Redesign of a water tank
- from metal to plastic

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by

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Abstract

This Master of Science thesis has been carried out in collaboration with Coffee Queen AB in Arvika, Sweden, to develop a construction basis for an improved water tank. From the beginning, the water tank was manufactured in metal. To reduce the costs, the company was interested in a plastic construction. The water tank, which is located inside a fresh brewing coffee machine, is used to boil water which later is mixed with coffee, tea or chocolate.

The first part of the project was to find out which manufacturing method to use. After some research in the area, it was decided to use injection moulding since the water tank is relatively complex. Also, it was the cheapest method since the total cost is divided over the production of 48 000 details in the coming eight years.

The second part of the project was to develop a construction basis for Coffee Queen to use in further development. Areas included in the construction basis was the tool solution, the water tank construction, the sealing of the tank, the outlet pipes, the overfilling protection, the cold water inlet, the level indicator and the electrical cables. An extensive literature study was made together with a number of company visits at plastic manufacturing companies. Concepts were developed and evaluated for all of the mentioned areas above and then put together into a final choice and recommendations.

The final choice of the authors consists of a plastic tank and a plastic lid. The tank should be made in a vertical tool with all outlet pipes in the front and the gasket stretched around the top edge of the tank. Both the over filling protection and the cold water inlet are plain pipes sticking out on the front of the tank. The snap fasteners and the level indicator are integrated in the plastic lid, which excludes several components and makes the assembly easier. The cable holes are rounded and the thermostat has been rotated by 90°. This plastic construction is considered to be the best choice since it is the simplest, cheapest and fastest solution to assemble.

It is recommended that to test a plastic lid before use to find out how well the plastic manages the heat. Also, heat testing of the integrated plastic snap fasteners has to be done.
Sammanfattning

Detta examensarbete har genomfömts i samarbete med Coffee Queen AB i Arvika för att ta fram ett konstruktionsunderlag för en förbättrad vattentank. Tidigare var tanken tillverkad i rostfritt stål, men för att minska kostnaderna var företaget intresserade av att ta fram en konstruktion i plast. Vattentanken, som sitter i en färskbryggande kaffemaskin, kokar vattnet som sedan blandas med kaffe, te eller choklad.

Den första delen av examensarbetet bestod i att ta reda på vilken tillverkningsmetod som är lämpligast att använda. Efter en inledande undersökning inom området bestämdes det att formsprutning var den bästa tillverkningsmetoden då vattentankens form är relativt komplex. Det var även den billigaste metoden, då totalpriset fördelas över totalt 48 000 detaljer som ska tillverkas de kommande åtta åren.

Den andra delen av examensarbetet bestod i att utveckla ett konstruktionsunderlag för Coffee Queens fortsatta utvecklingsarbete. Områdena som ingick i konstruktionsunderlaget var verktygslösningen, förlutningen av locket, avtappningsrören, överfyllnadsskyddet, kallvatteninloppet, nivåsensorn samt elkabeldragningen. En omfattande litteraturstudie genomfördes tillsammans med ett antal studiebesök och intervjuer hos plasttillverkande företag. Koncept utvecklades och utvärderades för alla ovan nämnda områden och sattes sedan samman till en slutgiltig helhetslösning samt rekommendationer.


Det är rekommenderat att testa ett plastlock innan det används för att ta reda på hur bra plasten tål värmen. De integrerade plastsnäppfästena måste också testas med avseende på värmetålighet.
Foreword

This Master of Science thesis has been preformed in collaboration with Coffee Queen AB in Arvika under a time period of 20 weeks. This thesis is the last part of the authors’ Master of Science in Mechanical Engineering degree at the Royal Institute of Technology. The authors have majored in Integrated Product Development. The contact person at Coffee Queen was Peter Larsson and the supervisor at the Royal Institute of Technology was Kaj Backström.

The authors would like to show gratitude to the persons who have given valuable help. Without the following persons’ participation and support this Master of Science thesis had been impossible to carry out:

Kaj Backström, supervisor, Company contact/Technical agent at the Department of Machine Design, the Royal Institute of Technology, for feedback on the concepts and general guidance.

Peter Larsson, contact person at Coffee Queen AB, for answering all questions coming up and for guidance along the way.

Bengt Stenberg, Professor in Polymer Technology at the Department of Fibre and Polymer Technology, the Royal Institute of Technology, who offered consultation about plastics and helpful books.

Further, the authors would like to thank Mikael Ulván at Vadstena Industriplast AB, Helge Steg and Robert Zajic at Arta Plast AB, Jörgen Wennstam at Örnplast AB and Anders Ljunggren at Ljunggrens Plastteknik AB for presenting their companies and offered valuable help concerning plastics and manufacturing techniques.

Stockholm, February 2006

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Terminology

To offer the reader an improved comprehension, some words are explained and presented below. These explanations are intended to be used as a dictionary when reading the report.

**Draft angle**

The angle of which the surfaces are sloping (See *Drafting*).

**Drafting**

When injection moulding, sloping surfaces on the detail is needed to ease the ejection of the detail when it is finished.

**Cavity**

The mould half that shapes the outside of the detail.

**Core**

The mould half that shapes the inside of the detail.

**Infusing**

Involving other materials in plastic material.

The injection moulding process is an important part of the report. The terms of the injection moulding tool is explained in the figure below.

![Figure 1. A cross section of the injection moulding tool (Becker et al, 2000, pp 241)](image)

(1) *Detail* – the plastic part

(2) *Mould halves* – where the detail is shaped

(3) *Ejector pins* – pushes out the detail when finished

(4) *Sprue* – where the plastic enters the mould

(5) *Water channels* – helps the detail to cool off
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1 Introduction

Coffee Queen AB manufactured their first coffee machines in 1983 and since they have developed rapidly. The company has about 65 employees and is located in Arvika, Sweden. Coffee Queen develops, manufactures and promotes coffee machines (Coffee Queen, 2005a).

1.1 Background

Inside one of Coffee Queen’s fresh brewing coffee machines, see the figure on the front page, is a water tank where the water is boiled. This tank is made of stainless steel and demands a lot of manufacturing procedures such as punching, bending and welding. Further, the assembly of the tank is rather complicated.

Coffee Queen was interested in investigating the possibilities of producing the water tank in plastic which resulted in this Master of Science thesis. A plastic solution would lead to cost savings for the company. According to Peter Larsson at Coffee Queen, 6 000 water tanks will be manufactured each year for 8 more years to come. This results in a total amount of 48 000 water tanks to produce.

1.2 Function of the original water tank

Water is boiled in the tank and then tapped off to mix with coffee, tea or chocolate. Cold water enters the tank from the \textit{cold water inlet} in the bottom, see number 1 in Figure 2. The water is heated inside the tank and then tapped off through the \textit{outlet holes}, which are marked with numbers 2 to 5 in Figure 2. On the outside of the tank is a layer of \textit{insulation} material.

![Figure 2. The outside of the tank: (1) Cold water inlet; (2) Outlet hole for coffee; (3) Outlet hole for topping; (4) Outlet hole for chocolate; (5) Outlet hole for tea; (6) Insulation; (7) Manual emptying of the tank; (8) Over filling protection; (9) Reset button for the over heating protection](image-url)
The cold water inlet is located in the bottom of the tank, pointing towards one of the walls, see the arrow next to number 1 in Figure 3. The inlet is a pipe, clamped together in the top, with a drilled hole in the side. In the short side is an outlet hole for a thyristor, see number 2 in Figure 3. The thyristor measures the temperature of the tapped water and sends the information to a display on the coffee machines front.

To protect the tank from being overfilled, there is an over filling protection. The protection consists of a vertical pipe along a wall inside the tank, see number 3 in Figure 3. If the water level reach the upper opening of the over filling protection, the water automatically leave the tank. If the tank needs to be emptied manually, there is a pipe in the bottom, see number 4 in Figure 3.

Figure 3. The inside of the tank: (1) Cold water inlet pointed towards the wall; (2) Outlet hole for a thyristor; (3) Over filling protection; (4) Manual emptying of the tank

Four water taps are located on the front of the water tank, see number 1 in Figure 4. To seal between the outlet holes and the water taps there are silicone plugs which are marked with number 2 in Figure 4.

Figure 4. The outside of the tank: (1) Three water taps; (2) Silicone plug
While reconstructing the tank, new plugs had to be used, see Figure 5. These require pipes instead of holes in the front of the tank.

![Figure 5. Silicon plugs; the two on the left are for the old outlet holes, the two on the right are for the new outlet pipes](image)

The lid is attached to the tank with eight screws, see number 1 in Figure 6. To seal between the lid and the tank there is a gasket, see number 2 in Figure 6. The electric components in the top are thereby sealed off from the steam in the tank. The cables from the electric components are led through the lid in two cable holes which are covered by rubber, see number 3 in Figure 6.

![Figure 6. An assembled view of the lid to the left and an exploded view on the right: (1) Screws; (2) Gasket; (3) Cable holes; (4) Heating element; (5) Level indicator; (6) Over heating protection](image)
In the middle of the tank is a heating element, see number 4 in Figure 6, which heats the water. The idea is that the water flows in layers, with the coldest water located on the bottom and the warmest water located on the top.

A level indicator is located in the lid, see number 5 in Figure 6. The long stick indicates the heating element when to switch on. The short stick indicates when the water level is too low and the water has to be refilled. To attach the sticks to the lid, they are screwed into a separate plastic plate which is secured to the lid with four screws. Between the plate and the lid there is a gasket which protects the plastic plate from the hot metal.

To protect the heating element from being over heated, an over heating protection is attached to the lid, see number 6 in Figure 6. The over heating protection turns the heating element off if it exceeds 115°C. If the over heating protection is once turned off, it has to be reset with the reset button.

