A project for Oslo University College and Oslo Heart Center

Corrosion

How to control it?

EPS (Fall 2009) – Group F

Erika Legrand (France)	Management and Biotechnology
Ernest Hidalgo Serra (Spain)	Mechanical Engineering
Frank Toenders (The Netherlands)	Mechanical Engineering

Supervisor: Erling Bøe

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Executive summary

Established in 1989, Oslo Heart Centre (OHC) is located in downtown Oslo, Norway. The hospital is a non-profit cardiac surgical clinic. To control the temperature in the hospital during the summer months, an air-conditioning system is installed. The ten years old air-conditioning system suffers from corrosion problems, inside and outside stainless steel pipes. The aim of this project is to find solutions in order to reduce the amount of corrosion. Heat loss due to an insufficient insulation, contamination and erosion are secondary, indirect problems.

To analyze the situation, various measurements were performed such as, pipe thickness (amount of corrosion), humidity and water quality. It appeared that:

- The pipes thickness is decreased with 0,7 mm due to corrosion.
- The humidity is 100%, for both inside and around the insulation.
- The pH value (pH = 8) and the amount of iron parts (0,15 mg/kg) are not within the boundaries of the recommended values. Moreover the measured O_2 level is misleading.

After an inspection concerning the existing conditions, the problems were defined and organized by priority. The main problem is corrosion which occurs due to three sub-problems:

- A too high O_2 level in the water-glycol mix, which provokes rust by a chemical reaction.
- Uninhibited glycol which turns sour in acids by reacting with the metal pipes.
- Insufficient insulation which provokes water vapour condensation at the pipes surface.

To control these problems, the following solutions have been suggested:

- Reduce the O_2 level.
- Remove the glycol and replace it with a product which contains inhibiters against corrosion.
- Change the old insulation and replace it with a more water vapour resistant insulation.

After several comparisons of different techniques, products, environmental consequences and an economic analysis based on a ten years period, solutions for each problem are suggested:

- Add H_2 to the water-glycol mix to form a chemical reaction with O_2. A system provided by the Norwegian company Niprox® (costs: less than 2000 €/year).
- Replace the glycol with an inhibited propylene glycol (costs: less than 10000 €/year).
- Use Armaflex® foam sheets as insulation outside the pipes, for a better resistance against water vapour. (cost: about 5000 €/year)

With all these alternatives, the OHC could reduce the amount of corrosion within the air-conditioning system.

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1: Introduction

Established in 1989, Oslo Heart Centre (OHC) is located in downtown Oslo, Norway. The hospital is a non-profit cardiac surgical clinic. On a yearly basis, about 700 heart operations are performed. The hospital has a capacity of 40 beds.

To control the temperature in the hospital during the summer months, a 10 years old air-conditioning system is used. This air-conditioning system suffers from corrosion problems, inside and outside stainless steel pipes. The aim of this project is to find solutions in order to reduce the amount of corrosion. Heat loss due to an insufficient insulation, contamination and erosion are secondary, indirect problems.

To analyze the situation, various measurements will be performed such as, pipe thickness (amount of corrosion), humidity and water quality. The measured values will be compared with the recommended values.

After an inspection of the existing condition, the problems are known and organized by priority. Alternative solutions will be suggested to improve the old system. Each solution will be discussed in order to find the best way to satisfy the customer requirements. Moreover, considerations such as the environmental consequences and the cost for a short or long term period must be taken into account.

2: Situation analysis

2.1 Introduction

The air-conditioning system at OCH composes of two parts, a chilled water system and a ventilation system. In order to well define the context and to know where the exact problem is situated, a detailed view on the system is required. A systematic overview of the system can be seen in *Figure 2.1.1, page 12*.

2.2 Chilled water system

The chilled water system consists of four units: a compressor, a condenser, a throttle valve and an evaporator (1). The principal of the chilled water system is based on a cycle, which starts at the compressor. The compressor produces hot gas (70°C) and transports it to the condenser. In here, the gas will change to liquid state.

The collected liquid (70 °C) is transported to the throttle valve. In this throttle valve, the temperature will decrease. In the case of OHC, a temperature of -4 °C will be reached.

The following unit, the evaporator, serves as a heat exchanger. Moreover, the evaporator changes the liquid into gas again. This gas is transported to the compressor and the cycle will start over again.

2.3 Ventilation System

Fresh air, from outside of the building will be transferred by a general ventilation system. In here, the fresh air comes in contact with the stainless steel pipes, filled with chilled water. As result, the air temperature will decrease (heat exchange). In this way, an appropriate temperature in the hospital can be reached. The chilled air will be divided over the rooms. The valve is used to control the amount of air.

(1) http://home.howstuffworks.com.htm

A systematic drawing of the system:

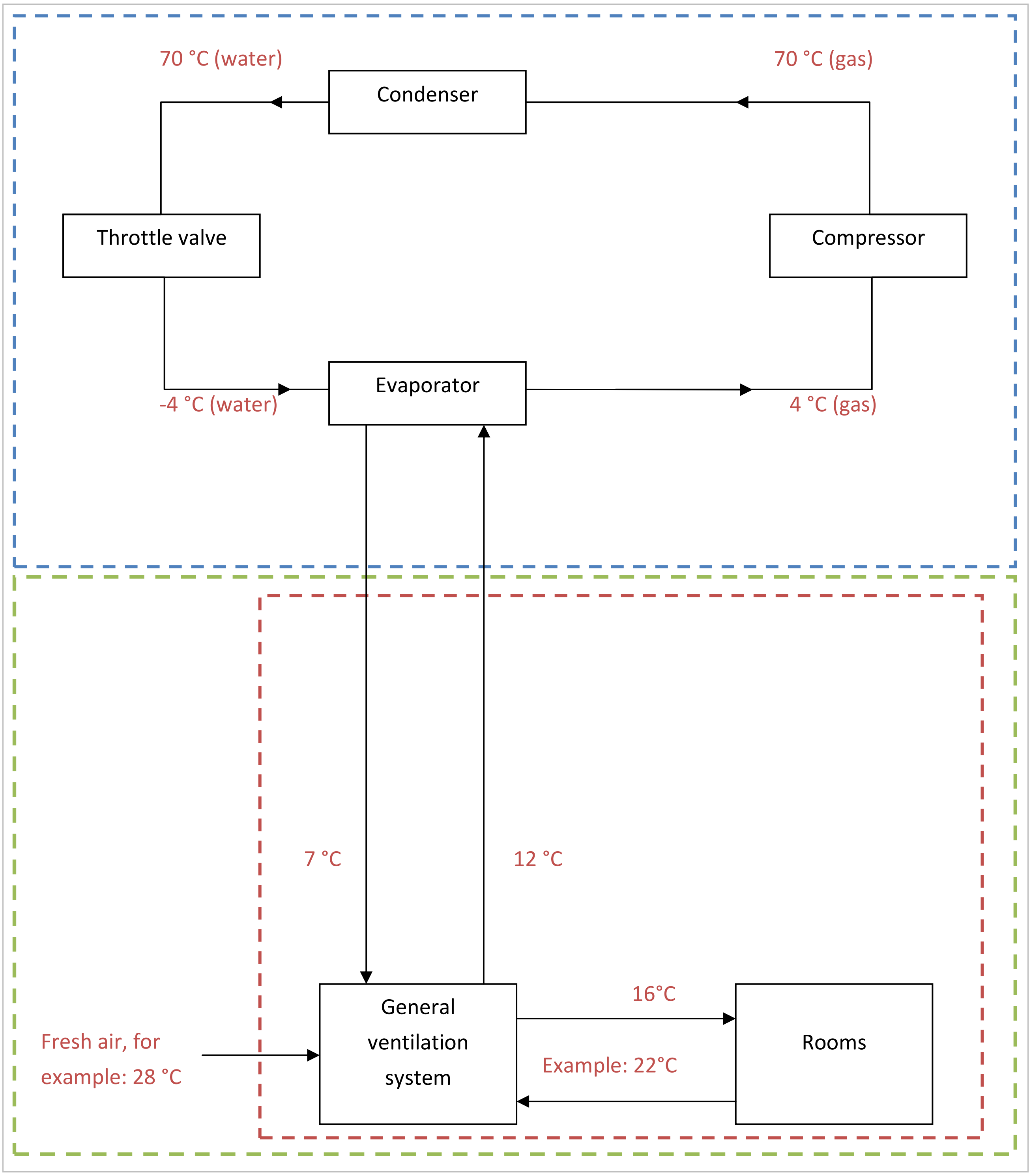

Figure 2.1.1: A systematic drawing of the system.

- - - = Chilled water system
- - - = Ventilation system
- - - = Pipes network, corrosion (liquid = water + glycol)

3: Problem analysis

3.1 First inspection

After a first inspection, obvious indications of corrosion in the system have been observed:

- Corrosion spots on the ground.
- Corrosion spots on the pipes surface.
- Water drops on the pipes surface.

Corrosion can be defined as: an unwanted degradation of a material (plastic, rubber, glass, concrete, metal, etc.) caused by a reaction with components from the environment. Two different reactions can cause corrosion, a chemical ("dry corrosion") and an electrochemical reaction ("wet corrosion"). Chemical corrosion occurs when a metal comes in contact with a gas (e.g. oxygen). A metal oxide layer will be formed on the top layer and will lead to corrosion. However, the air-conditioning system at OHC deals with corrosion based on an electrochemical reaction. This will be further explained in *paragraph 6.1, page 23.*

3.2 Corrosion and stainless steel

Stainless steel can be defined as steel that contains at least 10.5% chromium and maximum 1.2% carbon. There are many different kinds of stainless steel. The most common two are 304 and 316, both with 18% chrome and 8% nickel. However, stainless steel 316 contains molybdenum (Mo). The air-conditioning system at OHC contains stainless steel 304 pipes.

Symbol	**Full name**	**Chemistry by weight (%)**
Fe	Iron	65-74
Cr	Chromium	18
Ni	Manganese	8
Mn	Nickel	2
N	Nitrogen	0,10
S	Sulphur	0,03
C	Carbon	0,08
Si	Silicon	0,75
P	Phosphorus	0,045

Table 3.2.1: Chemistry by weight (stainless steel 304).

The surface of stainless steel consists of a chrome oxide layer. This will not corrode with oxygen. However, due to temperature changes in the winter and summer season, mechanical stress will lead to small cracks in the pipes. Corrosion can occur in these cracks. The unprotected steel under the chrome oxide layer will react with the oxygen in the water. This leads to corrosion.

3.3 Forms of corrosion

Corrosion occurs in many different forms. In the case of the OHC, corrosion occurs in three different forms: uniform (60%), local (30%) and erosion (10%). Uniform corrosion appears at a wide area. Therefore, it is less dangerous than other corrosion forms.

Local corrosion is far more hazardous and unwanted than uniform corrosion. This corrosion is better known as “pitting”. Small concentrated spots occur on the pipes surface, creating deep holes and cracks. Local corrosion often leads to leaks in the system.

An indirect problem of uniform and local corrosion is erosion. When corrosion occurs as described above, small iron parts will contaminate the water. These iron parts will erode the inside of the pipe, especially in corners and curves.

