all fluid from the tank in case of leakage in the system. A drain was placed at one of the corners to allow easy emptying of the container. A drawing of the spillage container can be found in *Appendix I*.

7 Result

A working test rig that fulfilled the requirements from Acosense was delivered in time for the SPCI fair in May 2011. The final design of the fluid system is shown in *Figure 7.1* and *Figure 7.2* shows the inside of the final rig. Three different parameters of the flow through the measuring tube can be controlled:

- The particle concentration is controlled by the diverter valve that determines which amount of the flow that should be taken from the ejector.
- The flow rate is controlled by the diverter valve that determines the amount of the flow that is returned to the tank.
- Air bubbles are inserted in the flow by pushing a button which activates a solenoid valve that permits air to be sucked into the system by two ejectors.

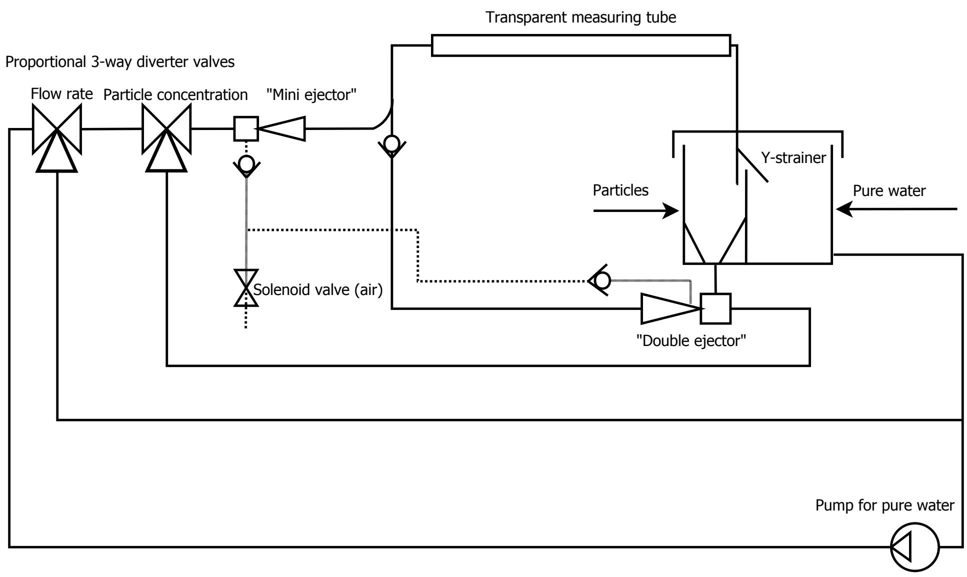


Figure 7.1: *Water is pumped from the tank to a 3-way diverter valve which controls the fluid flow. Some water is by passed back to the tank and some passed on to the next 3-way diverter. From here some water goes to the particle ejector and some through the mini-ejector. If the solenoid valve is open air is added to the fluid in the two ejectors. Next the fluid is mixed and sent through the measuring tube and back to the tank where a Y-strainer separates the particles from the water.*

The appearance of the body for the test rig is shown in *Figure 7.3*. The large, flat surfaces were designed to follow the graphical profile and fit into the showcase. The rig worked very well to demonstrate the instrument during the SPCI fair. The practical handling with transportation, filling and draining was also working well. *Figure 7.4* shows the measuring tube in close-up during operation.

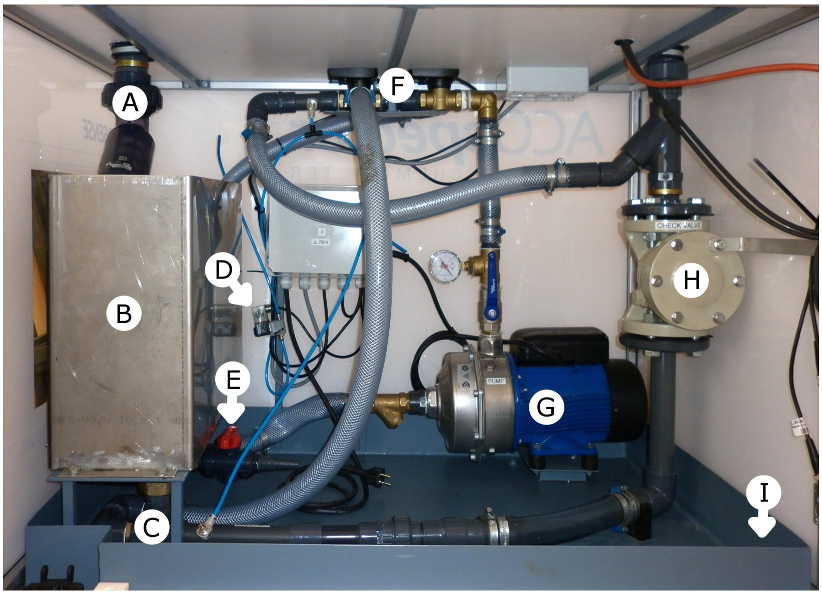
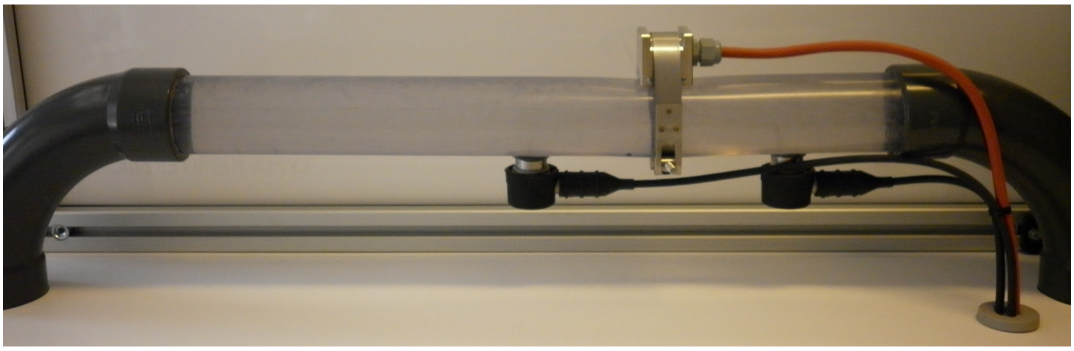
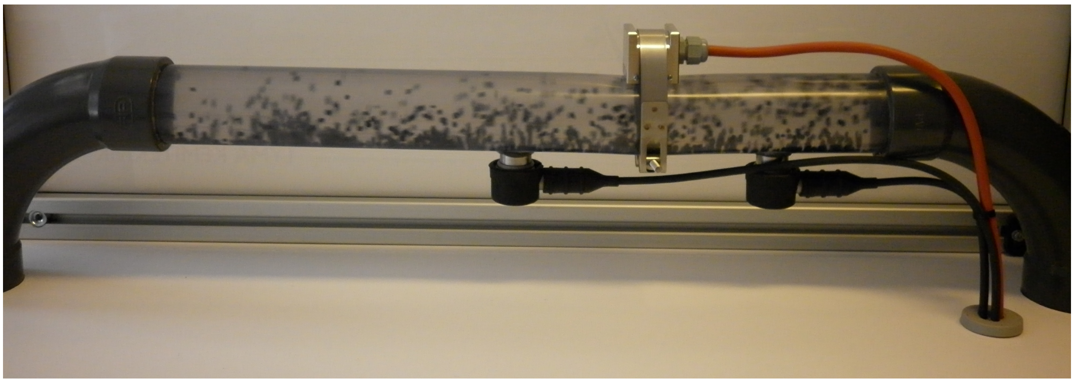


Figure 7.2: *Picture from the inside of the rig. A) Y-strainer for separation of water and particles, B) Tank for water and particles, C) Particle ejector, D) Solenoid valve for air bubbles, E) Emptying valve, F) Concentration and flow diverter valves, G) Pump, H) Check valve, I) Drain (not visible in picture).*

Figure 7.3: *The final rig at the SPCI fair in May 2011. On its short side is the window to the water and particles tank. On the top of the rig are the measuring tube with the sound emitter and accelerometers. The black boxes in front of the tube are the controls for flow rate and particle concentration. To the left of them are the button for air bubbles and a power switch.*



(a) *The measuring tube with the flow set to maximum and particle concentration set to minimum.*



(b) *The measuring tube with the flow set to maximum and particle concentration set to maximum.*

Figure 7.4: *The images above show the measuring tube with minimum and maximum particle concentration.*

8 Discussion

This project has carried through the development of a test rig from concept to product. We have had the opportunity to perform all steps, from idea generation to manufacturing of the actual product. Since we also attended the SPCI fair where the test rig were used for the first time, we could see how the product performed and get feedback from the users.

The rig worked very well to demonstrate the measurement device. The manual override was used to set the flow rate and the particle concentration, and the rig responded accordingly within a second. The air bubbles were a little slower and it took 2-3 seconds from pushing the button until bubbles appeared in the measuring tube. The rig also attracted customers to the stand since the mixed flow of granulate and water made people curious. Sales personnel as well as customers appreciated the rig since it enhanced the understanding of the measuring principles. The design was (according to us, Acosense and the trade fair visitors that commented on it) well suited to the rest of the showcase. The noise generated by the rig was barely notable during the trade fair since it drowned in the buzz from fair visitors.

The transportation and practical handling of the rig was also convenient. Since the outer dimensions and the space between the legs on the rig are similar to a standard EURO pallet it could be moved with a hand pallet truck. The rig was also light enough (approximately 100 kg) to be moved shorter distances by two people. A packaging has been manufactured to protect the rig during transportation (see *Appendix J*). Before running the rig only water and plastic granulate needs to be added. Then it is just to plug it in to a 230V 50Hz wall socket. When preparing the rig for shipment only the ball valve at the bottom of the tank needs to be opened to empty it from water. The particles can stay in the tank during transportation and storage, and be reused the next time the rig is used.

During the trade fair there were some problems with leakages in the fluid system, but thanks to the spillage container in the rig it could be handled. The leakages were repaired rather fast and the "uptime" of the test rig was good during the fair. The main reason for the leakages was the high temperature that emerged in the fluid system after a couple of hours in continuous operation. This is due to the small volume of fluid and the rather high power of the pump. This can probably be solved with a cooling system or by increasing the fluid volume in the tank. It is however not a problem that occurs if the rig is used for 1-2 hours at a time. Thus the importance of these modifications depends strongly on the planned usage of the rig in the future. No other major problems occurred with the rig during the fair.

The day before the SPCI fair began we got hold of some small, green, semitransparent plastic balls that fitted Acosense' color scheme very well. Despite that we had not tried them in the rig before, it was decided to use them together with the black PVC-granulate to get a more eye-catching fluid to measure upon. Unfortunately small parts of the green balls broke off and sealed the pump filter. This meant that we had to stop the rig once every hour to clean the filter instead of once every day as intended with the black granulate. Therefore only black granulate was used the other days at the fair.