1.3 Target definition

The assignment was to develop a proper basis for further development of the plastic water tank for the department of Research and Development at Coffee Queen. The main target was not to find a complete solution with a finished prototype, but to deliver a construction basis for the company to use in further development.

1.4 Problem definition

Coffee Queen was interested in manufacturing the water tank in plastic, since it would lead to cost reductions. The assignment was divided into two parts. The first part was to determine the manufacturing method of the plastic tank. The second part was to develop a construction basis for the new plastic tank.

1.4.1 Investigation of the manufacturing method

The first part of the assignment was to investigate which manufacturing method to use. Coffee Queen suggested that injection moulding and blow moulding should be examined. After some initial reading on the subject, it was decided to investigate rotational moulding and thermoforming as well. Some assembly techniques were also to be investigated.

1.4.2 Development of a construction basis

The second part of the assignment was to develop a construction basis for the plastic tank. The problem areas have been divided into smaller parts for an improved overview.

Tool construction

For all manufacturing methods there is a tool shaping the plastic detail. The tool is often expensive and therefore it was important to design it as simple as possible to lower the cost.
**Water tank construction**

The original water tank consisted of a tank and a separate lid, both in stainless steel. When constructing in plastic, several solutions with a tank and a lid were possible. All these solutions were to be investigated.

**Sealing of the tank**

The water tank had to be sealed to avoid leakage of steam from the boiling water. It was thought not necessary to seal against pressure. The mounting and the dismounting of the lid for cleaning took long time. The reason was that it was secured with eight fastening screws and eight washers. Further, the loose silicone gasket was difficult to align. To avoid this, an easier way to seal the tank without screws was desired.

**Outlet pipes**

While constructing the water tank in plastic, different silicone plugs had to be used. These plugs required outlet pipes instead of outlet holes. In addition, it is not preferred to maintain the five outlet pipes on two sides of the tank, since it would demand expensive wedges.

**Over filling protection**

The over filling protection consisted of a long vertical pipe inside the tank. When constructing in plastic, this construction was to be avoided. It is difficult to fill up the whole pipe with plastic and also to get it off the mould. A feasible solution for a plastic construction was to be investigated.

**Cold water inlet**

The cold water inlet caused an unwanted turbulent flow of the water, which resulted in water mixing. The amount of turbulence was accepted but an improved construction was desired.

**Level indicator**

The level indicator consisted of two threaded sticks indicating the water level, a plastic plate, a gasket, four screws and four washers, see Figure 7. The only necessary parts were the indicating sticks. If the other components was to be eliminated it would lead to cost savings.

**Cables**

The electric cables were placed around the lid and were held to place by two holes in the lid which were covered by rubber. An easier way of protecting the cables was searched.

*Figure 7. The level indicator*
1.5 Limitations

To get the assignment to a proper extent, limitations have been set up by both Coffee Queen and the authors. The limitations are the following:

Coffee Queen did not want the size and placement of the tank in the coffee machine to be affected. Also, the material was specified by the company to be polypropylene.

To get a proper size of the project, the authors also had some limitations. The assignment included the water tank only, the surroundings were not affected. Also, the components such as the over heating protection, the gasket and the heating element were not affected apart from possible relocations.

1.6 Methodology

The method to carry out this Master of Science thesis was done according to Ulrich and Eppinger’s Product Development Process model. This model is divided into five different phases, see Figure 8. However, this project only included the second phase, Concept Development, the white part in Figure 8. When this thesis was carried out, it was intended by Coffee Queen to continue the development of the water tank.

![Figure 8. Product Development Process (Ulrich & Eppinger, 2003, pp 203)](image)

The model for the Concept Development phase was modified to fit this project, see Figure 9. This phase have been divided into three phases; Planning, Pre-study and Concept Development.

![Figure 9. The Concept Development phase modified to fit this project](image)
In the Planning phase a visit to Coffee Queen was made to receive the problem description. In addition, a Gantt schedule, a problem definition and a target definition were made.

When all inputs were collected and the planning was made, the Pre-study phase began. An extensive literature study was made together with company visits and interviews at a number of plastic companies. Further, the first assignment – the determination of a manufacturing method – was finished.

With all information gathered, the Concept Development phase was started. This phase included concept generation, water flow tests, concept evaluation, tool construction and recommendations for Coffee Queen. Further, additional company visits were made. The best concepts were put together into a final choice of the authors’ and a recommendation for the future development.
2 Pre-study

To better understand how to construct in plastic, a pre-study has been made. This chapter contains a summary of the plastic to use, manufacturing methods and assembly techniques. The pre-study resulted in a decision of which manufacturing method and which assembly technique to use.

2.1 Polypropylene

The material was decided by Coffee Queen to be polypropylene. Polypropylene was chosen because it is already in use by the company for components in other coffee machines. It is also approved in contact with groceries. Further, it has great chemical resistance (Plast och Kemibrancherna, 2005).

The qualities of polypropylene are decided by the regularity level of the molecular structure, the length of the molecular chains and any added material (Plast och Kemibrancherna, 2005). Polypropylene is commonly modified by mixing the resin with glass fibres or mineral fillings. Common mineral fillings are talcum and chalk (Strömvall, 2002, pp 35). Mikael Ulván at Vadstena Industriplast recommended usage of 20 % talcum. This mix will give higher strength and thermal resistance but also a non transparent colour.

Polypropylene has no distinct melting point. The melting interval is between 160 and 170°C (Plast och Kemibrancherna, 2005). It is thought of great importance which manufacturing method is used, since the molecular structure is varying and affecting the melting temperature (Wennstam, 2005).

Polypropylene is colourless. It is thought difficult to paint or glue on polypropylene since it is a greasy plastic (Ulván, 2005). Therefore it is not suitable to paint the detail, it has to be coloured before manufactured. It can be manufactured in variations from almost transparent to any imaginable colour (Plast och Kemibrancherna, 2005).

While waiting for an EU standard of labelling for plastic products, it is recommended by Plastkretsen, PIR and Plast- och Kemibranscherna to use DIN 6120 standard. For the label of polypropylene, see Figure 10. The first number indicates the material; zero is equal to plastic. The second number indicates which plastic; five is equal to polypropylene (Plastkretsen, 2005).

![Figure 10. DIN 6120 standard labelling of polypropylene (Plastkretsen, 2005)]
2.2 Manufacturing methods

This section will present a description of four potential methods for manufacturing of the water tank. Two of the methods, injection moulding and blow moulding, were suggested by Coffee Queen. Rotational moulding was suggested by Bengt Stenberg, professor in Polymer Technology. Since these three methods are relatively expensive, an additional method, thermoforming, was added.

2.2.1 Injection moulding

*Injection moulding* is the most common method for plastic manufacturing. This method gives large advantages in speed and allows complex product designs, but it generally demands large batches because of the high tool cost (Berggren et al, 1997, pp 28).

**The process**

The first step in the process is to heat the polymer pellets so they become viscous. The pellets flow from the *feed hopper* into a barrel between the *screw* and the *heater bands*, see Figure 11. The pellets are melted by heating bands and by the friction heat from the rotating screw. This step also contains the storage of the melt. The size of the storage is the same as the volume that is needed to fill up the mould, which is called the *shot size* (Ladouceur & McKeen, 1999, pp 16).

*Figure 11. A schematic sketch of an injection moulding machine (Rosato, 2000, pp 31)*
When the barrel is filled, it is time for injection. The screw is pushed forward, without rotation, to inject the melt into the mould which consists of a cavity and a core, see Figure 12. A pressure of up to 2 500 bar can be used for the injection (Strömwall, 2002, pp 97).

![Figure 12. The cavity and the core of the injection moulding tool (Rosato, 2000, pp 31)](image)

At the time when the mould is filled and the plastic become solid, a pressure is set on the mould to compensate for the shrinking of the plastic. When the pressure in the mould is the same as the surrounding, the pressure is lowered and the cooling begins. When the detail is cold enough, the mould opens and the detail falls out (Strömwall, 2002, pp 100).

Cost estimates
To estimate the cost for one detail, some calculations have been made. Anders Ljunggren at Ljunggrens Plast estimated the cost for the tool and the production cost for the water tank. This resulted in a total price for one detail, see equation (1). The calculations include the tank only, not the lid.

- **Tool cost**: 180 000 SEK per tool
- **Production cost**: 10 SEK per detail
- **Batch size**: 48 000 details

\[
\text{Detail cost} = \frac{180\,000}{48\,000} + 10 = 14\,\text{SEK} \quad (1)
\]

Evaluation of the method
Injection moulding is a suitable choice for manufacturing of the water tank. It is a precise method which can be used for production of almost all shapes and details; it is just a matter of cost. In this case, the batch size is big enough to split the expensive cost into small pieces. The final cost is more than ten times cheaper than a rotational moulded product, see equation (1) and (2). For all the advantages and limitations with injection moulding, see TABLE 1.
### TABLE 1. Advantages and limitations with injection moulding (Ulván, 2005)

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A packed molecular structure provides high thermal resistance</td>
<td>High tool cost</td>
</tr>
<tr>
<td>No after-treatment is needed</td>
<td>High inner tensions</td>
</tr>
<tr>
<td>High accuracy</td>
<td></td>
</tr>
<tr>
<td>Injection moulded parts in polypropylene is resistant to boiling water</td>
<td></td>
</tr>
<tr>
<td>High production speed</td>
<td></td>
</tr>
<tr>
<td>Possibility to infuse other materials</td>
<td></td>
</tr>
<tr>
<td>Small screw threads can be done</td>
<td></td>
</tr>
</tbody>
</table>

#### 2.2.2 Blow moulding

*Blow moulding* is used for parts needing a void in the centre of the part (Ladouceur & McKeen, 1999, pp 26). Blow moulding is a combination of extrusion moulding and injection moulding.