3.4 Tree diagram

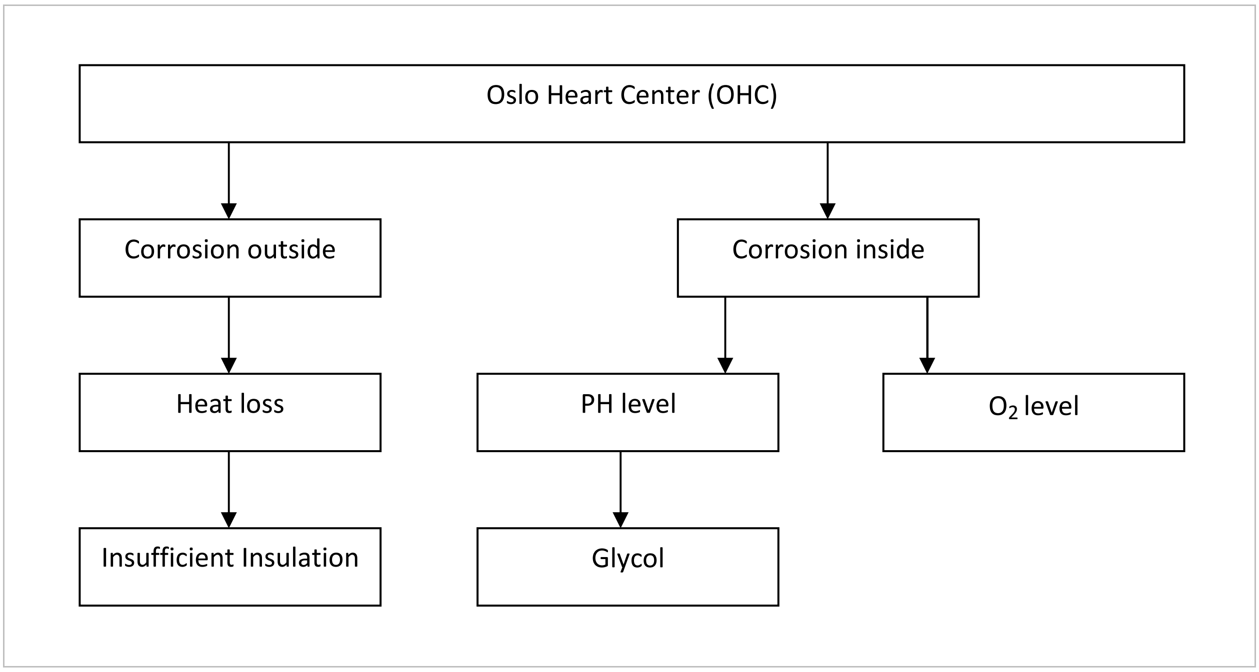

Figure 3.4.1: Problem analysis.

In conclusion, the main problem is corrosion. The corrosion occurs due to three sub problems:

- O_2 level
- Glycol
- Insufficient insulation

These problems will be further explained in *chapter 6, 7 and 8.*

4: Measurements

To get an overview of problem size, the following measurements are executed.

- Pipe thickness.
- Humidity.
- Insulation thickness.
- Water investigation.

4.1 Pipe thickness

To measure the current pipe thickness, the KrautKramer DM2 thickness gauge is used. It measures the pipes thickness by means of ultrasonic waves. To get exact measurements, requires a constant sound velocity in the test object. Normally this condition is fulfilled with steel objects, even with different alloy contents. The sound velocity changes so little that it is only noticeable with precision measurements. In other materials, e.g. nonferrous heavy metal or plastics, the sound velocity is subject to greater changes.

The DM2 generates an electrical initial pulse at first which is led to the transmitter element of the probe where it is converted into a mechanical ultrasonic pulse. Using Vaseline, the ultrasonic pulse is transmitted from the probe to the material to be tested through which it passes at a velocity typical of that material until it encounters a change in the material. Part of the pulse energy is reflected from this point and returned to the probe (echo). A probe can have one (single-element probe) or several transducer elements (dual-element probe).

Dual-element probes are particularly suitable in the case of flaws reaching close to the beam index or sound entry surface, and therefore especially in the case of deep-lying corrosion and erosion spots.

Procedure of use:

- Remove a part of the insulation.
- Apply Vaseline on the pipe.
- Apply the probe on the pipe.
- Read off the value on the DM2.

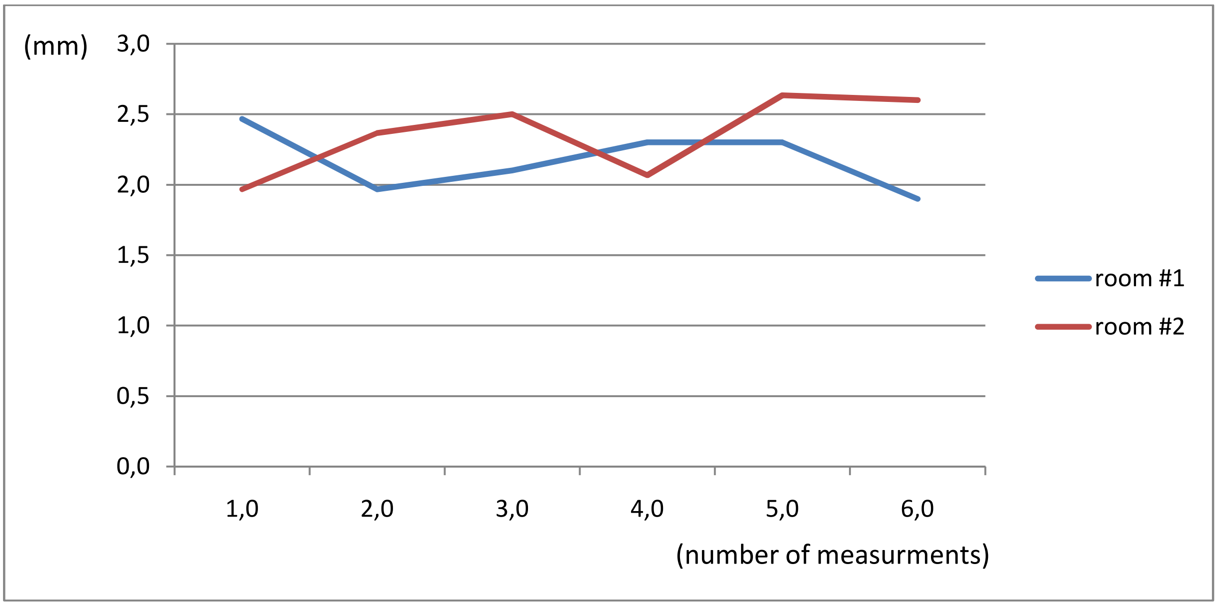

Figure 4.1.1: Pipe thickness measurement results.