A disadvantage with the chosen approach for adding air to the fluid is that it works best when the rig is set to "max flow and no particles" or "max flow and max particles". With these settings all flow is passed through only one air ejector. With other particle settings the flow is split up between the two ejectors which results in a too low flow to get enough suction to open the check valves on the air input. These valves could probably be removed to increase the span for air bubbles in the flow. The reason for not removing them is that an overpressure in the ejector may cause water to go into the solenoid valve and possibly harm it. Another solution to this problem is a single air ejector either before the flow is split up, or after it has been combined again. Both these solutions probably have a negative impact on the system. If the air ejector is placed before the split up, water with air bubbles will be used to drive the particle ejector which will affect the efficiency. If the air ejector is placed after the fluids are combined, water with particles will drive the ejector. This means that the ejector will need to be rather big to avoid particles sealing the ejector inlet. Therefore we think that the current solution is an acceptable compromise.

The systematic design methodology that has been used during the project has sometimes felt like a burden without positive aspects, but in retrospect we think it has been helpful in handling the different solution alternatives in a systematic fashion. Even though decision and morphological matrices probably have been biased by us and did not always have a clear winner, they have been a good support in the decision making to make sure all solutions got well thought-out before they were selected or discarded.

One important lesson learned in this project is the planning for delivery times. At several occasions during the project, the search for the best solution has resulted in late orders to suppliers. This has in turn resulted in waiting for delivery of critical components. This could have been diminished by a more stepwise decision-making process.

Improvements and further development of the rig can preferably be done in the area of interaction and control. The plan was to control the diverter valves with electrical output signals from the Acospector instrument. The version of the instrument that was used during the SPCI fair was a prototype and did not support this functionality, so the manual override of the valves were used instead. By implementing a control system for the valve actuators with connection to the instrument, the rig could be used to test the performance of different controller designs. Some kind of interaction with trade fair visitors could possibly also be achieved, which should be positive in the marketing perspective.

It would of course be interesting to develop possibilities to vary more properties of the fluid. If another property could be controlled, the ability to measure multiple properties with a single instrument could be emphasized.

9 Conclusion

The aim with this project was to build a test rig for a measurement device. The main function was the ability to achieve a fluid flow with variable properties through a tube. This was achieved by the use of an ejector to mix an adjustable amount of plastic particles in water. The flow rate through the tube can also be controlled. A function that makes it possible to add air bubbles in the flow to demonstrate the robustness of the measurement has also been implemented.

The final design fulfills all requirements that were set up at the beginning of the project. It could (of course) have performed better in some aspects. Most important to monitor is the problem with high temperature in continuous operation which increases the risk of leakage in pipe- and hose connections.

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A Acospector Product Sheet

ACO*spector*®
ACOUSTIC CHEMOMETER

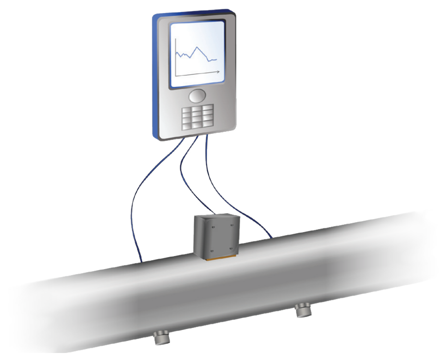
ACOSENSE

INNOVATIVE CLAMP-ON INSTRUMENT

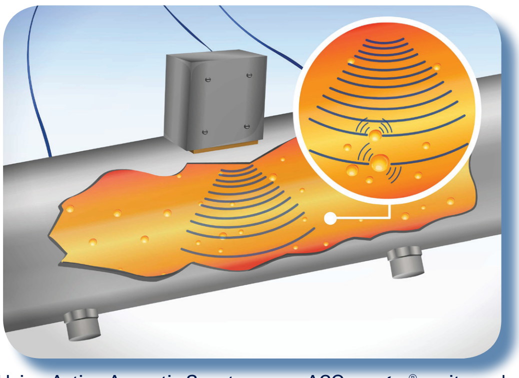
ACO*spector*® is a multi-analysis instrument
The instrument can be used to measure several properties in complex fluids simultaneously.

Difficult Measurements
ACO*spector*® can measure properties in fluids that are otherwise difficult or impossible to measure. Fluids that are corrosive, opaque, have high viscosity or concentration can all be measured in real time with high accuracy.

Suitable for different industries
ACO*spector*® can be used in processing industries such as pulp and paper, petrochemicals, chemical manufacturing, mining and many others.



ACO*spector*® can be installed in full production



Using Active Acoustic Spectroscopy ACO*spector*® emits and controls acoustic signals, for more accurate measurements.

Fast Real-time monitoring
Precise Accurate measurements
Non-invasive Not in contact with fluid
Easy No unnecessary stops in production

Innovation
ACO*spector*® Acoustic Chemometer is based on a patented non-invasive fluid analysis method. Unlike conventional methods, the technology produces accurate measurements also where traditionally seen as difficult or impossible.

Measurement is possible on just about every liquid medium and pipe material.

Viscosity	Concentration
Total Solids	Chemical Components
Density	Particle Size Distribution
Mass Flow	Fibre Length
	etc...

Enhanced product quality - Reduced environmental impact - Waste reduction

Accuracy

Measuring accuracy depends on customer requirements and calibration data. The measuring error is typically 1%.

Viscosity in Colloidal Silica: ±1 cP
Total solids in Black Liquor 1% TS

User friendly and a safer work place

Reducing lab tests and unnecessary stops in production creates a safer work place, as well as optimizing production. Installation is uncomplicated and the measuring procedures are easy and maintenance free.

Efficiency

Measuring is continuous, creating instant analysis which gives reliable data for real-time process control. Measurements can be accessed by the control system, but also by remote users.

Advantages

With no unnecessary stops in production and more reliable measuring results production can be optimized and product quality enhanced. Measurements impossible to obtain by conventional methods are now possible.

ACOSENSE
Gruvgatan 35 A
SE-421 30 Västra Frölunda
SWEDEN
+46 31 763 26 00

info@acosense.com
www.acosense.com

ACO*spector*® can measure in difficult areas on difficult fluids

ACO*spector*® - Specifications

Parameters	Specifications	Comments
Environment		
Pipe diameter	25mm - 1000mm (1"- 40")	Inquire for application sizes outside the range
Distance from signal converter to pipe	< 3 m	
Signal Converter:		
Processor	Intel ATOM N450 1,66GHz	Specifications may vary between different systems. Upgrades are available to fit customer need.
Memory	2GB DDR 667MHz	
Hard Drive	128 GB SSD	
Communication interfaces	PROFIBUS, MODBUS, 4-20 mA, RS-232/485, WLAN, Ethernet, etc	
Power output	< 7 W	
THD	< 0,001 %	
Frequency range	0 - 50 KHz	
Operating temperature range	-30°C to 65°C	Customizing can be made for higher temp ranges
Encapsulation	IP 65	
Size	H260xW180xD130 mm	
AC in	120/240 V 60/50 Hz	
Sensor		
Size	H20 Ø14 mm	
Operating temperature range	-76°C to 250°C	
Attachment	Adhesive	
Signal transmitter		
Operating temp range	-76°C to 250°C	
Size	H57xW37xD37 mm	
Attachment	Clamped on	

ACOSENSE "Fluids talk to us..."

B Prototypes

The final rig was evolved through a number of prototypes. Below is a short summary of their purpose, what parts they consisted of, and what the outcome of the tests on them were.

Prototype 1

Pump: Circulation pump, Grundfos UPS 20-35

Ejector: None

Particles: None

Tank: Half oil drum

Piping: None

The first prototype was merely a circulation pump pumping water from a tank through a hose and back again. The purposes of this prototype were just to familiarize with the concept and get inspiration for further ideas.

Outcome: The biggest outcome of the experiments on this prototype was the possibility to use the Venturi principle to add air to the flow. The original idea was to use an air compressor to add bubbles into the flow. When a T-fitting was inserted, it was discovered that no compressor was needed. The air was simply sucked in thanks to the Venturi principle. The idea to use the Venturi principle, in the form of an ejector, to add particles to the fluid was born. Much more sophisticated ejector designs were however needed to achieve sufficient performance.

Prototype 2

Pump: Centrifugal pump, Altech SUR 800

Ejector: Prototype in steel, see *Figure B.2*

Particles: Plastic granulate (unknown type, but probably PVC)

Tank: Half oil drum with a plastic bucket for the granulate

Piping: Hoses

The purpose of the second prototype was to find out whether it was possible to use an ejector pump to pump particles through the system. For this purpose a prototype ejector of steel was manufactured and a more powerful pump was tested.

The particles used were granulate of an unknown plastic material with a density around 1,3-1,4kg/l. Since the granulate had higher density than the surrounding water it sedimented. This made it easy to filter the granulate from the water and run it through the ejector in a closed loop.

A plastic bucket were mounted inside the oil drum. A hole was drilled through the bucket and the drum, and a bulkhead fitting was placed in the holes. The ejector was then connected to the bulkhead. Water was pumped from the drum through the ejector where particles were added. The water was then lead through a hose to the bucket where the particles sedimented and the water spilled over to the drum. See *Figure B.1*.

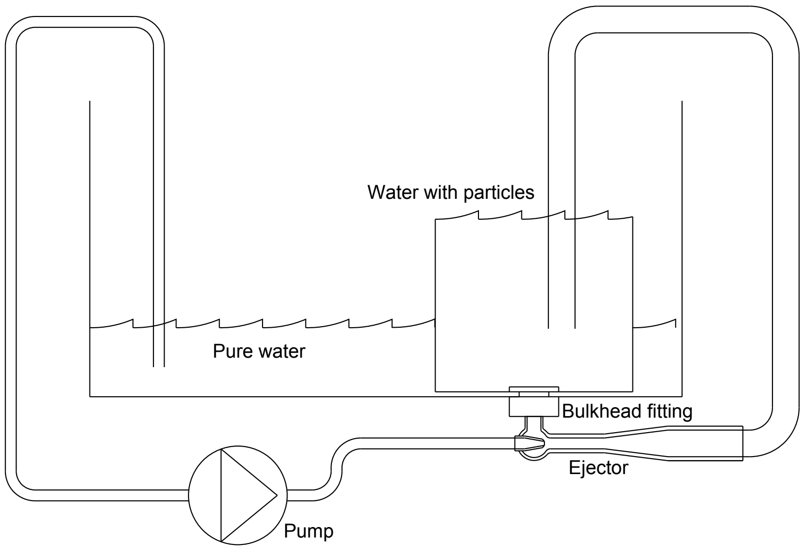


Figure B.1: *The test layout used.*

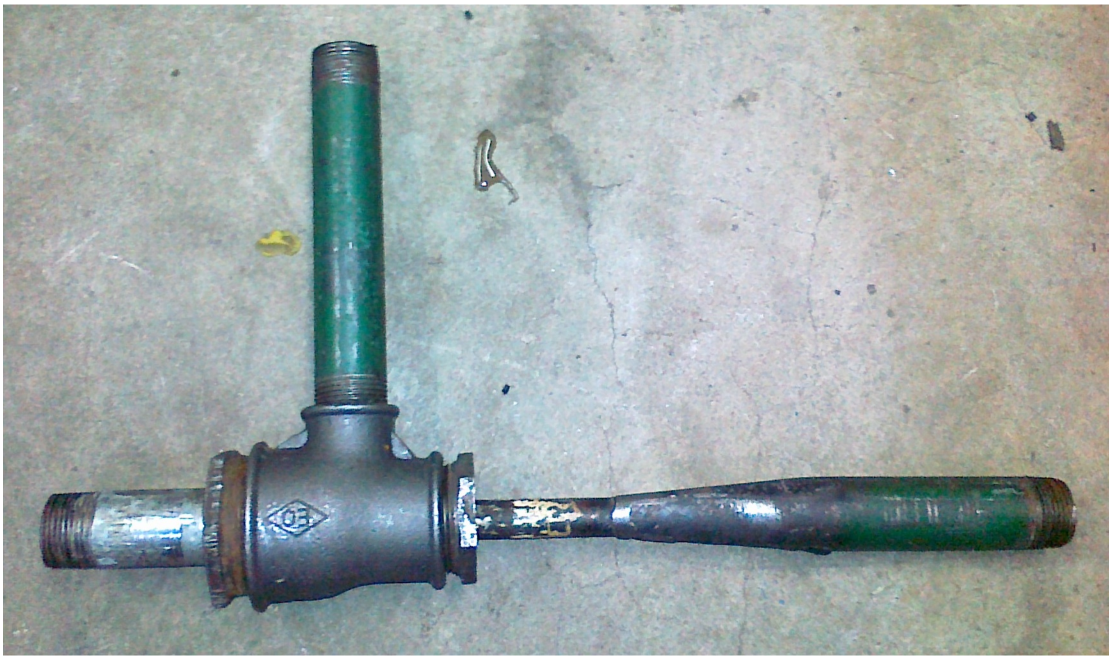


Figure B.2: *The first prototype for the ejector.*

Outcome: The ejector pump successfully added particles to the fluid. It was estimated that the particle contents in the fluid were 5-10%. This was considered enough and it was decided that the final rig would use an ejector pump to add particles to the fluid. The particles used where good enough, but a larger quantity was needed for the final rig.