**The process**

The process begins with an extrusion of a plastic tube. Around the tube, a two-part cavity is placed. With assistance of compressed air, the plastic tube is inflated against the cold cavity. Finally, the part falls out (Strömwall, 2002, pp 211). The process is illustrated in Figure 13.

![Figure 13. The four steps of blow moulding: (1) Extrusion of a plastic tube; (2) A two-part cavity surrounds the tube; (3) Compressed air is inserted to the mould; (4) The plastic is inflated against the cold cavity (Strömwall, 2002, pp 212)](image)
Evaluation of the method
Arta Plast is a company that provides both injection moulded and blow moulded details. During a visit at Arta Plast, Helge Steg strongly advised against the usage of blow moulding for the water tank. It is an inexact method that needs a large amount of after-treatment for complex details.

2.2.3 Rotational moulding
Just like blow moulding, rotational moulding offer the same opportunities concerning parts with an inner void and two-shell products (Strömvall, 2002, pp 217).

The process
Initially, plastic powder is added into a cold mould. After that, the mould is closed and inserted into an oven. During the whole process, including the melt and cooling step, the mould rotates around two axes. The powder melts by the heat in the oven and is evenly spread on the inner faces. The next is the cooling phase and when it is finished, the mould is opened and the part falls out (Strömvall, 2002, pp 219). The procedure is illustrated in Figure 14.

Cost estimates
To estimate the cost for one detail, some calculations have been made. Jörgen Wennstam (2005) estimated the cost for the tool and the production for the water tank which resulted in a total price for one detail, see equation (2). The cost estimate concerns the tank only, not the lid. The rotational moulded detail results in a closed tank which has to be cut open. The lid that is cut off is not useable in this case and is thrown away.

- Tool cost: 30 000 SEK per tool
- Production cost: 150 SEK per part
- Batch size: 2000 parts per tool

\[
\text{Detail cost} = \frac{30\,000}{2\,000} + 150 = 165\,\text{SEK} \quad (2)
\]

Evaluation of the method
It is possible to produce the water tank with rotational moulding. But after calculations, see equation (2), it is shown that it is more than ten times more expensive than injection
moulding. Further, it is a too inaccurate method for the purpose and all the small details in the tank are difficult to realize. For a listing of all the advantages and disadvantages, see TABLE 2.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>No inner tensions</td>
<td>Several tools are needed and it is impossible to make them exactly alike</td>
</tr>
<tr>
<td>Almost no draft angles are needed</td>
<td>Small screw threads cannot be done</td>
</tr>
<tr>
<td>The tool is cheap, <strong>but</strong> is only possible to use for 2000 details</td>
<td>Low production speed</td>
</tr>
<tr>
<td>Possibility to infuse other materials, <strong>but</strong> the porosity of the material can lead to leakage</td>
<td>After-treatment is needed since the rotational moulded detail is a closed container with only a small air hole</td>
</tr>
<tr>
<td></td>
<td>The complexity of the product is poor</td>
</tr>
<tr>
<td></td>
<td>There is no control over the distribution of material in the tool</td>
</tr>
<tr>
<td></td>
<td>The method is inexact, it can vary by several millimetres</td>
</tr>
</tbody>
</table>

*TABLE 2. Advantages and limitations with rotational moulding (Wennstam, 2005)*

### 2.2.4 Thermoforming

*Thermoforming* is a method appropriate for manufacturing of products with a relatively large face compared to the wall thickness (Strömvall, 2002, pp 223).

#### The Process

The process is simple. A heated plate of thermoplastic is formed after a mould with support of vacuum, see Figure 15.

![Figure 15. The principle of thermoforming: First, the plastic plate is heated. Then, the mould is sealed against the plate. Finally, the plate is shaped after the mould. (Strömvall, 2002, pp 225)](image-url)
Stretch and pull ratio
The stretch ratio is the quota between the surface of the formed detail and the original board’s surface area. An average ratio of 3:1 is maximum for thermoforming, normally the stretch ratio should be 2:1 or below (Strömvall, 2002, pp 228).

The pull ratio is the quota between the moulds maximum depth and the smallest distance across the mould opening. A pull ratio below 1:1 is recommended. This means that a detail that is 15 cm across should have a height larger than 15 cm (Strömvall, 2002, pp 228).

Evaluation of the method
After the literature studies, it was decided not to use thermal forming because of the lack of possibility to make complex products. Also, the stretch and pull ratio makes it impossible to manufacture the tank in one piece since the water tanks height is larger than the width.

2.3 Assembly techniques for plastics

By request of Coffee Queen, an investigation of assembly techniques has been made. The company suggested ultrasonic welding, but vibration welding and adhesive and solvent bonding has been considered as well.

There are two distinct categories of methods for assembling plastic parts without using additional fasteners or other features like snap fasteners. The two categories are welding and bonding. These methods do however require additional equipment and a secondary operation to join parts (Tres, 2000, pp 55).

2.3.1 Ultrasonic welding
The principle behind ultrasonic welding is based on vibration created by ultrasonic waves. One of the parts being assembled is vibrated against the other, stationary one. Heat is generated through vibration and melts the parts at the joint surface to accomplish the weld. (Tres, 2000, pp 55).

To assist the vibration, a weld leader is added to one of the parts; see Figure 16 (Berggren et al, 1997, pp 145).

![Figure 16. The weld leader on the left and the result on the right (Berggren et al, 1997, pp 145)](image)

Evaluation of the method
Ultrasonic welding is a cheap and widely used assembly technique according to Helge Steg (2005).

2.3.2 Vibration welding
Vibration welding is a friction welding technique for joining plastic parts. The idea is simple and based on that two parts are clamped together. One part is held stationary while the second
part is vibrated. Friction along the surfaces generates the heat that welds the two parts together (Tres, 2000, pp 94).

**Evaluation of the method**

Vibration welding is similar to ultrasonic welding. It is though an unusual and tricky technique, according to Helge Steg (2005). It should not be used for this application.

### 2.3.3 Adhesive and solvent bonding

Adhesive bonding is an assembly process by which two parts are held together by an adhesive. The adhesive itself is a substance capable of holding the parts together. The principle of solvent bonding is to add a liquid solvent where the parts should be joined. The liquid solvent dissolves the surfaces and when the solvent evaporates, the parts are joined (Tres, 2000, pp 107).

**Evaluation of the method**

There could be a problem with adding solvents or adhesives to the construction. The materials have to be approved to use in contact with food. Also, it is difficult to use this method since polypropylene is difficult to glue together with itself, see chapter 2.1.

### 2.4 Summary of the pre-study

The material was already given; polypropylene. Polypropylene is plastic which is suitable for almost all manufacturing methods. It was recommended by Mikael Ulván (2005) to add 20 % talcum into the plastic resin in order to increase strength and thermal resistance.

After a discussion with Peter Larsson, contact person at Coffee Queen, it was decided to continue the research of injection moulding. This method is more suitable for this semi-complex water tank than the others. Injection moulding is also superior since it turned out to be the cheapest. Further, injection moulded product can handle the heat better, which is desirable for the water tank.

Since polypropylene is difficult to glue together, the solvent and adhesive bonding was excluded. Further on, ultrasonic welding is more suitable than vibration welding according to Helge Steg (2005). For these reasons, ultrasonic welding was chosen for further consideration.
After deciding which manufacturing method to use, a study on design features that influence the product performance was made. This chapter includes aspects on wall thickness, tension concentrations, weld lines, parting lines, drafting surfaces, wedges, screw threads, ribs, snap fasteners and hinges. All these aspects are good to have in mind when constructing the water tank.

### 3.1 Wall thickness

For injection moulded products it is best for the finished detail to use the smallest possible wall thickness to minimize the cooling time. Generally, wall thicknesses of 2-3 mm are used. Uneven distributed material will lead to warping, sinking marks on the surface, porosities, difficulties to keep tolerances and long cycle times at the process. For a view of how warping and porosities occur, see Figure 17 (Berggren et al, 1997, pp 200).

Figure 17. Uneven distributed material leads to warping and porosities (Berggren et al, 1997, pp 200)

A corner with a straight angle on the outside and a rounded inside can lead to problems because of the accumulation of material in the corner. To maintain an even wall thickness, an outer radius should be used, see Figure 18 (Berggren et al, 1997, pp 201).

Figure 18. Accumulation of material in a corner (Berggren et al, 1997, pp 201)
Suddenly variations in wall thickness lead to internal tension or porosity. In the cases where the variations cannot be avoided, the transition should be performed gradually. When varying wall thickness is used, the sprue where the plastic enters the mould should be placed at the thick section to enable effective packing (Berggren et al, 1997, pp 201).

### 3.2 Tension concentrations

One of the most common reasons for breakdown of a plastic construction is the lack of radiiuses. The presence of ribs, holes, taps and corners involves discontinuity which results in higher locally tension levels, so called tension concentrations (Berggren et al, 1997, pp 206). To receive a construction with less tension concentrations, the radiiuses should be at least half the wall thickness (Berggren et al, 1997, pp 207).

### 3.3 Weld lines

In most injection moulded details, there are weld lines. Weld lines is the areas in a detail where two material flows meet during the forming process, see Figure 19. Those weld lines lead to reduced strength and surface defects (Berggren et al, 1997, pp 203).

Weld lines can for example be formed around a hole. These are generally meant to be used as screw holes and it is easy to realize that the weld lines often cause breakdown (Berggren et al, 1997, pp 203). Therefore, it is important to keep in mind that weld lines are weaknesses.

### 3.4 Parting lines

The mould is divided into two halves, which are mounted together during the form filling and the cooling process of the plastic material. The plane where the mould halves meets is called the parting plane. Plastic material will pour out in the parting plane which will create parting lines on the finished product (Berggren et al, 1997, pp 208).