To measure the pipe thickness, a few (random) points have been selected on the pipes surface. At every point, the measurement is repeated three times. The measurements are performed in two rooms, to compare any differences. A list of measurements can be found in *appendix 9.1, page 43.*

- Average pipe thickness in room #1 is 2,0mm.
- Average pipe thickness in room #2 is 2,4mm.
- Average pipe thickness (total) is 2,2mm.

When this value is compared with the original thickness, the amount of corrosion is known. The original thickness according to the ANSI/ASME 36.19M table is 2,9 mm. In conclusion, the pipe thickness is decreased with 0,7mm due to corrosion.

4.2 Insulation thickness

The insulation thickness is measured with a calliper.

- The insulation in the first room has a thickness of ± 11.5mm.
- The insulation in the second room has a thickness of ± 17mm.

4.3 Humidity

A Protimeter Surveymaster SM is used to measure humidity. The information obtained from the device shows the humidity values through all the insulation thickness. This method is based on a needle electrode that comes in contact with water vapour. This procedure has to be repeated in different deepness's of the insulation, to show the increment of humidity between the exterior surface and the internal surface.

Figure 4.3.1: Measurements performed with the KrautKramer DM2 thickness gauge.

- Humidity corridor: 32,6 % (1).
- Humidity pipe surface: 100%.

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(1) According to group E.

4.4 Water investigation

A water sample, taken out of the system was sent to “Telemark vannanalyse” laboratory and shows:

Parameters	**Measured values**	**Recommended values** (1)
pH value	8	9-11
Iron (Fe) [mg/kg]	0,15	<0,1
Copper(Cu) [mg/kg]	0,01	<0,02
Hardness [°dH]	1, 0	<1,0
O^2 Concentration [mg/kg]	0,01	<0,02
Oil[mg/kg]	0,5	<1,0
Glycol Concentration [%]	33	
Freezing point	-30°C	-30°C

Table 4.4.1: Water investigation, measured values versus recommended values.

In conclusion, the following parameters and their values are insufficient:

pH value	8	9-11
Iron (Fe) [mg /kg]	0,15	<0,1

Table 4.4.2: Water investigation, insufficient values.

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(1) Values provided by the Swedish Institute of District Heating.

5: Introduction on the sub problems

The sub problems that lead to corrosion (inside and outside) will be explained in more detail in the following three chapters. This includes the sub problems: O_2 level, glycol and insufficient insulation.

The following three chapters are structured as follows:

- Chapter 6: O_2 level.
- Chapter 7: Glycol.
- Chapter 8: Insufficient insulation.

Moreover, each chapter is divided into the following paragraphs:

- Problem explanation.
- Solutions.
- Advantages and disadvantages.
- Economy overview.
- Conclusion and suggestions.

6: O_2 level

6.1 Problem explanation

A negative electrical charge is transferred to a moist environment. The negative electrons will form a reaction with hydrogen ions, this will lead to corrosion. The following illustrations will explain the electrochemical reaction (1).

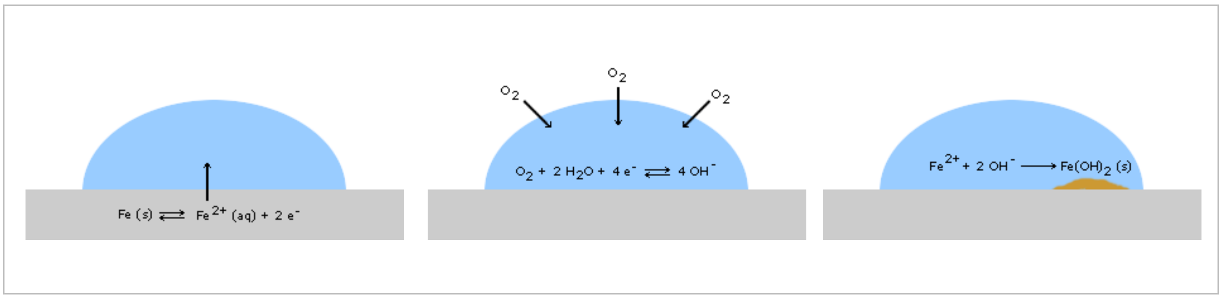

Figure 6.1.1: The reaction of oxygen on the pipes surface.

On the pipes surface, equilibrium will occur. The iron (Fe^{2+}) ions will dissolve in the water. The electrons can be transmitted through the surface of the iron plate.

$Fe \rightarrow Fe^{2+} + 2e^-$

Water contains oxygen molecules. These molecules react with the electrons. In this half reaction, hydroxide ions will occur.

$O_2 + 2H_20 + 4e^- \rightarrow 4OH-$

The water now contains iron (Fe^{2+}) ions and hydroxide ions. This forms a reaction and creates iron (Fe^{2+}) hydroxide.

$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$

Under the influence of water and oxygen the iron (Fe^{2+}) hydroxide will further oxidize (with dissolved oxygen) to (iron (Fe^{3+}) oxide or hydrous ferrous oxide), better known as rust. This is recognizable by a red/brown substance.

$4Fe(OH)_2 + O_2 + H_20 \rightarrow 4Fe(OH)_3$

(1) http://www.mediatheek.thinkquest.nl/

6.2 Solutions

The water in the air-conditioning system contains about 10 ppb (parts per billion) oxygen, equal to 0,01 mg/kg (1 mg/kg = 1000 ppb). To prevent corrosion, the recommended level of oxygen should be less than 20 pbb. In conclusion, the situation at OHC is sufficient.

However, the results of the water investigation might be misleading. Currently, an amount of oxygen is already resolved within the metal. When the water is refreshed, the oxygen value will be higher than the measured value. Moreover, a lower level of oxygen is always preferred.

The level of oxygen can be reduced by means of:

- A deaerator
- Chemicals
- Niprox®
- Liqui-Cel®

6.2.1 Deaeration

Deaeration is based on two scientific principles. The first principle can be described by Henry's Law, which asserts that gas solubility in a solution decreases as the gas partial pressure above the solution decreases. The second scientific principle is the relationship between gas solubility and temperature. Gas solubility decreases as the temperature rises and approaches saturation temperature. Easily explained, when a pan with tapped water is heated on a stove, small bubbles accumulating on the bottom, can be observed. These bubbles are air, coming out of the solution. Heating the water by using a boiler will reduce the level of oxygen. A deaerator utilizes both of these natural processes to remove dissolved oxygen. Deaerators are often used to remove gases from the feed water to steam-generating boilers.