Prototype 3

Pump: Centrifugal pump, Altech SUR 800

Ejector: Final ejector in PVC

Particles: PVC granulate

Tank: Final tank in stainless steel and transparent acrylic

Piping: Almost final piping

For the third prototype most of the piping was obtained and needed to be tested to make sure it all fitted together. Also the pump needed to be tested to confirm it generated enough flow both to fill the measuring tube and to bring particles with the flow.

Outcome: The ejector worked as supposed to. There were however problems with the flow rate. Due to the size of the measuring pipe the flow from the pump was not enough to fill the pipe or bring all particles with the flow (too low fluid velocity). Two solutions to this problem existed, either choose a measuring pipe with a smaller radius or obtain a pump that generates a higher flow. A thinner measuring pipe was considered to affect the aesthetic appearance of the rig negatively. Instead the pump was replaced with a pump that generates higher flow.

There were also problems with flow going in the wrong direction under certain circumstances. When the rig was set to only pump pure water through the measuring pipe some of the water went through the ejector in the wrong direction instead. To prevent this from happening a check valve could be installed close to the Y-pipe where the particle fluid and pure water are mixed.

Prototype 4

Pump: Centrifugal pump, Altech SUR 800

Ejector: Final ejector in PVC

Particles: PVC granulate

Tank: Final tank in stainless steel and transparent acrylic

Piping: Almost final piping and a check valve

In this prototype a check valve had been added on the particle side of the Y-fitting where pure water and particle-containing fluid are mixed. This was done to prevent the problems discovered in prototype 3 with water going in the wrong direction at some circumstances.

Two restrictors were manufactured to get a more linear control of the flow and particle concentration. One was put on the bypass hose from a shunt valve to the tank, and one on the hose for clean water between the shunt valve and the mixing pipe.

Outcome: The problem with clean water bypassing the measuring pipe was solved, and the nonlinear control of flow and particle concentration was considerably improved. A previously undiscovered problem with the ejector was found. When the pump to the system was turned off, particles were sometimes sucked into the ejector. The cause of the suction was water going in the wrong direction due to gravity, causing negative pressure at the ejector's motive nozzle. This caused the ejector to jam since particles are not intended to be inside the ejector's motive nozzle.

Prototype 5

Pump: Centrifugal pump, Altech SUR 800

Ejector: Final ejector in PVC

Particles: PVC granulate

Tank: Final tank in stainless steel and transparent acrylic

Piping: Almost final piping and a check valve

Four holes were drilled on the outlet side of the nozzle, and a 0.7 mm thick stainless steel wire where put in the holes to form a cross in the outlet. This cross would act as a filter to prevent granulates from going into the nozzle. The purpose of prototype five were to make sure that this alternation was enough to prevent granulate from going inside the nozzle.

Outcome: The rig was tested for a couple of hours, both continuous run as the rig is supposed to be used and with the pump started and stopped which previously had caused jamming. The tests were considered a success since no jamming occurred.

Prototype 6

Pump: Centrifugal pump, Lowara CAM 120/33

Ejector: Final ejector in PVC

Particles: PVC granulate

Tank: Final tank in stainless steel and transparent acrylic

Piping: Final piping, but not cut to length, with check valve

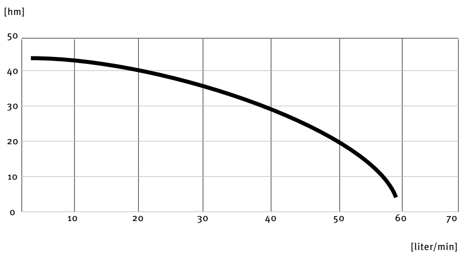
The purpose of the sixth prototype was to make sure that the new pump could produce a high enough flow to fill the measuring pipe and that the particles would follow. The final piping was used, but not cut to final length, to make sure that no parts were missing.

Outcome: The pump was able to fill the measuring tube without particles sedimenting. All piping fitted together without any temporary couplings. The prototype stages were considered to be done and the final rig was ready to be assembled.

C Altech SUR800 Product Sheet

SUR800

Bevattningspump med pumphus i rostfritt stål för rent vatten. Lämplig att använda för till exempel tömning av brunnar, bevattning, länspumpning med mera. Komplett med överhettningsskydd och elkabel med stickpropp. Med invändiga anslutningar G1” (R25).

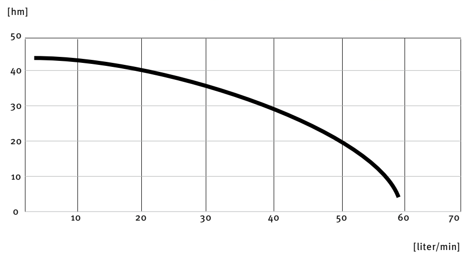


Art nr: 145655
230V/50HZ, 800 W
Max sughöjd: 7 meter
Maxkapacitet: 50 liter/minut (3,0 m³/ t)
Höjd: 257 mm
Längd: 320 mm
Bredd: 162 mm
Anslutningar sug- / trycksida: Inv G1” (R25)

PPT800

Helautomatisk pumpautomat med pumphus i rostfritt stål för rent vatten. Lämplig att använda i till exempel fritidshus eller i villor. Utrustad med 22 liters trycktank (vilket innebär att man kan tappa cirka 5-6 liter vatten innan pumpen startar), tryckströmbrytare, överhettningsskydd, elkabel med stickpropp och manometer.
Med invändiga anslutningar G1” (R25).

Art nr: 145650
230V/50HZ, 800 W
Max sughöjd: 7 meter
Maxkapacitet: 50 liter/minut (3 m³/ t)
Höjd: 460 mm
Längd: 542 mm
Bredd: 270 mm
Anslutningar sug- / trycksida: Inv G1” (R25)



För teknisk support, ring 020-583 000

Altech

D Lowara CAM 120/33

LOWARA

CEA(N)-CA(N) SERIES

STAINLESS STEEL THREADED CENTRIFUGAL PUMPS

Wide range of pumps for domestic and industrial applications.
Single-impeller (CEA) and dual-impeller (CA) models available.

- ❑ **IN THE AISI 304 STANDARD VERSION ALL COMPONENTS IN CONTACT WITH THE PUMPED LIQUID ARE MADE OF STAINLESS STEEL (AISI 304 OR AISI 316), WHILE IN THE "N" VERSION (AISI 316) ARE IN AISI 316 STAINLESS STEEL**
- ❑ **IP 55 MOTOR PROTECTION**

CEA-CA

APPLICATIONS

AISI 304 STANDARD VERSION

- **Handling of liquids compatible with AISI 304 stainless steel in a wide variety of civil and industrial systems.**
- Water circulation for domestic use.
- Sprinkler systems.
- Composition of surge tank units for pressure boosting in various applications.

"N" VERSION MADE OF AISI 316 (FOR AGGRESSIVE LIQUIDS)

- Reverse osmosis (where demineralized water is used).
- Industrial washing.
- Thermal waters.
- Chlorine dispensing in swimming pools.
- Jewellary industry.
- Wine production.

SPECIFICATIONS

- **Single-impeller CEA series, dual-impeller CA series.**
- **Delivery:** up to **31 m³/h.**
- **Head:** up to **62 m.**
- **Maximum** operating **pressure: 8 bar.**
- **Continuous duty.**
- **Temperature of pumped liquid: -10°C to 85°C (special CEA-V CA-V version, with O-ring or FPM seals, is available for temperatures up to +110°C).**
- Enclosed motor with external ventilation and aluminium alloy finned casing.
- Versions:
  Single-phase 220-240 V 50 Hz, permanently connected capacitor and built-in automatic reset overload protection up to 1,5 kW.
  Three-phase 220-240/380-415 V 50 Hz, overload protection to be provided by user (except for 2,2 kW version).
- Power up to 3 kW.
- Class **F Insulation.**
- **IP 55 protection.**

TABLE OF MATERIALS

CEA-CA

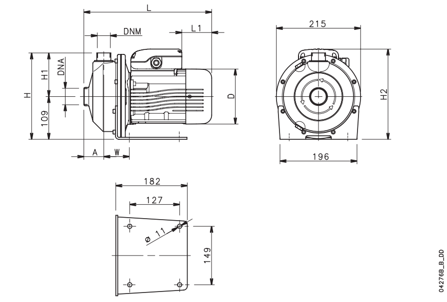
PART	MATERIAL
Pump body, Flange, Seal housing, Diffuser, Impeller	STAINLESS STEEL (AISI 304 - DIN 1.4301)
Shaft extension	STAINLESS STEEL (AISI 316 - DIN 1.4401
Fill and drain plugs	STAINLESS STEEL (AISI 316 - DIN 1.4401)
Mechanical seal	CARBON/CERAMIC/NBR
O-ring seals	NBR

CEA(N)-CA(N)

PART	MATERIAL
Pump body, Flange, Seal housing, Diffuser, Impeller	STAINLESS STEEL (AISI 316L - DIN 1.4404)
Shaft extension	STAINLESS STEEL (AISI 316 - DIN 1.4401
Fill and drain plugs	STAINLESS STEEL (AISI 316 - DIN 1.4401)
Mechanical seal	CARBON/CERAMIC/EPDM
O-ring seals	EPDM

Lowara
ITT Industries

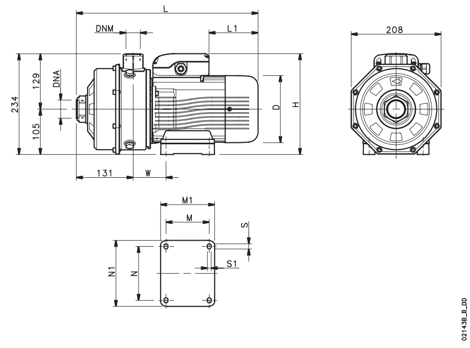
CEA-CEA(N) SERIES DIMENSIONS AND WEIGHTS