The parting lines will always be visible on the plastic detail. Therefore, it is important to place the parting plane in an appropriate location where the lines do not disturb the appearance (Berggren et al, 1997, pp 209).
3.5 Drafting surfaces

All the surfaces perpendicular to the parting plane, *drafting surfaces*, must be angled. Otherwise, scratches can appear on the detail and it can be difficult to part the detail from the mould (Berggren et al, 1997, pp 209).

The drafting angle can be discussed, but it should be at least 0.5° for a high lustrous finish or for normal finish when the polishing direction is the same as the opening direction. Regarding etched surfaces, the drafting angle should be at least 3° for fine textures and 7° for rough textures (Berggren et al, 1997, pp 210). A drafting angle of 10° is optimal, but an angle of about 3° is enough for the water tank construction according to Robert Zajic (2005).

3.6 Wedges

A lot of details have such a shape that the mould tool needs to be opened or parted in multiple directions. For example, see Figure 20. To produce a pitcher, three mould parts are needed; a core from the top, a cavity from below and a wedge from the side to accomplish the handle.

A *wedge* is a mould part which moves in another direction than the mould. In this way, a wedge can make holes, hooks and handles, which must be made with a movable mould part in another direction than the mould opening. Wedges can be placed in both mould halves and can be turned towards the outside or inside (Berggren et al, 1997, pp 144). Wedges should though be avoided as far as possible since they are expensive (Steg, 2005).

3.7 Screw threads

Introducing *screw threads* in an injection moulded detail means that the core needs to move to eject the detail. To achieve internal threads, the thread is released either by unscrewing the core or by using a *collapsing core*.

A collapsing core is able to mechanically change the diameter in order to pull it out without deforming the treads. These cores are available as standard elements to build into the tools (Strömvall, 2002, pp 160). An element like this is though expensive and should be avoided if necessary (Steg, 2005).
3.8 Ribs

Strengthening ribs is a commonly used way to increase stiffness and strength of an injection moulded product. A correct construction means material savings and thereby also weight and cost savings. Often are though ribs used in excess which could lead to warping and tension concentrations in the detail (Berggren et al, 1997, pp 210).

3.9 Snap fasteners

Snap fasteners is used to attach parts to each other, for example a tank and a lid. Problems can though appear at manufacturing, particularly when the part is separated from the tool. There are two types of snap fasteners; the ones that needs removable wedges and the ones with fixed mould halves that seals against each other (Strömvall, 2002, pp 178).

A removable wedge leads to an extra cost. The cost size is depending on the complexity of the wedge (Ulván, 2005). For an example of a removable wedge, see Figure 21. The wedge moves in two directions, first to the left and then downwards, which requires space. This is an expensive way to make a snap fastener.

Another way of creating snap fasteners is to let the mould halves meet, see Figure 22. The upper mould half is sealing against the lower with an angle of at least 10°. Then, the snap is created without any moving parts. This method is cheaper, but results in a hole under the snap (Ulván, 2005).

Polypropylene is though not a very suitable material for snap fasteners. The plastic is flexible, but not stiff enough (Ulván, 2005).
3.10 Hinges

*Hinges* in most constructions are often formed by an unfastened hinge in metal. But there are also injection moulded hinges in plastic to use with the same function as metal hinges. The advantage with the injection moulded parts is the possibility to make the hinges as a part of the construction, see Figure 23 (Strömvall, 2002, pp 181).

![Figure 23. Two types of injection moulded hinges: the left is a snap hinge; the right is a hinge made by meeting cores (Strömvall, 2002, pp 182)](image1)

The hinge will always be a weak place in the construction. Weld lines affecting the strength can often not be avoided. The strength in a hinge is extremely dependent of the material. Other demands on the product can require another choice of material that is not suitable for hinges (Strömvall, 2002, pp 181).
3.11 Summary of the injection moulding aspects

The study of injection moulding aspects resulted in a list of things to keep in mind when constructing the plastic water tank. See the list below for a short summary.

- It is important to remain an even wall thickness to not receive material defects.
- The material should be as thin as possible to minimize the cooling time of the detail. The cooling time determines the production speed.
- It is important to keep the weakness of the weld lines in mind, for example around a hole.
- The radius of the edges should be at least half the wall thickness.
- It is important to position the parting plane in an appropriate location where the parting lines do not disturb.
- All surfaces perpendicular to the parting plane must be angled at least 3°.
- Wedges are used to accomplish complex shapes, but should be avoided since they are expensive.
- While manufacturing screw threads, the thread is released either by unscrewing the core or by using a collapsing core which is expensive. Screw threads should therefore be avoided if possible.
- Ribs are used to increase stiffness and strength. Often are though ribs used in excess which could lead to warping and tension concentrations.
- There are two types of snap fasteners; the ones requiring a movable wedge and the ones included in the tool. Movable wedges should always be avoided if possible.
- Hinges can be made as a part of the plastic detail, but will always be a weak place in the construction.
4 Construction aspects

When reconstructing the water tank to be manufactured in plastic, there were first some construction aspects to consider. This chapter covers aspects for the tool construction and different options when constructing the lid.

4.1 Tool construction

When manufacturing for injection moulding, it is good to have in mind how the tool should look like. By doing that, the elements on the detail can be placed correctly from the beginning. After a discussion with the tool constructor Robert Zajic (2005), two tool options could be presented; a horizontal tool and a vertical tool.

It was chosen to call the two types of tool constructions horizontal and vertical since the parting planes are aligned in those directions. This section will describe the advantages and disadvantages with the horizontal and vertical tool.

4.1.1 Horizontal tool

A horizontal tool includes a cavity and a core, see Figure 24. When the detail has cooled and it is time for ejection, the cavity and core are separated and the detail is pushed off the core by ejector pins. The high depth of the cavity and the core makes the tool tall which requires a large injection moulding machine (Zajic, 2005).

Figure 24. The horizontal tool: (1) The core; (2) The detail; (3) The cavity
The design of the tool results in drafting surfaces on the short and long sides of the tank, see Figure 25. As mentioned before, a drafting angle of 3° is suitable. The sprue, where the plastic enters the mould, should be located in the centre of the bottom (Ljunggren, 2005).

4.1.2 Vertical tool

A vertical tool includes two cavity halves and a wedge instead of a core, see Figure 26. When the detail is cooled during the injection moulding process, the cavities are removed from the detail. At that point the detail is still attached to the wedge, of which it is pushed off with hydraulic assistance.

With the hydraulic wedge, the tool will be smaller than the horizontal tool. Further, the vertical tool becomes more stable than a horizontal tool since fewer wedges are needed (Zajic 2005).

Figure 25. The tank with drafting angles included

Figure 26. The vertical tool: (1) The wedge; (2) The detail; (3) The cavities
When designing for a vertical tool, drafting surfaces must be added to the short sides and the bottom of the tank, Figure 27. This tool construction also needs drafting angles of 3°. The sprue should be located below the outlet pipes on the front side (Zajic, 2005).

The drafting of the tank manufactured in a vertical tool results in larger faces on the front and back. This means that it is possible to locate more components on the front, where it is preferred.

4.2 Lid options

There are three lid options when constructing the tank. One option is to have a separate lid in stainless steel. The second option is to have a separate lid in plastic. The third option is to have a lidless water tank, where the tank and lid are sealed together permanently through ultrasonic welding. These three lid options will be described in this section.

4.2.1 Metal lid

In the beginning of the project, Coffee Queen had the idea to keep the lid in metal and only manufacture the tank in plastic. The advantages with a metal lid are the strength and the heat resistance.

The limitation with the metal lid is the inflexibility. All the components must be kept in the original performance and no cost savings can be done with them. Also, the fastening options are limited, metal snap fasteners and screws.

If screws are used, the original edge where the screws are attached has to be turned outwards to make a tool without wedges, see Figure 28. Since there is lack of space in the surroundings, the outline of the edge must be the same as of the original. Therefore, the volume of the tank decreases by approximately one decilitre. Also, the dimensions decreases and makes it difficult to make room for all components on the tank.
Figure 28. If fastening screws are used, the fastening edge must be turned outwards instead of inwards. As a result of this, the total volume of the tank decreases. The original is on the left, the flipped edge is on the right.

4.2.2 Plastic lid

If the lid is manufactured in plastic, components such as the level indicator and snap fasteners can be integrated. Also, the cable can be led through the cable holes without a gasket. This leads to cost savings since several elements are excluded. It is not necessary to implement ribs on the lid for stabilizing purposes. Both Ljunggren (2005) and Zajic (2005) advised against ribs, they believed it will be stable anyway.

A possible disadvantage with a plastic lid is the lower heat resistance. The steam from the boiling water could cause a weak lid. This has to be tested carefully before taken in production.

According to Anders Ljunggren at Ljunggrens Plastteknik, the tool cost for the lid is approximately 120 000 SEK. Further, he estimated the production and material cost to 7 SEK for each detail. With a batch size of 48 000 details, this leads to a total cost of 9.50 SEK for the lid, see equation (3).

\[
\text{Lid cost} = \frac{120\,000}{48\,000} + 7 = 9.50\,\text{SEK}
\]  

(3)

4.2.3 A lidless tank

The third solution of the sealing is to weld the lid and the tank together permanently. The sealing is preferably done with ultrasonic welding, see chapter 2.3.1. With this solution the service staffs replace the dirty tank instead of cleaning it. A replacement would take less time than a cleaning.