6.2.2 Chemicals

Treatment by chemicals is often done with sodium sulphite. Sodium sulphite will react with oxygen to sodium sulphate. The reaction that occurs:

$$2SO_3^{-2} + O_2 \rightarrow 2SO_4^{-2}$$

Sodium sulphite is used because it is low of cost and easy to handle. As alternative for sodium sulphite, hydrazine is used, which reduces oxygen to a lower level as well. The reaction that occurs:

$$O_2 + N_2H_4 \rightarrow N_2 + 2H_2O$$

6.2.3 Niprox®

Another way to reduce the amount of oxygen is adding H_2 to the liquid. Niprox® (1) systems, is a Norwegian company that is specialized in the removal dissolved oxygen in liquid. By adding H_2 to the liquid, the following reaction will occur:

$$2H_2 + O_2 \rightarrow 2H_2O$$

In addition to reduce the oxygen level, the Niprox® water treatment system filters iron (Fe) parts out of the liquid. Moreover, it adjusts the pH to a wanted level (9-10,5). Therefore, the pH level will not act as a catalyst anymore, which will slow down the corrosion process.

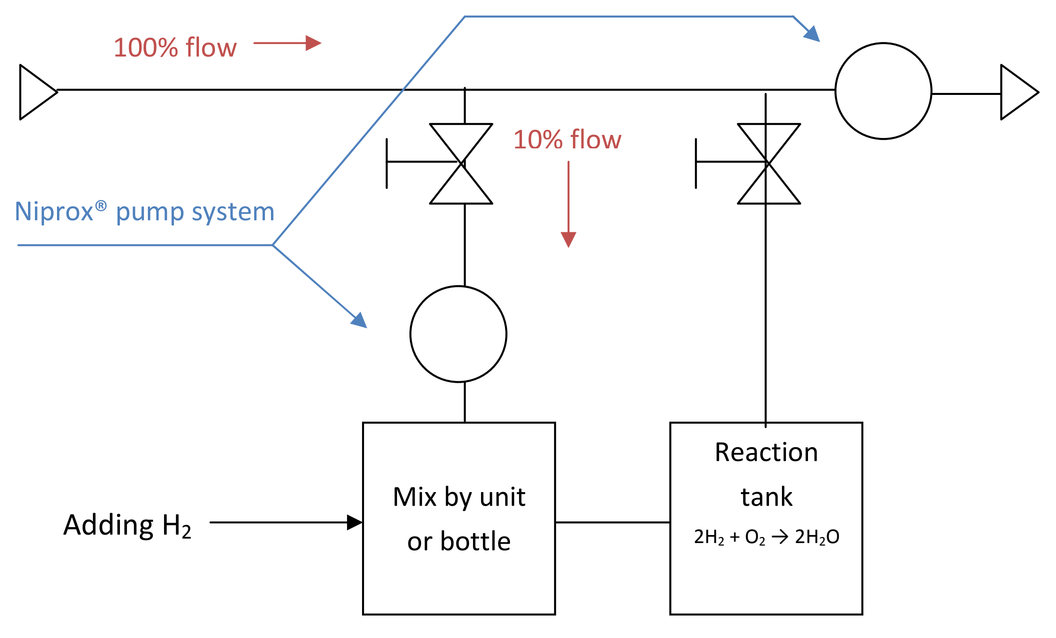

Figure 6.2.3.1: A systematic drawing of the Niprox® system

Niprox® mixes 10% of system flow with H_2. At a certain point, all the liquid has passed the mix unit. Niprox® estimates this period to one week. A complete explanation of the flow calculation can be found in *appendix 9.4, page 45*.

To determine which Niprox® type is needed in the case of OHC, the total water volume must be determined. The total amount of volume is 20.000 litres.

Now, the type of Niprox® can be determined, which is the Niprox® 4-Element (0-80 m^3) system. The format of the system is 1200mm*850mm*350mm.

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(1) http://www.niprox.no/

6.2.4 Liqui-Cel®

Based in Germany, Liqui-cel® (1) is a company that developed a device for the removal of dissolved gasses. The following illustration *(Figure 6.2.4.1)* gives a system overview.

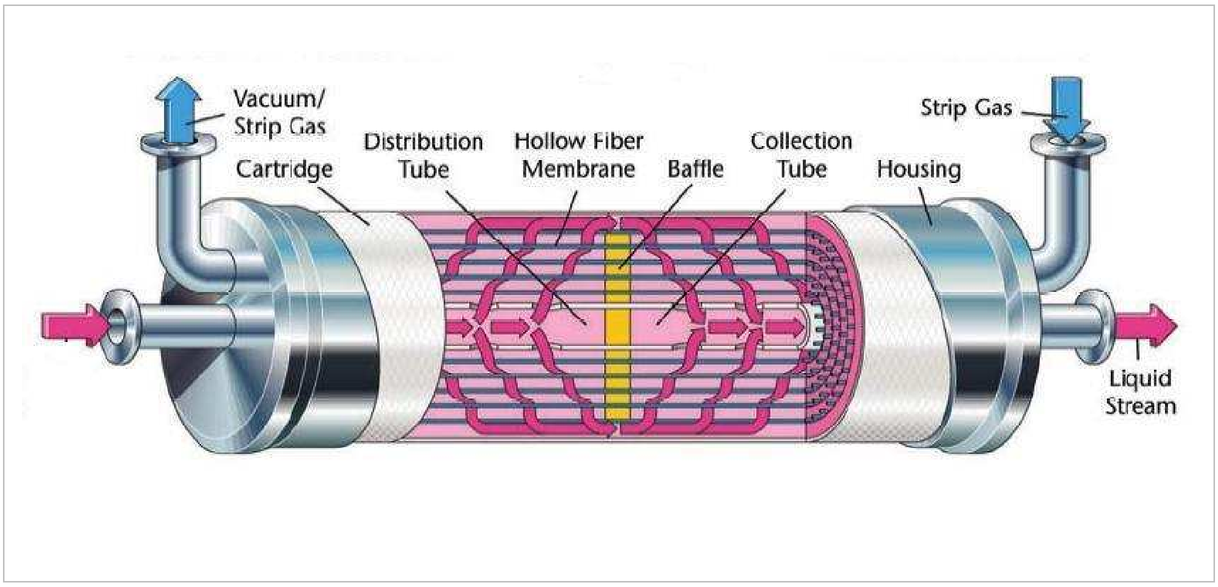

Figure 6.2.4.1: A systematic draw of the Liqui-cel® system

The Liqui-cel® system makes uses of polypropylene membranes. The hollow fibre membrane is hydrophobic, so water will not pass through it. However, gasses will pass through the pores of the hollow fibre membrane (including oxygen).