PUMP TYPE	DIMENSIONS (mm)								DNA	DNM	WEIGHT
	A	D	H	H1	H2	L	L1	W			kg
CEAM 70/3	51	120	220	111	220	311	62	65	Rp 1¼	Rp 1	9,7
CEAM 70/5	51	140	220	111	230	325	76	65	Rp 1¼	Rp 1	11,6
CEAM 80/5	51	140	220	111	230	325	76	65	Rp 1¼	Rp 1	12,5
CEAM 120/3	51	140	220	111	230	325	76	65	Rp 1¼	Rp 1	11,5
CEAM 120/5	51	140	220	111	239	325	31	65	Rp 1¼	Rp 1	13
CEAM 210/2	54	140	222	113	230	339	76	76	Rp 1½	Rp 1¼	13
CEAM 210/3	54	156	222	113	246	385	69	76	Rp 1½	Rp 1¼	14,5
CEAM 210/4	54	156	222	113	246	385	69	76	Rp 1½	Rp 1¼	16,1
CEAM 210/5	54	176	222	113	230	416	114	76	Rp 1½	Rp 1¼	14,4
CEAM 370/1	54	156	222	113	246	385	69	76	Rp 2	Rp 1¼	14
CEAM 370/2	54	156	222	113	246	385	69	76	Rp 2	Rp 1¼	16,1
CEAM 370/3	54	176	222	113	230	416	114	76	Rp 2	Rp 1¼	17,7
CEA 70/3	51	120	220	111	220	311	62	65	Rp 1¼	Rp 1	9,7
CEA 70/5	51	140	220	111	230	325	76	65	Rp 1¼	Rp 1	11,6
CEA 80/5	51	140	220	111	230	325	76	65	Rp 1¼	Rp 1	12,5
CEA 120/3	51	140	220	111	230	325	76	65	Rp 1¼	Rp 1	11,5
CEA 120/5	51	140	220	111	230	325	76	65	Rp 1¼	Rp 1	13
CEA 210/2	54	140	222	113	230	339	76	76	Rp 1½	Rp 1¼	13
CEA 210/3	54	156	222	113	238	385	114	76	Rp 1½	Rp 1¼	14,5
CEA 210/4	54	156	222	113	238	385	114	76	Rp 1½	Rp 1¼	16,1
CEA 210/5	54	156	222	113	238	385	114	76	Rp 1½	Rp 1¼	14,4
CEA 370/1	54	156	222	113	238	285	114	76	Rp 2	Rp 1¼	14
CEA 370/2	54	156	222	113	238	385	114	76	Rp 2	Rp 1¼	16,1
CEA 370/3	54	156	222	113	238	385	114	76	Rp 2	Rp 1¼	17,7
CEA 370/5	54	176	222	113	230	416	149	76	Rp 2	Rp 1¼	18

cea-2p50_c_td

CA-CA(N) SERIES DIMENSIONS AND WEIGHTS



PUMP TYPE	DIMENSIONS (mm)											DNA	DNM	WEIGHT
	D	H	L	L1	M	M1	N	N1	S	S1	W			kg
CAM 70/33	140	226	383	76	90	113	112	135	12	7	66	Rp 1¼	Rp 1	15
CAM 70/34	140	235	383	31	90	113	112	135	12	7	66	Rp 1¼	Rp 1	15,8
CAM 70/45	156	242	420	69	100	125	125	153	12	9	76	Rp 1¼	Rp 1	18,5
CAM 120/33	156	242	420	69	100	125	125	153	12	9	76	Rp 1¼	Rp 1	18,4
CAM 120/35	156	242	420	69	100	125	125	153	12	9	76	Rp 1¼	Rp 1	20,2
CAM 120/55	176	226	450	114	125	156	140	170	13	9	98	Rp 1¼	Rp 1	24,5
CAM 200/33	176	226	450	114	125	156	140	170	13	9	98	Rp 1½	Rp 1	24,2
CA 70/33	140	226	383	76	90	113	112	135	12	7	66	Rp 1¼	Rp 1	14,9
CA 70/34	140	226	383	76	90	113	112	135	12	7	66	Rp 1¼	Rp 1	15,7
CA 70/45	156	234	420	114	100	125	125	153	12	9	76	Rp 1¼	Rp 1	17
CA 120/33	156	234	420	114	100	125	125	153	12	9	76	Rp 1¼	Rp 1	16,8
CA120/35	156	234	420	114	100	125	125	153	12	9	76	Rp 1¼	Rp 1	18,7
CA 120/55	156	234	420	114	100	125	125	153	12	9	76	Rp 1¼	Rp 1	20,3
CA 200/33	156	234	420	114	100	125	125	153	12	9	76	Rp 1½	Rp 1	20
CA 200/35	176	226	450	149	125	156	140	170	13	9	98	Rp 1½	Rp 1	22,3
CA 200/55	176	226	450	149	125	156	140	170	13	9	98	Rp 1½	Rp 1	24,3

ca-2p50_b_td

CEA-CEA(N) SERIES OPERATING CHARACTERISTICS AT 2850 rpm 50 Hz

PUMP TYPE	RATED POWER		Q = DELIVERY																	
			l/min 0	30	40	60	80	100	120	140	160	180	200	250	300	350	400	430	480	520
			m^3/h 0	1,8	2,4	3,6	4,8	6	7,2	8,4	9,6	10,8	12	15	18	21	24	26	29	31
	kW	HP	H = TOTAL HEAD METERS COLUMN OF WATER																	
CEA(M) 70/3	0,37	0,5	22	20,1	19,1	16,6	12,8													
CEA(M) 70/5	0,55	0,75	31,1	28,8	27,7	24,7	20,2													
CEA(M) 80/5	0,75	1	32	30	29,3	27,4	24,7	21												
CEA(M) 120/3	0,55	0,75	22,4			18,9	17,5	15,9	14	11,8	9,2									
CEA(M) 120/5	0,9	1,2	31,8			28,2	26,5	24,6	22,4	20	17,3									
CEA(M) 210/2	0,75	1	17,7						16,5	16,1	15,6	15	14,4	12,6	10,4					
CEA(M) 210/3	1,1	1,5	20,8						19,7	19,3	19	18,5	18	16,5	14,4					
CEA(M) 210/4	1,5	2	25,5						24,8	24,5	24	23,6	23	21,3	19					
CEA(M) 210/5	1,85	2,5	29						28,2	27,9	27,5	27,1	26,6	25,1	23,1					
CEA(M) 370/1	1,1	1,5	16,3									15,5	15,2	14,3	13	11,4	9,4	8,1		
CEA(M) 370/2	1,5	2	20,4										19,1	18,3	17,2	15,8	14,1	13	10,8	
CEA(M) 370/3	1,85	2,5	24,4										22,9	22,1	21,1	19,8	18,2	17,1	15	13
CEA370/5	3	4	30,4										28,3	27,5	26,5	25,3	23,8	22,8	21	18,9

cea-2p50_c_th

PUMP TYPE SINGLE-PHASE	INPUT POWER* kW	INPUT CURRENT* 220-240 V A	CAPACITOR µF / 450 V
CEAM 70/3	0,6	2,72	14
CEAM 70/5	0,97	4,55	16
CEAM 80/5	1,07	4,87	20
CEAM 120/3	0,91	4,33	16
CEAM 120/5	1,39	6,24	25
CEAM 210/2	1,13	5,1	20
CEAM 210/3	1,48	6,68	30
CEAM 210/4	1,91	8,6	40
CEAM 210/5	2,31	10,6	50
CEAM 370/1	1,49	6,75	30
CEAM 370/2	2,05	9,26	40
CEAM 370/3	2,47	11,2	50

PUMP TYPE THREE-PHASE	INPUT POWER* kW	INPUT CURRENT* 220-240 V A	INPUT CURRENT* 380-415 V A
CEA 70/3	0,61	2,51	1,45
CEA 70/5	0,88	2,86	1,65
CEA 80/5	1,06	3,65	2,11
CEA 120/3	0,82	2,74	1,58
CEA 120/5	1,32	4,52	2,61
CEA 210/2	1,12	3,76	2,17
CEA 210/3	1,43	4,68	2,7
CEA 210/4	1,84	6,04	3,49
CEA 210/5	2,28	8,35	4,82
CEA 370/1	1,44	4,71	2,72
CEA 370/2	1,99	6,32	3,65
CEA 370/3	2,47	8,63	4,98
CEA 370/5	3,34	9,93	5,74

*Maximum value in specified range

cea-2p50_b_te

CA-CA(N) SERIES OPERATING CHARACTERISTICS AT 2850 rpm 50 Hz

PUMP TYPE	RATED POWER		Q = DELIVERY											
			l/min 0	30	40	50	60	70	80	100	120	150	180	210
			m^3/h 0	1,8	2,4	3	3,6	4,2	4,8	6	7,2	9	10,8	12,6
	kW	HP	H = TOTAL HEAD METERS COLUMN OF WATER											
CA(M) 70/33	0,75	1	42,9	38,8	36,9	34,6	31,7	28,2	23,9					
CA(M) 70/34	0,9	1,2	48,8	45,1	43,2	40,7	37,7	34,0	29,5					
CA(M) 70/45	1,1	1,5	56,2	52,0	49,8	47,1	43,9	39,9	35,3					
CA(M) 120/33	1,1	1,5	44,3			39,1	37,8	36,4	34,8	31,4	27,6	21,0		
CA(M) 120/35	1,5	2	54,0			49,4	48,1	46,6	44,9	41,2	36,8	29,3		
CA(M) 120/55	2,2	3	63,8			59,6	58,2	56,6	54,8	50,6	45,7	37,1		
CA(M) 200/33	1,85	2,5	43,2			41,8	41,2	40,6	39,9	38,3	36,4	33,2	29,5	25,5
CA 200/35	2,2	3	53,5			52,4	51,9	51,4	50,7	49,2	47,5	44,3	40,6	36,5
CA 200/55	3	4	62,6			61,0	60,6	60,1	59,5	58,2	56,6	53,8	50,4	46,2

ca-2p50_b_th

PUMP TYPE SINGLE-PHASE	INPUT POWER* kW	INPUT CURRENT* 220-240 V A	CAPACITOR µF / 450 V
CAM 70/33	1,15	5,16	20
CAM 70/34	1,39	6,22	25
CAM 70/45	1,76	7,92	30
CAM 120/33	1,67	7,53	30
CAM 120/35	2,18	9,87	40
CAM 120/55	2,61	11,7	50
CAM 200/33	2,36	10,8	50
-	-	-	-
-	-	-	-

PUMP TYPE THREE-PHASE	INPUT POWER* kW	INPUT CURRENT* 220-240 V A	INPUT CURRENT* 380-415 V A
CA 70/33	1,14	3,78	2,18
CA 70/34	1,32	4,52	2,61
CA 70/45	1,71	5,23	3,02
CA 120/33	1,62	5,06	2,92
CA 120/35	2,13	6,58	3,8
CA 120/55	2,62	8,89	5,13
CA 200/33	2,34	8,44	4,87
CA 200/35	3,14	9,18	5,3
CA 200/55	3,68	10,9	6,3

*Maximum value in specified range

ca-2p50_a_te

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Lowara
ITT Industries

cod. 191003791 05/06

E ESBE Shunt Valve VRG131

ROTARY MOTORIZED VALVES

MIXING VALVE
SERIES VRG130

The compact rotary 3-way mixing valve series VRG130 is available in DN 15–50, and is made of DZR brass, PN10. Four types of connections are available; internal thread, external thread, compression fitting and rotating nut.