For this to be an adequate solution, the total cost of the sealed tank must be lower than the two-piece tank together with the service cost for cleaning. The cost for the sealed tank includes two moulding tools and a welding procedure. In addition, the cost includes components as the level indicator and the heating element, since these are thrown away together with the tank if replaced. Further, the environmental aspects on a lidless tank must be considered. It is not healthy for the environment to throw away the whole tank with several different components inside.
4.3 Summary of the construction aspects

First, the tool construction was discussed. A vertical tool would give the best result, according to Robert Zajic (2005). The tool would become smaller and more stable. While concerning the drafting, the vertical tool would result in a tank with a larger face in the front. Since most of the components are located in the front, this space is needed. For these reasons, it is recommended to use a vertical tool solution.

Secondly, the lid options were discussed. The lidless tank was the first to be excluded. It results in a lot of unnecessary operations and it is estimated to be more expensive compared to use of a cleanable tank with a separate lid. The remaining two options are the metal lid and the plastic lid. The plastic lid is more flexible; some components can be excluded which leads to cost savings. In addition, it is simple to integrate fastening devices on this option. There is though a big disadvantage with the plastic lid; it may not handle the heat. Therefore, careful testing is required before it is taken in production. The recommendation is to use a plastic lid if it can handle the heat. If not, the metal lid should be used.
5 Concept generation and evaluation

The concept generation started with a brainstorming session which considered each problem area separate. The initial brainstorming session resulted in a large number of concepts, of which some were rejected immediately. The next step was to obtain ideas for plastic solutions. Companies like IKEA, Rusta and Claes Ohlsson were visited.

Thereafter, a number of company visits were made to collect more knowledge of how to construct in plastic. The concepts were discussed with people at the companies with competence in the area. This resulted in economical aspects, feasibility aspects and advices of how to improve the concepts. In addition, some additional concepts were generated.

After the brainstorming, the idea gathering and the consultation of experts, the concepts were refined. This chapter will present the result of the refined concepts. The concepts covers the areas of snap fasteners, plastic lid, outlet pipes, over filling protection, cold water inlet, level indicator, electrical cables and design of the flaps.

The concepts are marked with letters, see explanation below. Some of the rejected concepts are presented in Appendix 1.

- A concept marked with a $V$ is a good choice if a vertical tool is used
- A concept marked with an $H$ is a good choice if a horizontal tool is used
- A concept marked with a $P$ is a good choice if a plastic lid is used
- A concept marked with an $M$ is a good choice if a metal lid is used

If the letter is excluded, the concept is not feasible with the construction choice. If the letter is shaded, the concept is feasible with the construction choice, but not recommended.
5.1 Snap fasteners

To lower the assembly time of the water tank, it is preferred to eliminate the eight screws which hold the tank and lid together. By introducing snap fasteners, the assembly time could be reduced significantly. This section will present wire snap fasteners, fixed metal snap fasteners, integrated snap fasteners and plastic snap fasteners with hinges.

5.1.1 Wire snap fasteners

Wire snap fasteners added to the water tank can be seen in Figure 29. The snap is held in place by a wire that goes around the tank. The wire is held in place by an edge in the plastic.

Advantages
- The metal snap fastener is strong and is hard to break
- The wire around the tank stabilises the plastic

Disadvantages
- The assembly time is increased
- An additional part leads to an additional cost

The wire must be custom made for the water tank.

Figure 29. Wire fastener

5.1.2 Fixed metal snap fasteners

A fixed metal snap fastener is shown in Figure 30. The snap fastener is attached to the metal lid by a weld or by screws.

Advantages
- The metal snap fastener is strong and is hard to break
- A standard snap fastener can be used, no customisation is needed

Disadvantages
- The assembly time is increased
- An additional part leads to an additional cost

Figure 30. Fixed metal snap fastener

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5.1.3 Integrated plastic snap fasteners

Plastic snap fasteners can be integrated in the water tank by adding them to the lid. The snaps are bended and attached to a knob on the tank. The plastic is thin at the bend to make the bending possible, see Figure 31. A thickness of about 0.3 mm is reasonable for the bend (Ljunggren, 2005). For a full view of the snap fasteners, see Figure 32.

![Figure 31. A cross section of the snap fastener](image)

To accomplish these snap fasteners, the location of the sprue is important. According to Mikael Ulván (2005), the molecule chains create the bend and therefore they have to cross the bend with an angle of 90º, see Figure 33. If the molecules are wrongly organised the snap fastener will break. For this reason, the sprue has to be located in the middle of the lid.

**Advantages**
- Since the snap is integrated in the lid, it is cheap to manufacture
- No extra part to purchase
- No extra part to assemble

**Disadvantages**
- When water is boiled in the tank, the plastic is heated and the bend could loose its strength. A similar plastic solution has been tested in boiling water and it worked satisfactorily. Additional tests are though necessary before the concept is taken in production.

![Figure 32. Plastic snap fasteners integrated in the lid](image)

![Figure 33. How the molecule chains must be organised to make a strong fastener](image)
5.1.4 Plastic snap fasteners with a hinge

The plastic snap fasteners can also be made as separate parts, see Figure 34. The hinges for the fasteners are located on the tank and can be made with both a vertical and a horizontal tool. The vertical tool gives though a much better result.

![Figure 34. Plastic snap fastener with a hinge](image)

Advantages
- The plastic handles the heat better since it is not bent

Disadvantages
- A hinge leads to an extra assembly operation
- An additional injection moulded part leads to an extra tool cost

5.1.5 Evaluation

Initial tests have been preformed to find out how well the integrated plastic snap fasteners can handle the heat. The tests showed that the plastic lid and the fasteners can handle the heat perfectly. Additional test should though be done before the concept is taken in production.

If a plastic lid is used, the integrated plastic snap fasteners are the best choice. They are the most simple and least expensive fasteners. If a metal lid is used, the fixed metal snap fasteners should be used. They are stronger and cheaper than the wire fasteners.
5.2 Plastic lid

If a plastic lid is used, the gasket can be integrated in a satisfying way. In the original water tank solution, the gasket was loose and therefore difficult to align correctly. This section will present two concepts for a plastic lid with the gasket integrated in two different ways.

5.2.1 Food saver I

The idea for the concept has been taken from a regular food saver, see Figure 35. There is a gasket between the lid and the tank, which is placed in a slit in the lid. Additional fasteners for the lid are though necessary.

![Figure 35. A cross-section of the Food saver I; the dark area is the gasket](image)

**Advantages**
- Easy manufacturing
- Easy to assemble since the lid is designed to fit the tank

**Disadvantages**
- Demands further investigation of the gasket
- If the lid curves as a result of the steam, the sealing can fail

5.2.2 Food saver II

The second food saver concept is similar to the first, see Figure 36. The difference is the placement of the gasket. Instead of placing the gasket in a slit in the lid, the gasket goes around the tank.

![Figure 36. A cross-section of the Food saver II; the dark area is the gasket](image)
Advantages

- Steam sealed even if the lid is curved by the heat
- Easy manufacturing
- Easy to assembly since the lid is designed for the tank

Disadvantages

- Demands further investigation of the gasket

5.2.3 Evaluation

The concepts are almost equal, the only difference is the gasket location. Tests on the plastic lid have to be performed. If the tests show that the lid is curved by the heat, the second food saver concept should be used since it would seal better against steam.
5.3 Outlet pipes

The outlet pipes were not to be affected apart from changing of the holes to pipes. The vertical placement should be maintained but the horizontal placement could be rearranged if there was enough space. This section will present a concept with all outlet pipes in the front.

5.3.1 All outlet pipes on the front

The original pipes were spread over two sides of the tank, see Figure 37. This requires two wedges when designing for plastic which makes the tool weak and leads to a bad result. To get around the problem, the idea is to move the pipe on the side next to the others on the front, see Figure 38.

Advantages

- If a vertical tool is used for the concept with the pipes on the front, no wedge is needed
- If a horizontal tool is used, the moulding tool becomes cheaper since only one wedge is needed instead of two

Disadvantages

- There can be short of space to fit all the five pipes on the same side, especially if a horizontal tool is used. Also, rounds on the edges are necessary, which takes up extra space.

5.3.2 Evaluation

It is recommended to relocate the pipe to the front if there is enough space since it becomes a lot cheaper.
5.4 Over filling protection

The original solution with a long pipe is difficult to manufacture with injection moulding. This leads to an over filling protection consisting of a short pipe at the top of the side which can be designed in different ways. This section will present two concepts; a plain pipe and a down pointing pipe.

5.4.1 Plain pipe

The idea is to place a short pipe on the top of the front side, see Figure 39. As long as there is enough space for the hose, it is possible to locate the pipe on any of the sides. Most space is though available on the front of the tank.

Advantages

- Easy to manufacture
- If placed on the front, the pipe can be made with the same wedge as for the outlet pipes and no extra cost is added

Disadvantages

- When the hose is attached to the pipe and bended 90º, it takes up much space.

Figure 39. The over filling protection consists of a short pipe on one of the long sides
5.4.2 Down pointing pipe

Another idea is to place the pipe in an indentation in the side of the tank, see Figure 40. The hose is attached vertically and is placed in the indentation. This idea is only possible to manufacture with a horizontal tool without a wedge. A vertical tool demands a wedge.

**Advantages**
- Easy to manufacture
- The hose takes up no space in the surroundings

**Disadvantages**
- A slightly smaller volume of the tank

5.4.3 Evaluation

The plain pipe is cheaper to manufacture than the down pointing pipe, but takes up more space. If there is enough space on some of the water tank’s sides, the plain pipe should be used. Otherwise, the down pointing pipe is a satisfactory choice.

*Figure 40. The over filling protection is placed in an indentation of the tank*
5.5 Cold water inlet

The cold water enters the tank from the cold water inlet. It is important to get a non-turbulent flow in order to allow the water to create layers with the coldest water on the bottom and the warmest on the top. The solution today with a metal pipe, see chapter 1.2, is accepted by Coffee Queen concerning the flow. The plastic solution has to be equal or better. This section will present a cold water inlet from below, a plain pipe from the side and an indented pipe from the side.