Gasses in the atmosphere dissolve into water until equilibrium is reached. A vacuum and strip/sweep gas changes the equilibrium between the liquid and gas phase. This creates a driving force to move gasses from the liquid phase into the gas phase.

A baffle for the liquid phase is created in the middle of the contactor. This maximizes surface area and improves gas transfers efficiency. The liquid enters the shell side port and travels into the distribution tube. Liquid is forced through the membrane on each side of the baffle and it exits through the collection tube and the second shell side port.

The hollow fibre membrane is open from one end of the contactor to the other. Depending of the operating mode, a vacuum is pulled from one gas side port of the contactor while a sweep gas is introduced to the other gas side port. At the end of the process, the liquid will contain less gas than before.

(1) http://www.liqui-cel.com/

6.3 Advantages and disadvantages

Parameters	**Deaeration**	**Adding chemicals**	**Niprox®**	**Liqui-Cel®**
Outlet dissolved O_2	< 7 ppb	100-500 ppb	< 20 ppb	< 5 ppb
Amount of maintenance	Average	Average/high	Low(1)	Average(1)
Usability	Large device	Difficult to control	Usability friendly	Usability friendly
Toxicity	Non-toxic	High	Non-toxic	Non-toxic
Environmental effects	Uses a lot of energy	Leads to chemical waste	Environmental friendly	Environmental friendly
Lifetime	15 years	4 months	15 years	15 years

Table 6.3.1 Advantages and disadvantages table for a to high O_2 level solutions.

Other parameters of interest:

- Liqui-Cel® controls O_2, CO_2 and NO_2 with one device.
- Niprox® adjusts the pH to a wanted level and removes sludge and iron particles as well.
- Niprox® is located in Florø, Norway.

(1) Estimated value according to the companies website.

6.4 Economic overview

For this part, only the Niprox® solution can be discussed. Unfortunately, the Liqui-cel® company did not reply to various e-mails concerning the costs. Therefore, an economic overview for the Liqui-cel® solution can not be given.

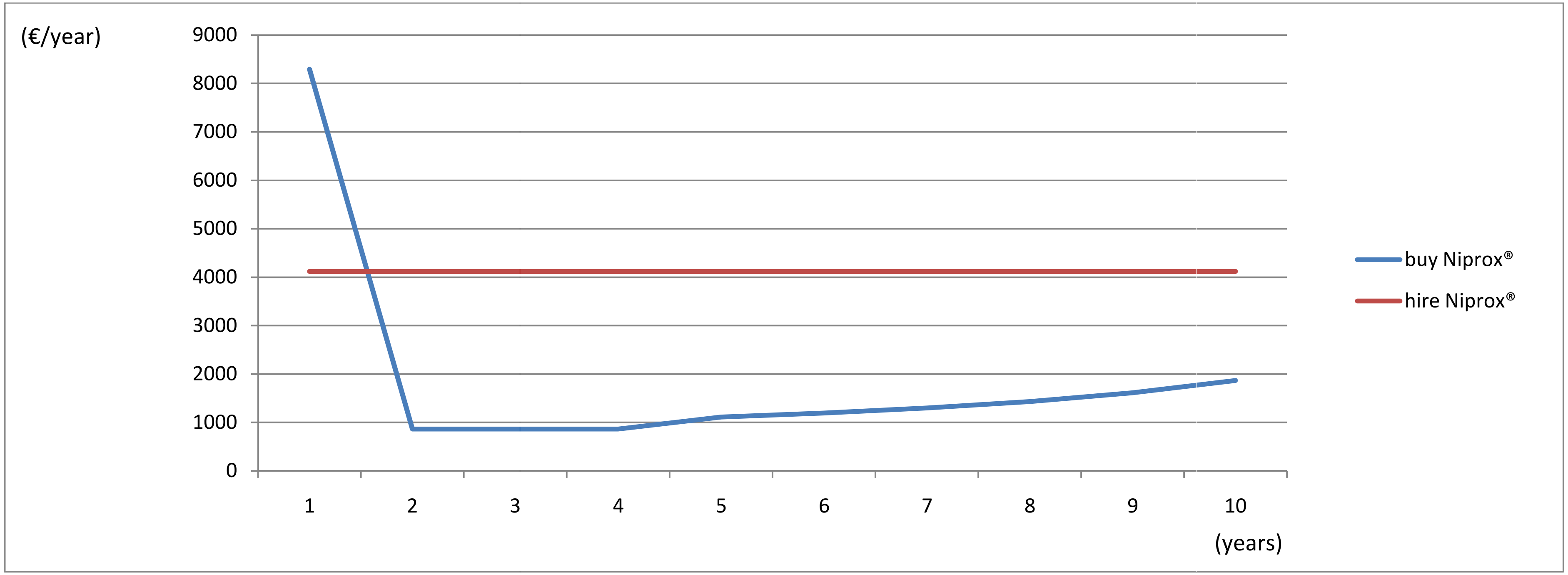

Table 6.4.1 Costs versus time for each Niprox® solution.

The table above illustrates the two options for Niprox®, hire or buy a system. To get an idea which option is the best for the case of OHC, a graphic is made. For the calculations, see in *appendix 9.7, page 48*. In conclusion, after approximately 1,5-2 years, buying a Niprox system would be a better option.