Internal thread — External thread — Compression fitting — Rotating nut — Rotating nut/ External thread

OPERATION
The ESBE series VRG130 is a range of compact low leakage mixing valves made of a special brass alloy (DZR) allowing use in both heating, cooling and tap water installations.

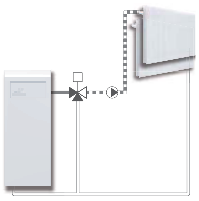
For easy manual operation the valves are equipped with non-slip knobs and end stops for an operation angle of 90°. The valve position scale can be turned over and rotated, allowing a wide choice of mounting positions. Together with actuator series ESBE ARA600 the VRG130 valves are also easily automated and have extraordinary regulating accuracy thanks to the unique valve-to-actuator interface. For more advanced control functions, the ESBE series 90C controllers allows even more applications.

ESBE VRG130 valves are available in dimensions DN 15 – 50 with internal or external thread, with rotating nut in DN20 or with compression fittings for pipe O.D. 22 and 28 mm.

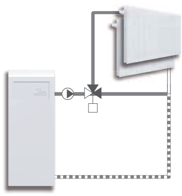
SERVICE AND MAINTENANCE
The slender and compact design of the valve allows for easy tool access when assembling and disassembling the valve.

Repair kits are available for key components. An extra O-ring can also be installed as additional shaft seal without any need for draining the system or dismantling the valve, as long as the system is depressurized.

INSTALLATION EXAMPLES
All the examples of installations can be mirrored. The valve position scale can be turned over and rotated to fit a number of installation layouts and should at the installation be fitted in the correct position as shown in the instruction for installation. The symbol markings of the valve ports (■●▲) minimize the risk of incorrect installation.



Mixing



Diverting

VALVE VRG130 DESIGNED FOR
- ● Heating
- ● Comfort cooling
- ● Potable water
- ● Floor heating
- ● Solar heating
- ● Ventilation
- ● Zone
- ○ District hot water
- ○ District heating
- ○ District cooling

SUITABLE ACTUATORS
The valve series VRG130 may most easily be fitted with ESBE actuators:

- ● Series ARA600
- ● Series 90*
- ● Series 90C
- ● Series 90K

*Adaptor kit necessary, see product page

TECHNICAL DATA

Pressure class:	PN 10
Media temperature:	max. (continuously) +110°C
	max. (temporarily) +130°C
	min. -10°C
Torque (at nominal pressure):	< 5 Nm
Leakrate in % of flow*:	Mixing < 0.05%
	Diverting < 0.02%
Working pressure:	1 MPa (10 bar)
Max. differential pressure drop:	Mixing, 100 kPa (1 bar)
	Diverting, 200 kPa (2 bar)
Close off pressure:	200 kPa (2 bar)
Rangeability Kv/Kvmin, A-AB:	100
Connections:	Internal thread, EN 10226-1
	External thread, ISO 228/1
	Compression fitting, EN 1254-2

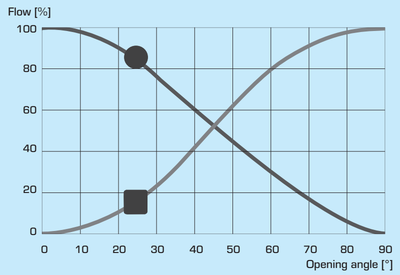
* Differential pressure 100kPa (1 bar)

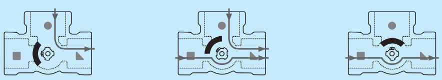
Material

Valve body and slide:	Brass DZR, CW 602N
Shaft and bushing:	PPS composite
O-rings:	EPDM

PED 97/23/EC, article 3.3

VALVE CHARACTERISTICS





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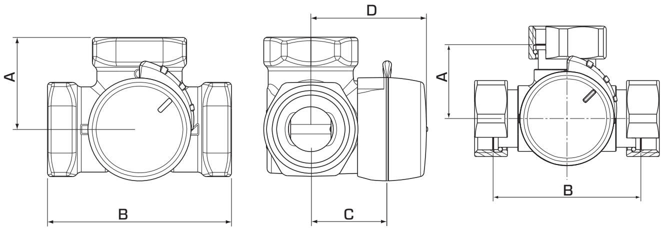
ESBE 2010/11 VALVES AND ACTUATORS

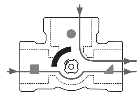
ROTARY MOTORIZED VALVES

MIXING VALVE

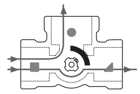
SERIES VRG130



VRG131, VRG132, VRG133 VRG138



Mixing



Diverting

The flat-sided spindle top points towards the sleeve position.

SERIES VRG131, INTERNAL THREAD

Art. No.	Reference	DN	Kvs*	Connection	A	B	C	D	Weight [kg]	Note
1160 01 00	VRG131	15	0.4	Rp ½"	36	72	32	50	0.40	
1160 02 00			0.63							
1160 03 00			1							
1160 04 00			1.6							
1160 05 00			2.5							
1160 06 00			4							
1160 07 00	VRG131	20	2.5	Rp ¾"	36	72	32	50	0.43	
1160 08 00			4							
1160 09 00			6.3							
1160 10 00	VRG131	25	6.3	Rp 1"	41	82	34	52	0.70	
1160 11 00			10							
1160 12 00	VRG131	32	16	Rp 1¼"	47	94	37	55	0.95	
1160 34 00	VRG131	40	25	Rp 1½"	53	106	44	60	1.68	
1160 36 00	VRG131	50	40	Rp 2"	60	120	46	64	2.30	

SERIES VRG132, EXTERNAL THREAD

Art. No.	Reference	DN	Kvs*	Connection	A	B	C	D	Weight [kg]	Note
1160 15 00	VRG132	15	0.4	G ¾"	36	72	32	50	0.40	
1160 16 00			0.63							
1160 17 00			1							
1160 18 00			1.6							
1160 19 00			2.5							
1160 20 00			4							
1160 21 00	VRG132	20	2.5	G 1"	36	72	32	50	0.43	
1160 22 00			4							
1160 23 00			6.3							
1160 24 00	VRG132	25	6.3	G 1¼"	41	82	34	52	0.70	
1160 25 00			10							
1160 26 00	VRG132	32	16	G 1½"	47	94	37	55	0.95	
1160 35 00	VRG132	40	25	G 2"	53	106	44	60	1.69	
1160 37 00	VRG132	50	40	G 2¼"	60	120	46	64	2.30	

SERIES VRG133, COMPRESSION FITTING

Art. No.	Reference	DN	Kvs*	Connection	A	B	C	D	Weight [kg]	Note
1160 29 00	VRG133	20	4	CPF 22 mm	36	72	32	50	0.40	
1160 30 00			6.3							
1160 31 00	VRG133	25	10	CPF 28 mm	41	82	34	52	0.45	

SERIES VRG138, ROTATING NUT AND EXTERNAL THREAD

Art. No.	Reference	DN	Kvs*	Connection	A	B	C	D	Weight [kg]	Note
1160 38 00	VRG138	20	4	2x RN 1" + G 1"	36	72	32	50	0.56	
1160 39 00			4	3x RN 1"					0.59	
1160 40 00			6.3	2x RN 1" + G 1"					0.56	
1160 41 00			6.3	3x RN 1"					0.59	

* Kvs-value in m^3/h at a pressure drop of 1 bar. See also flow chart on page 32. CPF = compression fitting RN = Rotating Nut

F ESBE Actuator ARA639

ROTARY MOTORIZED VALVES

ACTUATOR

SERIES ARA600 PROPORTIONAL

Proportional

ESBE Actuator Series ARA600 for operating ESBE mixing valves DN 15–50. The actuators have an operating range of 90° and can easily be manually operated.

OPERATION

The ESBE series ARA600 is a compact actuator designed for operating rotary mixing valves DN 15-50. The actuators ARA6X9 are controlled by proportional signal, and are recommended for mixing applications. The actuator has an operating range of 90° and the valve can easily be manually operated by the pull-and-turn knob on the front of the actuator.

In addition to the proportional signal control, actuators series ARA639 can also be used for 3- and 2-point signal control.

VERSIONS

The actuators ARA6X9 are available for 24 V AC/DC, 50/60 Hz power supply. An auxiliary switch, which can be set in any position, is available as an optional kit to be ordered separately. The auxiliary switch is easily set by a unique solution, by just lifting off the turning knob the switch cam is accessible, no tools or disassembly required.

The ARA659 can be set to running times of 45 and 120 seconds and is supplied with a 1.5 m cable attached.

The ARA639 can be set to running times of 15, 30, 60 and 120 seconds. The ARA639 also have the additional features of proportional analogue output signal for monitoring devices etc, optional advanced noise reduction of the input signal and positioning memory for fast startup after power failure.

SUITABLE MIXING VALVES

Thanks to the special interface between the actuator series ARA600 and the ESBE valve series VRG100, VRG200 and VRB100, the unit as a whole has a unique stability and precision when regulating. The actuator series ARA600 is also easily mounted on the ESBE valve series MG, G, F, BIV, H and HG.

- Series VRG100
- Series VRG200
- Series VRG300
- Series VRB100
- Series MG
- Series G
- Series F ≤ DN50
- Series BIV
- Series H and HG

LINKAGE KITS

The actuator is supplied complete with an adaptor kit for easily fitting onto an ESBE rotary mixing valve. Adaptor kits can also be ordered separately.

Art. No.
1600 04 00 _______________ ESBE valve series G, MG
1600 05 00 (= supplied with actuator)
________________ESBE valve series VRG, VRB, G, MG

Adaptor kits for other mixing valves are available as follows:

Art. No.
1600 06 00________________________________ Meibes
1600 07 00_________________________________ Watts
1600 08 00_______________________ Honeywell Corona

TECHNICAL DATA

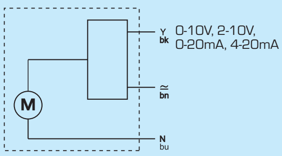
Ambient temperature: ________________ max. +55°C
______________________________ min. -5°C
Enclosure rating:______________________ IP41
Protection class:_______________________II
Power supply: ____________ 24 ± 10% VAC/DC, 50/60 Hz

Power consumption - Operation, AC: ______________ 5 W
DC: ______________ 2.5 W
Power consumption - Dimensioning, AC: _______ ARA639, 11 VA
__________ ARA659, 8 VA
DC: _______ ARA639, 6 VA
__________ ARA659, 4 VA
Rating auxiliary switch: ___________________6(3)A 250 VAC
Weight: ____________________________________ 0.4 kg

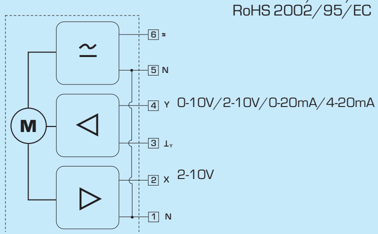
CE LVD 2006/95/EC
EMC 2004/108/EC
RoHS 2002/95/EC

WIRING

The actuator should be preceded by a multi-pole contact breaker in the fixed installation.