5.5.1 From below

In order to do a construction resembling the original, the concept in Figure 41 was created. The inlet is a pipe from the bottom to where the hose is attached. This concept demands a horizontal tool. If a vertical tool is used, an extra wedge is needed.

The hole can be tricky to manufacture. However, if an angle of $10^\circ$ on the hole can be allowed, the hole-problem is solved with meeting cores, see Figure 42.

Advantages

- Similar to the original
- Easy manufacturing

Disadvantages

- Since the inlet is from below, the water will flow diagonally upwards because of $10^\circ$ angle instead of horizontal which causes a lot of turbulence

Figure 41. The inlet from below is similar to the original

Figure 42. Two meeting cores can accomplish the otherwise tricky hole, $\alpha>10^\circ$
(Ulván, 2005)
5.5.2 Plain pipe from the side

It would be preferred to let the water flow horizontally from the side to decrease the risk of turbulence. An easy way to accomplish this is to simply add a short pipe on one of the sides, see Figure 43.

It is possible to place the inlet anywhere around the tank where it is enough space. It is though preferred to locate the inlet on one of the long sides since it is much easier to integrate in the tool solution. If a horizontal tool is used, the inlet can be included in the outlet pipe wedge. If a vertical tool is used, no wedge is needed at all.

Advantages
- Easy manufacturing if placed on the front or the back

Disadvantages
- While the hose is attached, the side pipe concept takes up a lot of space from the surroundings

5.5.3 Indented pipe from the side

Concerning the concept above, lack of space can be a problem. This can be avoided by placing the pipe in an indentation on the side or on one of the corners, see Figure 44 and Figure 45. The middle position is slightly cheaper to manufacture (Zajic, 2005).

When designing this concept for manufacturing, it is good to keep in mind that good cooling is necessary. In order to include water channels for cooling, a distance between the pipe and the wall of the indentation of about 8 to 10 mm are needed (Zajic, 2005).
Advantages

- Space saving
- Easy to integrate in the mould

Disadvantages

- More expensive than a plain pipe
- Takes up space from the surroundings, but not as much as the plain pipe concept

Figure 45. The cold water inlet is located on an indentation on the middle of the side

5.5.4 Evaluation

The plain pipe on the side and the indented pipe from on side result in less turbulence than the pipe from below. They are also easier to manufacture if they are located on the front.

It is cheaper to manufacture the plain pipe than the indented pipe. It takes though up more space when the hose is attached. If there is enough space in the surroundings on the long sides, the plain pipe should be used. Otherwise, an indented pipe is recommended to use.

Tests have been preformed on the cold water inlet concepts to find out how well different locations of the inlet affect the water flow. The tests showed that the original cold water inlet and the inlet from below concept made the water flow upwards and caused a lot of turbulence.

Further, the plain pipe on the side and the indented pipe on the side resulted in satisfying results. It does not matter on which side the inlet is placed, as long as there is enough space. In addition, it does not matter that the inlet is indented and closer to the opposite wall. The best result was received when the inlet was placed in the middle of the long side and therefore this location is preferred. For more details of the cold water inlet tests, see Appendix 3.
5.6 Level indicator

The level indicator is originally attached to the lid with a plastic plate, a gasket, four screws and four washers. Several of the original parts can be excluded when constructing in plastic. This section will present a built-in solution and an infused solution for the level indicator.

5.6.1 Built-in solution

If the lid is in plastic, the plastic component where the sticks are attached can be integrated in the lid, see Figure 46.

Advantages

• Several parts can be excluded which decreases the assembly cost

Disadvantages

• The threaded sticks have to be ordered separately and probably be screwed in by Coffee Queen

5.6.2 Infused solution

Another idea is to infuse two small metal knobs or sticks in the side of the tank, see Figure 47. These would be located on the same height as the original sticks and have the same function.

Advantages

• Takes up no space
• Several components can be excluded which lowers the assembly cost

Disadvantages

• Expensive to infuse metal parts

5.6.3 Evaluation

If the lid is in plastic, the built-in solution is recommended to use. If the lid is in metal, the original solution should be used. The infused solution is far too expensive and is not recommended to use at all.
5.7 Electrical cables

To avoid the electrical cables to be tangled up they have to be separated from each other. The original solution had two holes covered by rubber to protect the cables. This section will present holes similar to the original and open cable holes.

5.7.1 Holes

The concept is similar to the original solution with holes in the lid, see Figure 48. When manufacturing in plastic, the rubber protections can be excluded because of the rounded holes.

Advantages
- Easy to manufacture
- No rubber protections are needed

Disadvantages
- It is tricky to lead the cables through the holes

5.7.2 Open cable holes

To get the cables through the holes easier, the cables could be placed in open cable holes in the lid, see Figure 49. The cables can then be placed in the hole one at a time which is easier.

Advantages
- Easy to manufacture
- Easy to attach the cables

Disadvantages
- The cables may not be held to place properly

5.7.3 Evaluation

The open cable holes have to be tested before taken in production. If they work as intended, they are slightly better than the closed cable holes.
5.8 Design of the flaps

It is difficult to manufacture the plastic lid with the bended flaps for the thermostat and the screws. The flaps are thin and would be complicated to get off the mould, according to Robert Zajic at Arta Plast (2005). This section will present a solution with a rotated thermostat and a solution with foldable flaps.

5.8.1 Rotated thermostat

Zajic (2005) suggested that the flaps for the screws can be formed by two wedges from the side. The thermostat flap is though too large and should be reconstructed. The idea is to rotate the thermostat by 90°, see Figure 50 and Figure 51. In this way, the lid is easy to manufacture and the reset button will still be reachable.

Advantages

• A stable construction

Disadvantages

• The wedges on the side lead to a higher cost
• The reset button is not as visible as before

Figure 50. The original placement of the thermostat

Figure 51. The thermostat rotated by 90°
5.8.2 Foldable flaps

Another idea is to make the flaps flat with a thin hinge, similar to the hinges in the integrated plastic snap fasteners. In the assembly, the flaps are folded down for attachment, see Figure 52 and Figure 53.

Advantages

- No wedges are needed, the tool becomes much cheaper

Disadvantages

- Not as stable as without a fold

5.8.3 Evaluation

Both concepts are feasible, but the folded flaps are cheaper. There is also a possibility to combine these two concepts. The thermostat can be rotated upwards and the screw flaps can be folded.

5.9 Summary of the concept generation and evaluation

Concepts were generated for all problem areas: snap fasteners; plastic lid; outlet pipes; overfilling protection; cold water inlet; level indicator; electrical cables and design of the flaps.

The concepts were evaluated and then summarized in two overview matrices, see Appendix 2. One matrix considers the concepts regarding the lid and the other matrix considers the concepts regarding the tank. In both matrices, the concepts are rated good or bad.
6 Recommendations

The main task of the thesis was to develop a construction basis for the water tank. In this chapter follows recommendations for Coffee Queen’s continued research and development.

All concepts have been evaluated separately and were put together into suggestions to a final solution. The tank solutions are separated from the lid solutions and can be mixed and matched as wanted. Finally, the best tank solution has been combined with the best lid solution to be the best alternative for the water tank. First, some general recommendations are listed.

6.1 General recommendations

- The manufacturing method injection moulding should be used. It is the most accurate and profitable solution.
- Mikael Ulván at Vadstena Industriplast recommended usage of 20 % talcum in the plastic. This mixture will give higher strength and thermal resistance to the plastic.
- The plastic has to be tested. A plastic lid prototype should be made to test if it handles the heat.
- It also has to be tested if it is possible to make plastic snaps fasteners and bends. For example, the integrated plastic snap fasteners and the folded flaps are relying on a bendable plastic.
- Choose what kind of tool solution that should be used before getting into details. Many concepts failed when the tool construction was considered.
- Avoid wedges if possible since they are expensive (Steg, 2005).
- Always consider the drafting. A drafting angle of about 3° is appropriate.
- It is important to have an even wall thickness.
- Both Ljunggren (2005) and Zajic (2005) advised against the usage of ribs in the lid, they believed it will be stable anyway.

6.2 Tank solutions

There are two options when making the tool for the tank, a horizontal solution and a vertical solution. Both solutions are satisfactory, but the vertical tool solution is better according to Robert Zajic (2005). The vertical tool becomes smaller and more stable than the horizontal tool. Both solutions are though presented below.
6.2.1 Vertical tool

If a vertical tool is used, the mould halves meet vertically in the middle of the short sides on the tank. Thereby, it is preferred to locate components on the front, back or on the bottom, where they can be located without an extra wedge. Below follows a list of things to keep in mind when designing the water tank for a vertical tool.

- All the outlet pipes should be located on the front.
- Drafting has to be added to the short sides and to the bottom. In addition, components like pipes and knobs for snap fasteners need drafting.
- Place as many components as possible on the front or back since these do not require any extra wedges. There is lack of space on the back, so the front is recommended.
- Pipes on the bottom are possible to make, but a cold water inlet from below is impossible without a wedge.
- An alternative to snap fasteners is to make a sealed tank with an ultrasonic weld, see chapter 4.2.3.

Vertical tool solution I

The vertical tool solution in Figure 54 is equipped with a plain pipe as overfilling protection, an intended cold water inlet and infused knobs for the level indicator. For fastening, there are separate snap fasteners with hinges. The gasket is located inside the lid.

Vertical tool solution II

The other vertical solution, seen in Figure 55, is equipped with a plain pipe over filling protection, a plain pipe cold water inlet and knobs for fastening of fixed metal snap fasteners or integrated plastic snap fasteners. The gasket is stretched around the tank in a slit.
Horizontal tool

If a horizontal tool is used, the mould halves meet at the opening of the tank. Therefore, it is preferred to add components from below, where they can be made without a wedge. Below follows a list of things to keep in mind when constructing the water tank for a horizontal tool.