6.5 Conclusion and suggestions

In the case of OHC, the liquid within the pipes contains a too high level of O_2. There are four options to solve this problem: a deaerator, adding chemicals, Liqui-Cel®, Niprox®.

To dissolve the oxygen to the desired level, a deaerator, Liqui-Cel® and Niprox® are suitable. Therefore, adding chemicals (concerning a 100-500 ppb level of oxygen) is no option in the case of OHC. Moreover, adding chemicals has various disadvantages compared with the other solutions.

A deaerator, Liqui-Cel® or Niprox® all lead to approximately equal levels of dissolved O_2. Disadvantages for a deaerator compared with Liqui-Cel® or Niprox® are the size of the device and the lost of energy by install a heating device within a system that uses chilled liquid.

Although Liqui-Cel® and Niprox® are based on different techniques, the results are almost equal. Niprox® would be a better choice for a lower amount of maintenance. Liqui-Cel® is slightly better concerning the dissolved O_2 level.

Unfortunately, due to lack of (economic) information by the Liqui-Cel® company, a good comparison between both options is not possible. Therefore, the suggestion would be to choose for the Norwegian based Niprox® company because their system meets the requirements within a known, limited budget. In the case of OCH, the best option would be to buy a Niprox® system.

7: Glycol

7.1 Problem explanation

According to the laboratory results in *paragraph 4.4, page 20*, the pipes network of the air-conditioning system contains a mix of 66% water and 33% uninhibited ethylene glycol of the Bayer company.

Ethylene glycol is a colourless syrupy alcohol, $HOCH_2CH_2OH$, used as antifreeze in cooling and heating systems. It is used to avoid ice forming in water and acts as a heat transfer fluid. In the case of OHC, the freezing point of the mix is -30°C, which is sufficient for the hospital's utilization.

Normally, a mix with 33% of glycol leads to a freezing point of -15°C. In conclusion the glycol amount should be more than 33%. According to the graph on the website (1), the real glycol amount is around 50%.

The problem is that uninhibited ethylene glycol in water degrades into five organic acids - glycolic, glyoxylic, formic, carbonic, and oxalic (2) - in the presence of heat, oxygen, and common cooling system metals such as copper and aluminium. Copper, even if this quantity is under the recommended value, acts as a catalyst in the presence of uninhibited ethylene glycol.

Degradation of the glycol:

$$HOCH_2CH_2OH \rightarrow HOCH_2COOH + HCOCOOH + HCOOH + HOCOOH + HOOCCOOH$$

These organic acids will then chemically attack copper to form metal organic compounds in the fluid, which can lead to clogging of pipes, pumps, valves, etc. Moreover, the chemical reaction releases H^+ ions that acidify the fluid, decreasing the pH and causing corrosion inside metal pipes (reaction with iron). Therefore, the pH level will be less acidic. Reaction between acids and water:

$$AH + H_2O \rightarrow A^- + H_3O^+_{acid} \, (H^+_{acid})$$

The reaction between the iron and oxygen ions is explained in *paragraph 6.1, page 18*. Concerning the water hardness, the value is low because communal water of Oslo is used (3).

(1) http://www.ketemalp.com/

(2) Book: "Technical Insights into Uninhibited Ethylene Glycol - Keith Wheeler"

(3) http://www.vann-og-avlopsetaten.oslo.kommune.no/

7.2 Solutions

In order to avoid the corrosion formation inside pipes, several solutions can be purposed. The first step is to remove the old water-glycol mix out of the pipes network (1). Then, the pipes have to be cleaned and refilled by a new product.

- Inhibited ethylene glycol.
- Inhibited propylene glycol.
- Thermera®.
- Temper®.

7.2.1 Inhibited ethylene glycol

Nowadays, there are mixes containing ethylene glycol with corrosion inhibitors. An inhibitor is a product that postpones corrosion when it occurs in low concentration to the environment.

Several types of inhibition exist:

- Organic inhibition: non-toxic for the environment.
- Inorganic inhibition: less used due to environmental toxicity.
- Anodic inhibition and cathode inhibition.
- Interfacial action inhibition.

Some specific corrosion inhibitors for the iron are organic chemicals like amine derivatives ($-NH_2$), carboxylic acid salt ($-COO^-$) or phosphoric acid (2).

7.2.2 Inhibited propylene glycol

An alternative to the ethylene glycol is propylene glycol. It is a colourless, viscous, and non-toxic liquid, $CH_3CHOHCH_2OH$, used in antifreeze solutions, in hydraulic fluids, and as a solvent. Like ethylene glycol, propylene glycol is available with inhibitors.

(1) http://www.fernox.com/
(2) http://docinsa.insa-lyon.fr/

7.2.3 Thermera®

According to the manufacturer's description, Thermera® (1), a new heat transfer fluid with extremely low environmental impact, was developed and tested in cooperation with end-users and raw material manufacturers. Thermera® is a good solution as antifreeze in heating, ventilation and air-conditioning (HVAC) systems.

Thermera®, a new non-toxic, high-performance heat transfer fluid for use in heat-recovery units, air conditioning, heat pumps and industrial heat transfer, has been developed by Neste Oil Corporation Espoo, Finland.

The basis of Thermera® is natural, water-soluble, biodegradable betaine, a by-product of sugar beet processing, which is separated from molasses using a method developed by the world's leading supplier of betaine, Finnfeeds Finland Oy, a subsidiary of Danisco.

Betaine is a natural corrosion preventing agent. Because of its good anti-corrosion features, only a minor amount of corrosion inhibitators have been added to Thermera®.

7.2.4 Temper®

According to the manufacturer's description, Temper® (2) is based on the idea of using water as a heat and cold medium. Water has ideal thermodynamic properties, which gives it a good heat transfer ability, high heat capacity and low viscosity. By dissolving optimal amounts of potassium acetate and potassium formats in water the freezing point has been reduced considerably. Thus the water's advantageous properties are maintained.

Temper® contains a special corrosion inhibitor which forms an extremely thin local layer. This layer locally eliminates the risk of corrosion, with practically no effect on heat transfer. Temper® is readily biodegradable and therefore classified as non-hazardous to health and the environment and does not contain any amines, nitrites or phosphates.