Actuator series ARA659

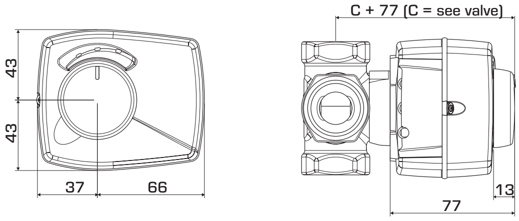


Actuator series ARA639

ROTARY MOTORIZED VALVES

ACTUATOR

SERIES ARA600 PROPORTIONAL



Installation dimensions for Actuator Series ARA600 with ESBE VRG100, VRG200, VRG300 and VRB100 mixing valves

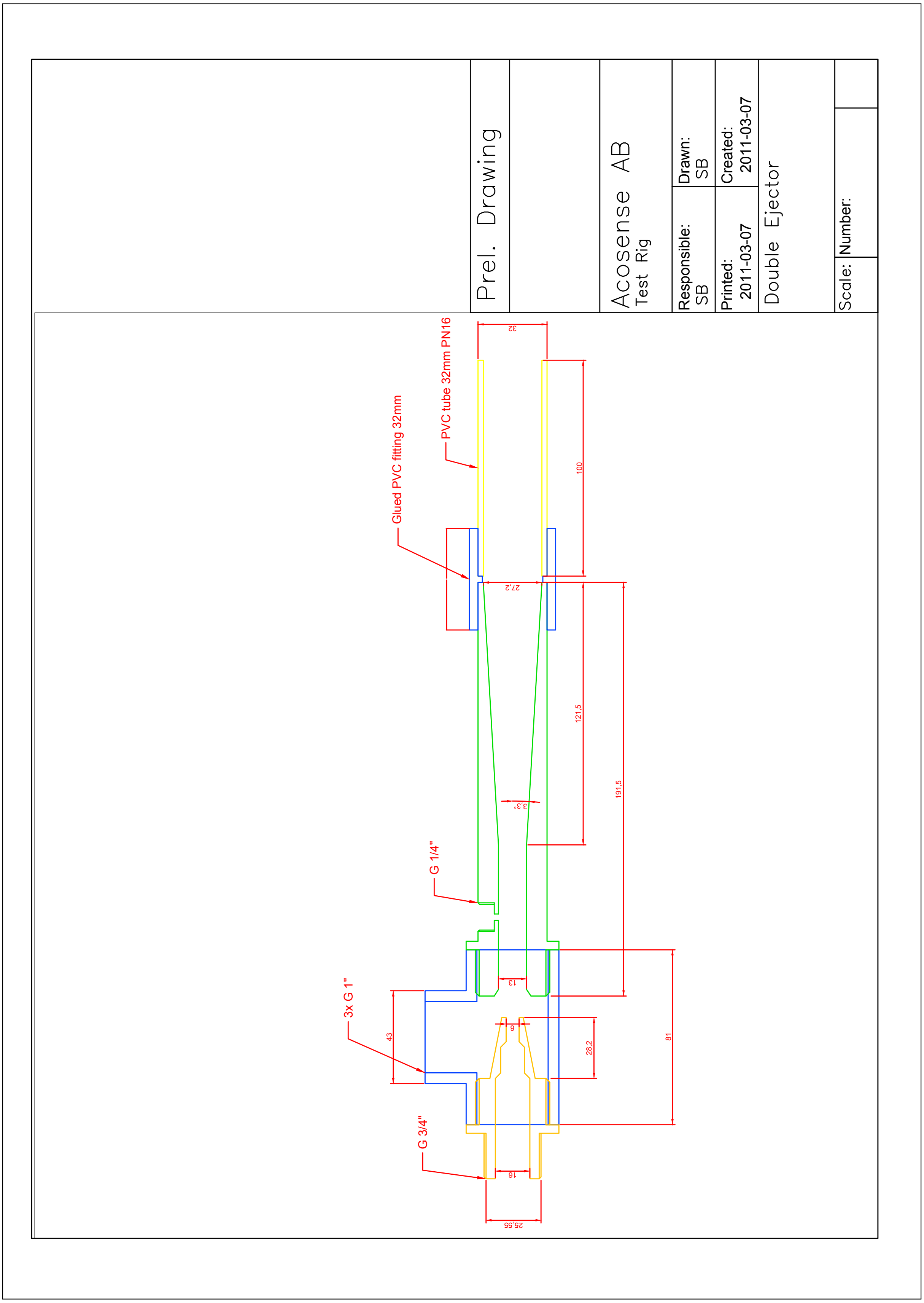
SERIES ARA600, PROPORTIONAL 24 V AC/DC

Art. No.	Reference	Voltage [V]	Running time 90° [s]	Control signal	Torque [Nm]	Note
1252 01 00	ARA639	24	15/30/60/120	0..10 V, 2..10 V, 0..20mA, 4..20mA	6	
1252 02 00	ARA659	24	45/120	0..10 V, 2..10 V, 0..20mA, 4..20mA	6	

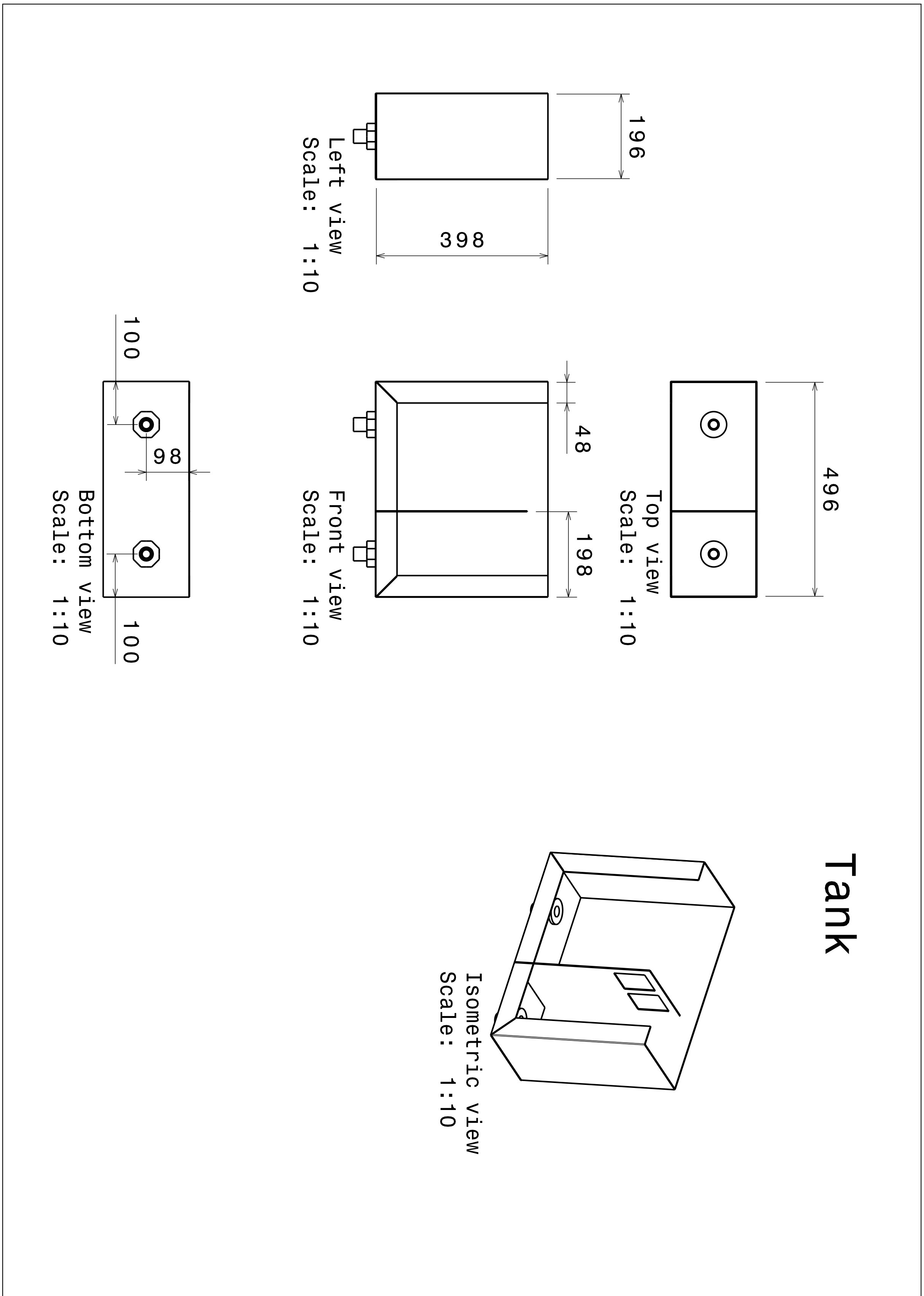
OPTION

Auxiliary switch kit________________ Art. No. 1620 07 00
Cable hatch ______________________ Art. No. 1620 08 00