- A wedge is necessary to accomplish the outlet pipes, all located in the front. The outlet pipes are located a bit closer to each other since the drafting takes space from the front.
- Make the most use of the wedge in the front by placing as many components as possible close to the outlet pipes.
- Wedges on additional sides are not recommended since they would make the mould unstable.
- Drafting has to be added to the long sides. Also, the pipes and possible knobs need drafting.
- The cold water inlet can be located both on the front and on the bottom.
- An alternative to snap fasteners is to make a sealed tank with an ultrasonic weld, see chapter 4.2.3.

Horizontal tool solution I

The horizontal solution in Figure 56 is equipped with an indented overfilling protection on the back, an indented cold water inlet and an infused level indicator on the front. One of the corners is rounded for a better flow of the water. For fastening, wire snap fasteners are applied. The gasket is located in the lid.

Horizontal tool solution II

The horizontal solution in Figure 57 is equipped with a plain pipe as overfilling protection, a cold water inlet from below and knobs for fixed metal snap fasteners or integrated plastic snap fasteners. If a knob is used in the horizontal solution, an edge for the gasket is not possible to make without a wedge. The gasket is therefore located in the lid.
6.3 Lid solutions

It is recommended to use a plastic lid if the plastic can stand the heat from the heating element. But since these tests are not yet done, both plastic lid solutions and metal lid solutions are presented below. If a metal lid is used, further investigation of the gasket is needed. Common for all lid solutions is the removal of the eight fastening screws and the introduction of snap fasteners.

Metal lid I
The metal lid in Figure 58 is similar to the original metal lid apart from the snap fasteners. In this solution, fixed, standard snap fasteners are added to the lid.

Metal lid II
The metal lid in Figure 59 is also similar to the original design. Instead of snap fasteners, there are holders for snap fasteners attached to the tank. Possible snap fasteners are the wire snap fasteners or the separate snap fasteners with hinges.

Plastic lid I
In Figure 60, the plastic lid is equipped with a built-in level indicator, cable holes and integrated plastic snap fasteners. No rubber protections are needed, and several parts of the level indicator are excluded.

Plastic lid II
The plastic lid in Figure 61 has knobs for wire snap fasteners or separate plastic snap fasteners with hinges. No level indicator is integrated in the lid, it is instead possible to use an infused level indicator in the side of the tank. The lid has open cable holes for easier attachment of the cables. No rubber protections are needed.
6.4 The authors’ choice

This is the authors’ choice of a plastic water tank with a lid, see Figure 62. The authors have chosen a vertical tool solution for the tank, see chapter 4.1.2, since a vertical tool becomes smaller and more stable than a horizontal tool. When considering the drafting, the vertical tool provides more space in the front for the outlet pipes.

A plastic lid was chosen to be the best alternative since it is flexible and makes a lot of cost savings possible. The chosen level indicator is the built-in level indicator from chapter 5.6.1, which excludes a lot of components. The electrical cables will be led through cable holes, see chapter 5.7.1, in the lid. These do not require rubber protection as in the original solution. A 90° rotation of the thermostat from chapter 5.8.1 has been made for easier tool construction of the lid. Folded flaps from chapter 5.8.2 are used to achieve a cheaper tool.

The sealing of the tank is made with the concept food saver II from chapter 5.2.2. The concept has the ability to seal even if the lid is curved by the steam. The fastening of the lid and the tank is accomplished by integrated plastic snap fasteners, see chapter 5.1.3. This concept was chosen because of the simplicity and the cost savings. The snap fasteners must be tested carefully before taken in production to evaluate if they can manage the heat. Consideration has to be taken to the drafting when constructing the snap fastener knobs on the tank.
Both the overfilling protection and the cold water inlet are chosen to be *plain pipes* on the front, see chapter 5.4.1 and 5.5.2. It is important not to place the overfilling protection below the thermostat due to lack of space. To keep the same height of the over filling protection when using the concept food saver II, it was necessary to enlarge the height of the water tank by eight millimetres. There should be enough space for that.

After the tests of the cold water inlet, it was decided to locate the inlet in the middle of the front side for the best water flow. The pipe for manually emptying of the tank has not been changed, it is similar to the original. All outlet pipes have been located on the front to not use any extra wedges.

Drawings for both the lid and the tank can be found in Appendix 4 and Appendix 5. The snap fasteners are not precisely done. To get maximum fit of the snap fasteners, they have to be tested out carefully when manufacturing the tool.

### 6.4.1 Part list

To show how many details that could be excluded if the authors’ choice is used, a part list for the original water tank is compared to a part list for the authors’ choice below. If the authors’ choice is used, 28 parts can be excluded.

<table>
<thead>
<tr>
<th>Original water tank</th>
<th>The authors’ choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank</td>
<td>Tank</td>
</tr>
<tr>
<td>Lid</td>
<td>Lid</td>
</tr>
<tr>
<td>Gasket between lid and tank</td>
<td>Gasket between lid and tank</td>
</tr>
<tr>
<td>Level indicator sticks</td>
<td>Level indicator sticks</td>
</tr>
<tr>
<td>Level indicator plastic component</td>
<td>-</td>
</tr>
<tr>
<td>Level indicator gasket</td>
<td>-</td>
</tr>
<tr>
<td>Screw M4</td>
<td>-</td>
</tr>
<tr>
<td>Washer</td>
<td>-</td>
</tr>
<tr>
<td>Spring washer A4</td>
<td>-</td>
</tr>
<tr>
<td>Heating element</td>
<td>Heating element</td>
</tr>
<tr>
<td>Cable hole protections</td>
<td>-</td>
</tr>
<tr>
<td>Thyristor</td>
<td>Thyristor</td>
</tr>
<tr>
<td>Over heating protection</td>
<td>Over heating protection</td>
</tr>
<tr>
<td>Silicone plug for outlet pipe</td>
<td>Silicone plug for outlet pipe</td>
</tr>
<tr>
<td>Silicone plug for thyristor</td>
<td>Silicone plug for thyristor</td>
</tr>
</tbody>
</table>

**Total: 41** **Total: 13**
6.5 Summary of the recommendations

First, some general recommendations were listed. Things to have in mind when constructing the water tank are among others: use injection moulding and a mixture of 20 % talcum in the plastic. Further, the plastic has to be tested if it handles the heat, both the lid and the integrated snap fasteners have to be tested. In addition, an important thing to keep in mind is the tool construction since it affects the whole plastic construction.

After that, complete water tank solutions for a vertical and a horizontal tool were presented. The vertical tool is recommended to use, since it is smaller and more stable than the horizontal tool. Things to keep in mind when constructing for the vertical tool: all outlet pipes should be located in the front; drafting have to be added to all concerned surfaces and as many components as possible should be located on front or back of the tank.

Further, two metal lids and two plastic lids were presented. If a plastic lid is to be used, it is important to test it first to make sure it handles the heat. If the test results show that a plastic lid is feasible to use, it is possible to integrate components such as snap fasteners, the level indicator and the gasket. Therefore, a plastic lid is recommended to use.

The best tank solution and the best lid solution were chosen and then put together into the authors’ choice. The best concepts of all problem areas were combined in a vertical tool solution. When comparing the parts of the original water tank and the authors’ choice, it was clear that 28 parts of the original 41 can been excluded.
7 References

To accomplish this report, several references have been used. In the beginning of the project, an extensive literature study was carried out, using both literature and the Internet. There are also a number of people who have been consulted. These three categories will follow.

7.1 Literature


7.2 Internet


IKEA. (No date) *IKEA* [online]. Available from


7.3 Personal contacts


Stenberg, Bengt, Professor in Polymer Technology at the Department of Fibre and Polymer Technology, KTH, 2005. Personal communication.

Ulván, Mikael, Managing Director at Vadstena Industriplast AB, (2005). Personal communication.

Wennstam, Jörgen, Product Manager Custom Moulding at Örnplast AB, (2005). Personal communication.

Appendix 1 Rejected concepts

While developing concepts, many of them were rejected for various reasons. Some concepts were difficult to manufacture and some did not work as first intended. Although, the rejected concepts are presented in this appendix to not lose any information that could be useful for Coffee Queen's continuous work.

Cold water inlet for good flow

In order to obtain a good water flow with as little turbulence as possible, a cold water inlet with a large round was introduced, see Figure 63. The radius of the round should be at least a fifth of the diameter on the pipe (Kelso, 2004).

Advantages
- Good flow from the inlet into the tank

Disadvantages
- Demands an advanced extra wedge which is very expensive
- Lack of space for the hose

Curved cold water inlet to get less turbulence

The cold water inlet is curved like a periscope, see Figure 64. It is similar to a previous solution by Coffee Queen, which was later replaced by the straight pipe as can be seen in this report.

Advantages
- Less turbulence

Disadvantages
- Demands an advanced extra wedge which is very expensive
Cold water inlet with a lid

While trying to spread the water evenly, this concept was added, see Figure 65.

Advantages
- Spreads the water evenly

Disadvantages
- Several expensive wedges are needed
- Much turbulence

Bent over filling protection to save space

Since there is a problem with lack of space on the short side of the tank, an idea with a bent over filling protection was developed, see Figure 66.

Advantages
- Takes up less space than a plain pipe

Disadvantages
- This concept is difficult to manufacture. It requires a complex wedge on the inside.
Cable snap fasteners

In order to attach the cables to the tank, these snap fasteners were invented, see Figure 67.

![Figure 67. Cable snap fasteners on the tank](image)

**Advantages**

- The cables are easily attached

**Disadvantages**

- Polypropylene is not recommended for usage of snap fasteners according to Ulván (2005) and Zajic (2005)
- The cables are not attached stably

Guidance slot in the plastic to attach cables

The cable slot run along the whole side of the tank, see Figure 68. The cable is snapped into place and will stay in place by the flexing walls.