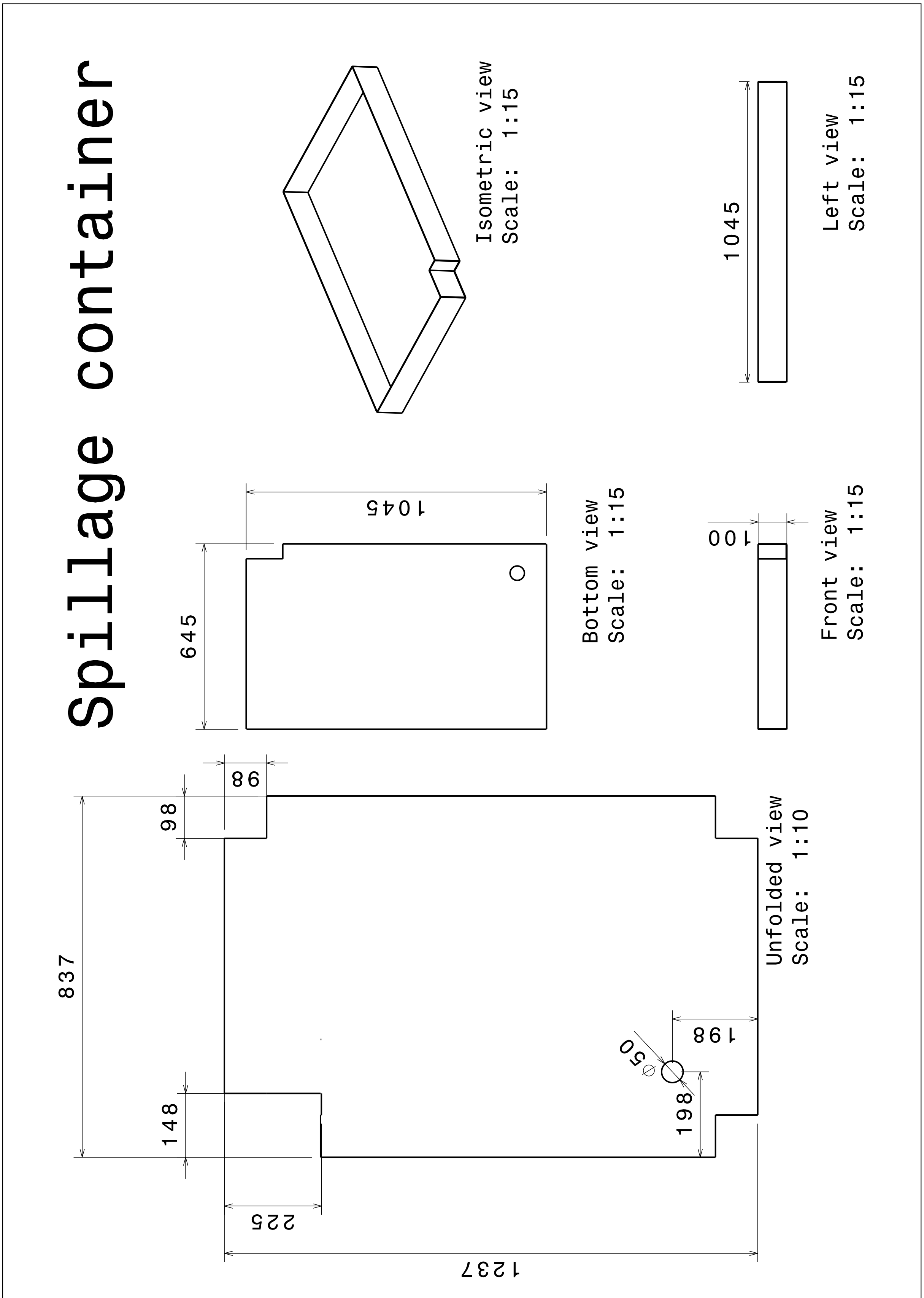
G Drawing of Double Ejector



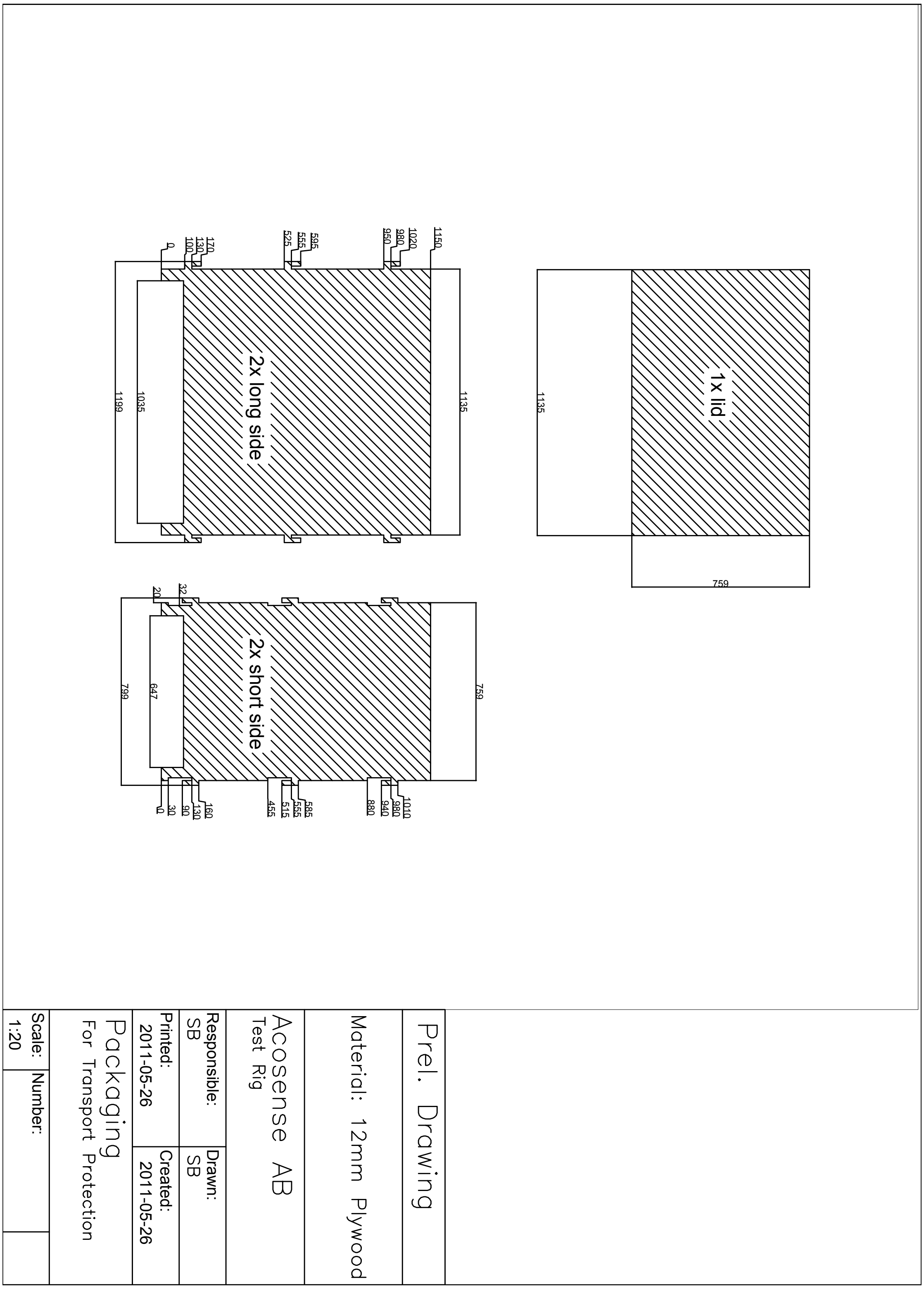
H Drawing of Tank



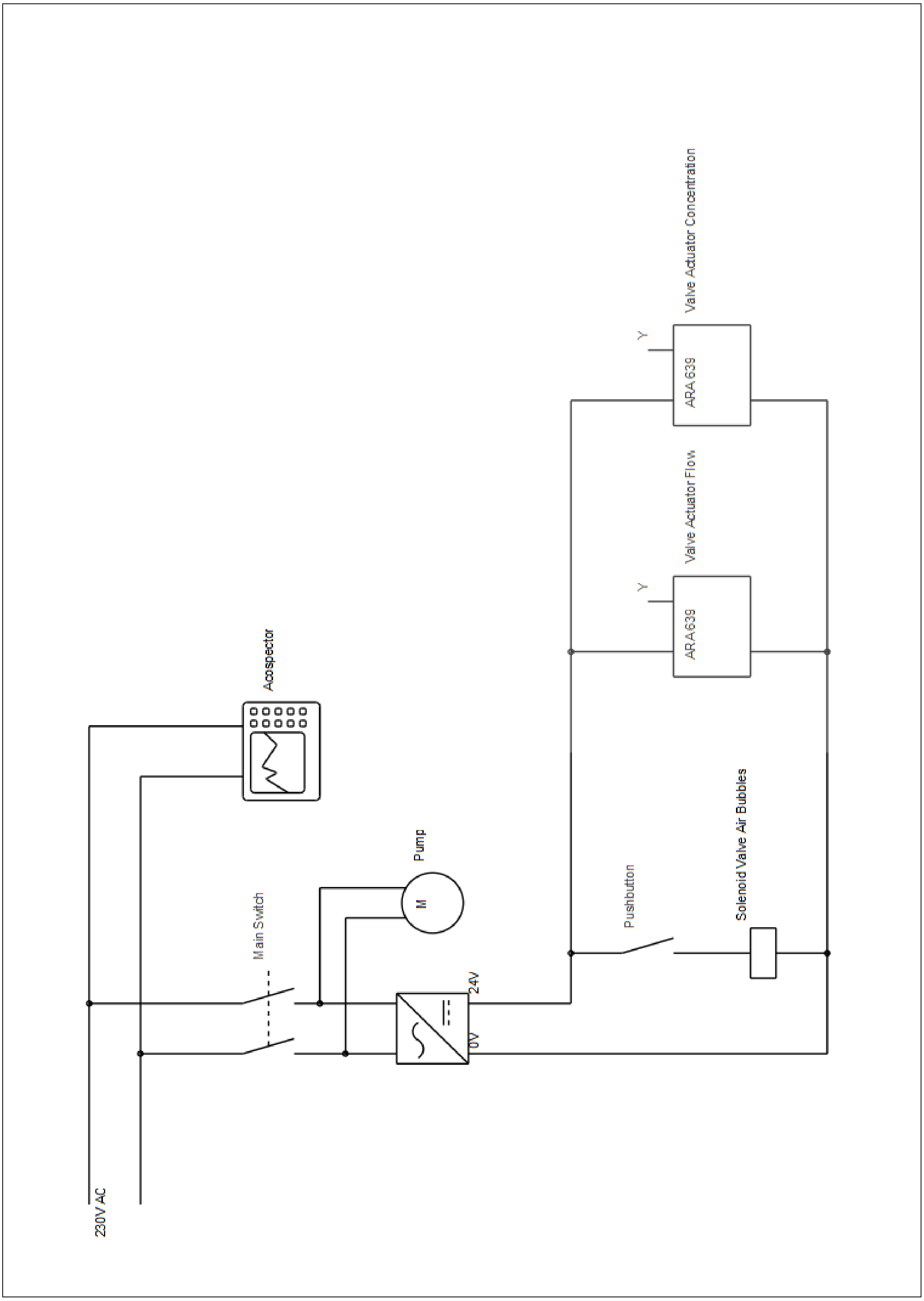
I Drawing of Spillage Container



J Drawing of Packaging for transport protection



K Wiring diagram



L User Manual (Swedish)

Användarmanual

Testrigg för akustiska mätningar på vätskor

Typ 1

Acosense AB

Göteborg

2011-05-20

Tekniska data

Stativ	Profilsystem 40mm aluminium
Vikt	Ca 100 kg
Längd x Bredd x Höjd	1130 x 730 x 1080 [mm]
Sidor	Transparent akrylplast 5mm
Bordsskiva	Vit, skummad PVC-plast 10mm
Pump	Lowara CAM 120/33
Pumptyp	Tvåstegs rostfri centrifugalpump
Märkeffekt	1,1[kW]
Ström	7,5 [A]
Spänning	230V, 50Hz växelspänning
Maximalt arbetstryck	8 [bar]
Vätskesystem	
Rör	Limmade PVC-delar, max 10 bar
Slang	Armerad PVC, max 7 bar
Tank	Rostfritt stål. Volym 40 l
Backventil	Asahi klaffbackventil typ 33 DN30
Filter	Asahi Y-filter typ 51 DN 40
Fördelningsventiler	ESBE typ VRG 131 DN25
Ställdon	ESBE typ ARA 639
Magnetventil luft	Direktverkande med 1/8” anslutning. Spolspänning 24 VDC
Vätska	Vatten med partiklar
Partiklar	Plastgranulat helstyv svart PVC, densitet 1,4 kg/dm^3

Leverantörer

För reservdelar eller kompletteringar kontakta:

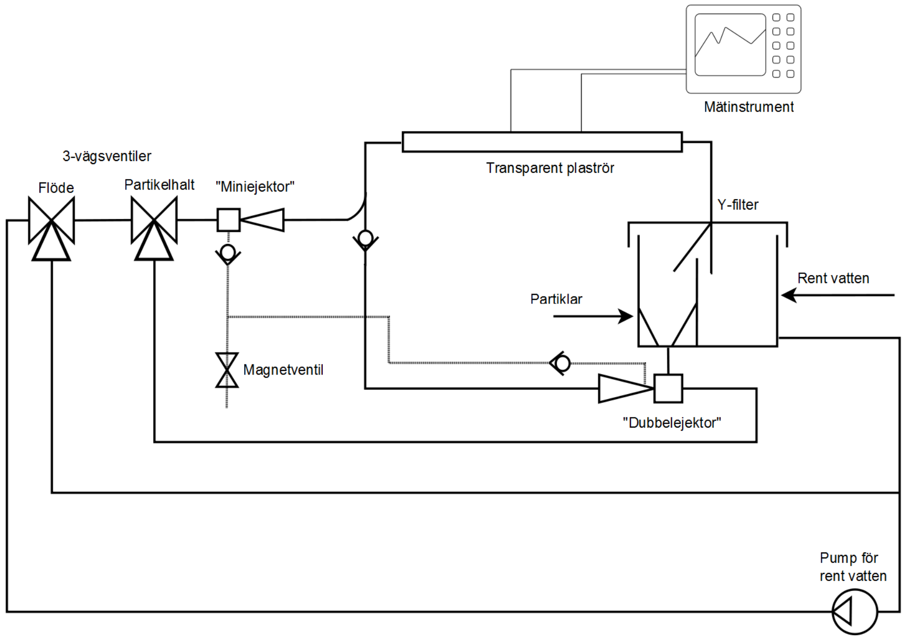
Lyma Kemiteknik AB, Malmö	Rörsystem, backventil, filter
ESBE AB, Reftele	Fördelningsventiler med ställdon
Processpumpar AB, Motala	Pump
Swedol AB, Västra Frölunda	Slang, slangklämmor m.m.
Bosch Rexroth AB, Malmö	Aluminiumprofiler, beslag, magnetventil
Vink Essåplast AB, Göteborg	Akrylplastskivor, Bordsskiva
Talent Plastics Göteborg AB, Kållered	Plastgranulat

Specialtillverkade komponenter

Följande komponenter har specialtillverkats för testriggen. Tillverkningsunderlag hittas som bilagor till examensarbetesrapporten.

- Tank
- Spillkärl
- Ejektor för partiklar
- Ejektor för luft

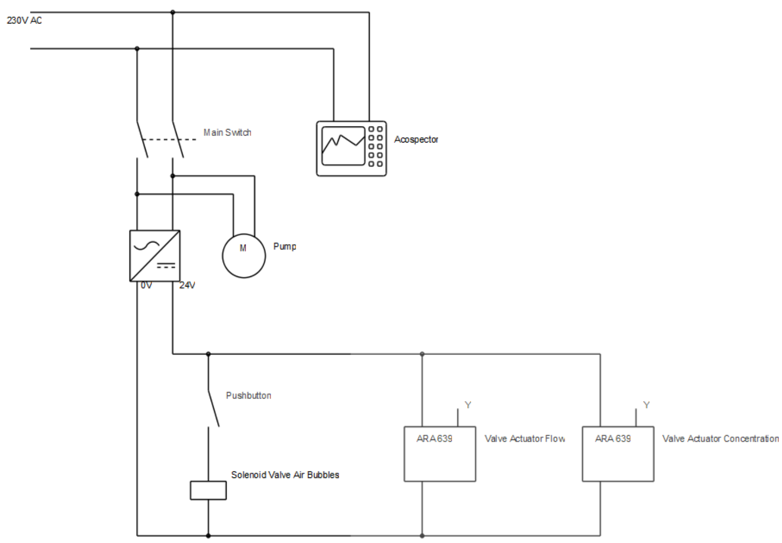
Funktionsbeskrivning



Figur 1. *Funktionsbeskrivning av testriggen. Rent vatten pumpas tillbaka till tank och en del in i ejektorn som drar med sig partiklar. Partikelblandat vatten blandas med rent vatten och leds in i mätröret.*

En centrifugalpump pumpar rent vatten från tanken till fördelningsventilen för flöde. Där ställs flödet i systemet genom att ett delflöde leds tillbaka till tank. Resten av flödet leds till fördelningsventilen för partikelkoncentration. Där leds ett delflöde av vattnet till en ejektor som tillsätter partiklar till vätskan. Resten av flödet leds till mätröret genom en ”miniejektor” som kan användas för att tillsätta luftbubblor. Det partikelbemängda och det rena vattnet blandas i ett grenrör och leds upp i mätröret. Där sitter mätinstrumentet som används för att mäta olika egenskaper hos vätskan. Efter mätröret leds vätskan tillbaka till tank, där vatten och partiklar delas upp på olika sidor om en mellanvägg. Uppdelningen sker i första hand med ett Y-filter. Beroende på i vilket läge riggen körs så behöver vatten ibland också rinna genom filtret i tankens mellanvägg som förhindrar partiklar från att hamna på fel sida.

Funktionsbeskrivning elsystem



Figur 2. *Funktionsbeskrivning av elsystem. En huvudströmbrytare är kopplad i serie med pump och transformator till magnetventil. Kablar är dragna för att enkelt kunna koppla in shuntventilerna till elsystem.*

Plint stora lådan

Plint	Beskrivning
SKYDDSJORD	
1	230V in direkt från stickpropp
2	230V in direkt från stickpropp
3	230V efter strömbrytare
4	230V efter strömbrytare
SKYDDSJORD	
5	+24V
6	+24V
7	+24V
8	0V (-)
9	0V (-)
10	0V (-)
11	24V signal till magnetventil för luftbubblor (från blå knapp)
12	Y-signal till ESBE shuntmotor flöde (0-10V, 2-10V, 0-20 mA, 4-20 mA)
13	Y-signal till ESBE shuntmotor koncentration (0-10V, 2-10V, 0-20 mA, 4-20 mA)

Y-signalerna är plintade men används ej i dagsläget.

Påfyllning och uppstart

1. Kontrollera att det finns ungefär 0,5 liter partiklar i tanken. Fyll på vid behov.
2. Fyll på vatten, ungefär 25.
3. Ställ reglagen för flöde och partikelhalt i min-läge.
4. Starta pumpen.
5. Låt pumpen arbeta tills ljudet stabiliseras.
6. Vrid långsamt reglaget för flöde till max.
7. Vänta tills vattenflödet genom mätröret är stabilt.
8. Vrid långsamt reglaget för partikelhalt till max.
9. Vänta tills flödet av partiklar och vatten genom röret är stabilt.
10. Kontrollera att inga läckor finns i rörsystemet samt att testriggen reagerar som förväntat vid ändring av flöde respektive partikelhalt.
11. Då vattnet i riggen blivit varm, och där med rör och slangar lite mjuka, kolla så att alla slangklämmor sitter ordentligt fast och att inga gängade kopplingar börjat lossna.

Drift

Flödet genom mätröret kan regleras med de två rattarna på bordets ovansida. Luftbubblor tillsätts genom att trycka på den blå knappen. Luftbubblor fungerar bäst i de två extremlägena ”fullt flöde, inga partiklar” och ”fullt flöde, fullt med partiklar”.

Avstängning under kortare perioder kan ske utan särskilda åtgärder genom att vrida på strömbrytaren på riggens ovansida.

Kontrollera med jämna mellanrum att inga läckor uppstått, eller att gängade anslutningar eller slangklämmor sitter löst. Vid läckage följ instruktionerna i kapitlet ”Felsökning / Åtgärder”.

Avstängning och tömning

Vid transport och lagring av riggen rekommenderas tömning av vätskesystemet.

1. Starta pumpen
2. Ställ reglaget för partikelkoncentration i min-läge.
3. Låt pumpen gå några minuter för att skölja ut så mycket partiklar som möjligt ur systemet.
4. Stäng av pumpen.
5. Placera lämpligt kärl jämte riggen och ta ut avtappningsslangen. Öppna kulventilen och låt den vara öppen tills allt vatten runnit ut.
6. Se till att inget vatten lämnas kvar i spillkärlet vid förvaring. Eftersom detta endast är rostskyddat med färg finns risk för korrosion.
7. Riggen behöver inte tömmas på partiklar, utan de kan ligga kvar i tanken.

Byta dekaler

Enklaste sättet att byta dekaler är genom att montera loss akrylskivorna (väggarna) en efter en och fästa dekalen.

1. Skruva loss ett ben. En Torx T50 mejsel behövs för skruvarna på ovansidan, och blocknyckel 13mm för undersidan.

2. Dra ut akrylskivan, fäst dekalen och sätt tillbaka skivan. För att underlätta i och urtagningen kan lite såpvatten strykas i och kring de svarta listerna.
3. Montera tillbaka benet.
4. Repetera steg 1-3 för varje akrylskiva.

Felsökning / Åtgärder

Motorskydd

Testriggens pump är försedd med ett så kallat motorskydd. Det har till uppgift att slå ifrån strömmen till motorn vid strömrusning (t.ex. vid låst axel). Om inget händer när strömmen till riggen slås på, kontrollera att tryckknappen på pumpmotorn är intryckt. Om pumpen stannar upprepade gånger så måste orsaken till problemet letas upp. (Exempelvis kan pumpen gå för tungt eller ha fastnat).

Stockning

Om inga partiklar tillsätts till flödet trots att reglaget står på maximal koncentration kan partiklarna ha stockat sig i ejektorn. Kontrollera först att tillräcklig mängd partiklar finns i tanken. Eventuellt kan en ståltråd användas för att rensa ejektorn utan att demontera den. Det kan också hjälpa att variera partikelkoncentrationen upp och ner upprepade gånger. Annars måste ejektorn plockas loss för rensning. Kontrollera då att det sitter ståltråd som ett kors i ejektormunstycket. Saknas detta skall ny 0,7mm rostfri ståltråd monteras som ett kors genom de fyra hålen på ejektormunstycket.

Läckage

Läckage i testriggen bör åtgärdas snarast. Vilken åtgärd som behövs beror naturligtvis på problemet. Generellt gäller att det är svårt att se exakt var det läcker eftersom vattnet sprider sig nedåt på utsidan av komponenterna. Ett tips är att torka torrt runt läckaget för att lättare se var vattnet läcker ut. Exempel på åtgärder mot läckage:

Läckage vid anslutning mellan slang och rör: Troligen räcker det att dra åt slangklämman/-klämmorna.

Läckage vid gängad anslutning, t.ex. vid pump eller ventiler: Prova först att dra åt anslutningen. Om detta inte hjälper, lossa anslutningen helt och lägg på ny gängtejp. Montera därefter tillbaka anslutningen och kontrollera att det är tätt.

Läckage vid gummitätad anslutning, t.ex. fläns vid backventil eller unionskoppling till ejektor: Prova först att dra åt anslutningen. Om detta inte hjälper, lossa anslutningen helt och kontrollera att gummipackningen ligger rätt samt att tätningsytorna är rena. T.ex. kan partiklar lätt orsaka läckage i en unionskoppling.

Läckage vid limmad rörkoppling: Ovanligt. Om det läcker i en skarv måste den bytas ut och limmas på nytt. Delarna kan inte återanvändas.

Läckage från andra komponenter, t.ex. tank, pump eller ventiler: Reparera eller byt ut den defekta komponenten.