![Figure 68. Guidance slot on the side to attach cables](image)

**Advantages**

- If there were one cable instead of several it would be easily attached and removed

**Disadvantages**

- It is difficult to get the slot to let go of the mould according to Mikael Ulván (2005)
- The cables will probably not stay in place
Hooks for attachment of the electrical cables

To hold the cables into place, these small hooks were invented, see Figure 69. The cables are placed through the hooks and are therefore held into place. Since the cables are running not only at the short side, hooks must be located on additional sides as well.

**Advantages**
- Easy to attach one cable

**Disadvantages**
- The hooks are complicated to manufacture. A large number of wedges are needed which makes this concept expensive (Ulván, 2005).
- It would be difficult to attach many cables

Figure 69. Hooks for attachment of cables

Hinges for easier attachment of the lid

Many hinge concepts were considered. See one of the concepts in Figure 70.

**Advantages**
- Easy to manufacture
- Decreases the assembly time

**Disadvantages**
- Impossible to open the lid while the heating element is attached to it

Figure 70. Hinges on the lid for easier attachment
Magnetic fasteners to attach the lid

While discussing how to fasten the lid to the tank, magnets came up as an idea, see Figure 71.

Advantages
- Decreases the assembly time

Disadvantages
- The magnets have to be attached to the plastic which is difficult while using polypropylene
- The magnets have to be strong enough to seal against steam, but weak enough to make it possible to open the tank. Hard compromise.

Plastic snap fasteners as separate parts

To avoid bending the plastic in the snaps, a separate part could be used, see Figure 72.

Advantages
- Heat will not destroy the bend
- Fast assembly

Disadvantages
- An additional tool is needed which leads to an extra cost
- This kind of fastener is not appropriate to use when constructing in polypropylene, since polypropylene is flexible but not stiff enough (Ulván, 2005)
Appendix 2 Overview matrices

The concepts influencing on the lid was evaluated in the cases of usage of a plastic lid and usage of a metal lid. The result can be seen in TABLE 3.

<table>
<thead>
<tr>
<th>Fastening devices</th>
<th>Plastic lid</th>
<th>Metal lid</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire snap fasteners</td>
<td>😊😊</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed metal snap fasteners</td>
<td>😊😊</td>
<td></td>
<td>1. Limited fastening options</td>
</tr>
<tr>
<td>Integrated plastic snap fasteners</td>
<td>😊</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Plastic snap fastener with a hinge</td>
<td>😊😊</td>
<td></td>
<td>1,2. An extra tool is needed</td>
</tr>
<tr>
<td>Separate plastic snap fasteners</td>
<td>😊😊</td>
<td>-</td>
<td>Not feasible ⇒ Rejected</td>
</tr>
<tr>
<td>Magnet fasteners</td>
<td>😊😊</td>
<td>-</td>
<td>Not feasible ⇒ Rejected</td>
</tr>
<tr>
<td>Hinges</td>
<td>😊</td>
<td>-</td>
<td>Not feasible ⇒ Rejected</td>
</tr>
<tr>
<td>Plastic lid concepts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food saver I</td>
<td>😊</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Food saver II</td>
<td>😊</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Level indicator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Built-in solution</td>
<td>😊</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holes</td>
<td>😊😊</td>
<td></td>
<td>2. Gaskets are though needed</td>
</tr>
<tr>
<td>Open cable holes</td>
<td>😊😊</td>
<td></td>
<td>2. Bad for the cables</td>
</tr>
<tr>
<td>Thermostat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotated thermostat</td>
<td>😊😊</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Folded flaps</td>
<td>😊</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

*TABLE 3. An overview matrix of the concepts concerning the tank. The grey marked fields are the rejected concepts.*
The concepts that have influence on the tank were evaluated in the cases of usage of a horizontal and usage of a vertical tool solution. The result can be seen in TABLE 4.

<table>
<thead>
<tr>
<th>Fastening devices</th>
<th>1</th>
<th>2</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire snap fasteners</td>
<td>😊😊</td>
<td>😊😊</td>
<td></td>
</tr>
<tr>
<td>Fixed metal snap fasteners</td>
<td>😊😊</td>
<td>😊😊</td>
<td></td>
</tr>
<tr>
<td>Integrated plastic snap fasteners</td>
<td>😊😊</td>
<td>😊😊</td>
<td></td>
</tr>
<tr>
<td>Plastic snap fastener with a hinge</td>
<td>😊😊</td>
<td>😊😊</td>
<td>1.2. An extra tool is needed</td>
</tr>
<tr>
<td>Separate plastic snap fasteners</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Not feasible ⇒ Rejected</td>
</tr>
<tr>
<td>Magnet fasteners</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Not feasible ⇒ Rejected</td>
</tr>
<tr>
<td>Hinges</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Not feasible ⇒ Rejected</td>
</tr>
<tr>
<td>Plastic lid concepts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food saver I</td>
<td>😊😊</td>
<td>😊😊</td>
<td></td>
</tr>
<tr>
<td>Food saver II</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Outlet pipes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All in the front</td>
<td>😊😊</td>
<td>😊😊</td>
<td>1. Extra wedge, could be tight of space</td>
</tr>
<tr>
<td>Over filling protection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain pipe</td>
<td>😊😊</td>
<td>😊😊</td>
<td></td>
</tr>
<tr>
<td>Indented pipe</td>
<td>😊😊</td>
<td>😊😊</td>
<td>2. Extra wedge</td>
</tr>
<tr>
<td>Bent over filling protection</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Complicated wedges ⇒ Rejected</td>
</tr>
<tr>
<td>Cold water inlet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain pipe from the side</td>
<td>😊😊</td>
<td>😊😊</td>
<td></td>
</tr>
<tr>
<td>Indented pipe from the side</td>
<td>😊😊</td>
<td>😊😊</td>
<td></td>
</tr>
<tr>
<td>Good flow inlet</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Complicated wedges ⇒ Rejected</td>
</tr>
<tr>
<td>Bent cold water inlet</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Complicated wedges ⇒ Rejected</td>
</tr>
<tr>
<td>Inlet with a lid</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Complicated wedges ⇒ Rejected</td>
</tr>
<tr>
<td>Level indicator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infused solution</td>
<td>😊😊</td>
<td>😊😊</td>
<td>1,2. Demands a robot or a person</td>
</tr>
<tr>
<td>Cables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable snap fasteners</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Not strong enough ⇒ Rejected</td>
</tr>
<tr>
<td>Tracks in the plastic</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Difficult manufacturing ⇒ Rejected</td>
</tr>
<tr>
<td>Hooks for attachment</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Complicated wedges ⇒ Rejected</td>
</tr>
</tbody>
</table>

**TABLE 4. An overview matrix of the concepts concerning the lid. The grey marked fields are the rejected concepts.**
Appendix 3 Cold water inlet tests

The cold water inlet is a critical element concerning the water flow. To find out how well the original solution and the concepts of the cold water inlet worked, some practical water tank tests were performed.

The water tank tests were not precisely done. It was difficult to provide the correct velocity of the water flowing through the inlet. The velocity was though approximately the same in all tests. The tests are performed to give an indication of the exact result.

While performing the tests, cold water was used in the tank with cold water coming from the inlet. It is possible that the outcome would have been different with hot water in the tank and cold water coming from the inlet. Unfortunately, the test tank did not handle the heat. The tests were made with coloured, red water. Since the red colour is not visible enough in greyscale, the red areas are marked out with a dashed line.

The original solution

The original water tank was cut open and sealed with a plastic board. After that, the tank was filled with water. Coloured water was poured through the inlet to evaluate the functionality of the cold water inlet, see Figure 73.

The original cold water inlet flowed diagonally upwards right into the long side of the tank. When water poured in, it caused a mixture of the water in the whole tank. The result was not satisfying.

The cold water inlet concepts

To evaluate the concepts, a tank of plastic boards were built with the same dimensions as the original tank. Also, a hose was modified to resemble the original inlet.

The original inlet pointing towards the short side

With an idea of better flow results when the water has a long way before hitting the wall, the inlet was pointed towards the short side, see Figure 74. It was also tested what happened while the inlet was lowered against the bottom.
When turning the inlet towards the short side, the water flowed diagonally upwards into the heating element. This caused a total mixture of the water. The result of the lowered inlet gave a slightly better result.

**Plain pipe inlet pointing towards the short side**

Still trying to give the water the opportunity to flow a long way before hitting the wall, a plain pipe inlet was used pointing towards the short side, see Figure 75.

The result was not satisfying, since the water flowed nicely until hitting the wall, when the mixture occurred. The mixture were not as large as when using the original inlet, but still not satisfying.

**Plain pipe inlet pointing towards the long side**

The idea with a long way for the water to flow did not work as intended. So instead of pointing the inlet towards the short side, it was pointed towards the long side. Both a corner and a middle location were tried out, see Figure 76.

The corner position gave a fair result. Some turbulence occurred against the short side. However, the middle position gave the best result so far. The water hit the wall and then created a layer of coloured water on the bottom of the tank.
Plain pipe inlet with rounded edges of the tank

An idea of better results with rounded edges of the tank was also tested. Plastic sheets were bended in the corners to provide rounds. All the plain pipe inlet positions were tested with round edges; see Figure 77 and Figure 78.

The round edges tests resulted in improvements for all concepts. Nevertheless, the plain pipe inlet pointing towards the long side in the middle were superior to the others.
Appendix 4 Drawing of the plastic lid

Figure 79. Drawing of the plastic lid
Appendix 5 Drawing of the plastic tank

Figure 80. Drawing of the plastic tank