(1) http://www.thermera.com/

(2) http://www.temper.se/

7.3 Advantages and disadvantages

Parameters	**Inhibited ethylene glycol** (1)	**Inhibited propylene glycol** (2)	**Thermera®**	**Temper®**
Heat transfer capacity (3)	3.50 KJ/Kg K	3.75 KJ/Kg K	3.07 KJ/Kg K	3.20 KJ/Kg K
Density (4)	1058 Kg/m^3	1036 Kg/m^3	1082.4 Kg/m^3	1159 - 1163 Kg/m^3
Thermal conductivity (5)	0.424 W/m K	0.410 W/m K	0.382W/m K	0.497 W/m K
Kinematic viscosity (6)	3 mm^2/s	5 mm^2/s	4.8 mm^2/s	1.64 mm^2/s
Usability	Dilution	Dilution	Ready to use	Ready to use
Toxicity	High	Low	Non-toxic	Non-toxic
Environmental effects	Toxic for life	Non toxic for life	Biodegradable	Biodegradable
Waste water treatment	Specific	Specific	Normal	Normal
Lifetime	10 years	10 years	-	-
Degradation	Acids	Acids	-	-

Table 7.3.1 Advantages and disadvantages table for glycol solutions.

(1) Properties of DOWCAL™ 10 / DOWTHERM™ 10 Fluid at 40% Ethylene Glycol concentration by volume

(2) Properties of DOWCAL™ N / DOWFROST™ Fluid at 40% Propylene Glycol concentration by volume

(3) Specific heat capacity is the measure of the heat energy required to increase the temperature of a unit quantity of a substance by unit degree.

(4) The density of a material is defined as its mass per unit volume.

(5) Thermal conductivity is the property of a material that indicates its ability to conduct heat.

(6) Viscosity is a measure of the resistance of a fluid.

7.4 Economic overview

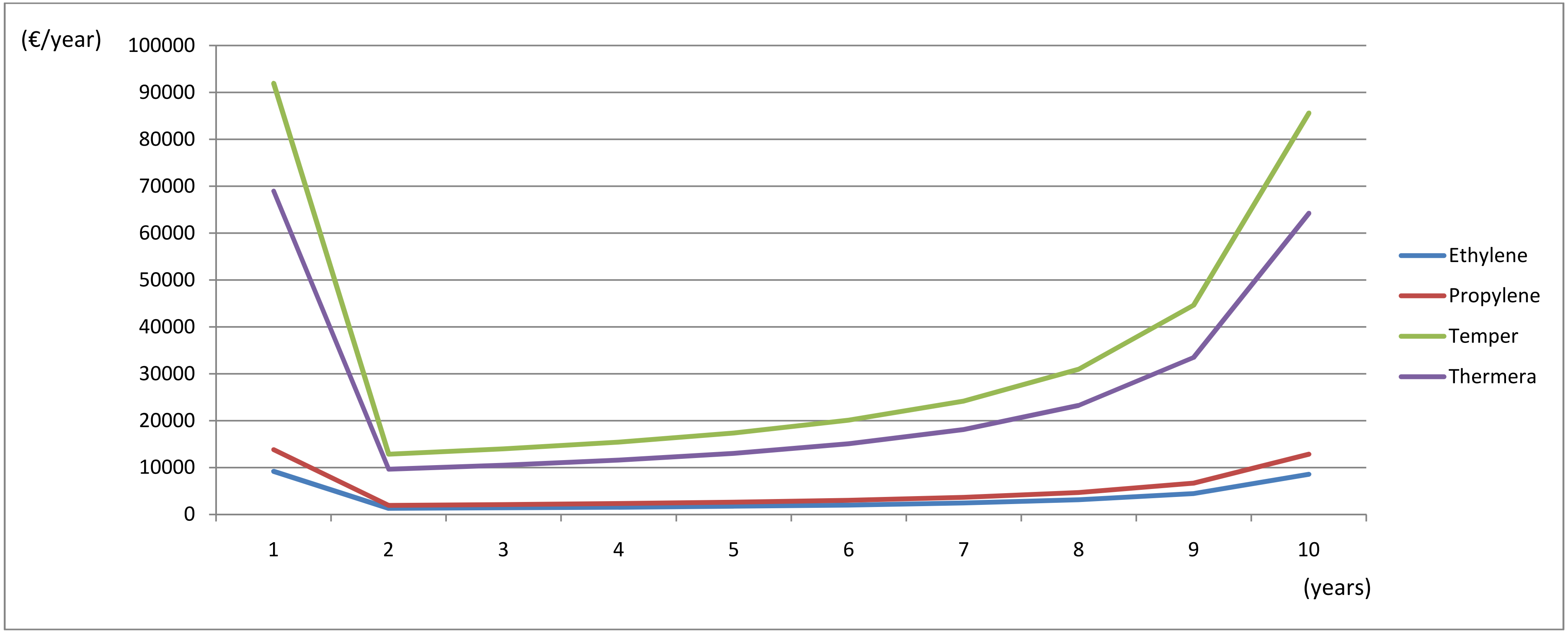

Table 7.4.1 Costs versus time for each antifreeze solution.

The table above illustrates the four options for the antifreeze solution. To get an idea which option is the best for the case of OHC, a graphic is made. For the calculations, see in *appendix 9.8, page 49*. In conclusion, ethylene glycol appears to be the best solution concerning the price.

7.5 Conclusion and suggestions

Inside the pipes, a bad quality of glycol leads to corrosion. To solve this problem, all new purposed solutions have corrosion inhibitors inside. So the comparison between the products is executed by other factors.

Compared to the others products, Temper® possesses lots of quality but its cost is expensive. Ethylene glycol and propylene glycol are more affordable. However, propylene glycol offers more advantages. Despite a high viscosity that increases the pumps work and a higher price, propylene glycol carries more heat than ethylene glycol and its toxicity for human health and environment is lower. The inhibitors of inhibited propylene glycol fight actively against corrosion.

However, more information about the energy cost (e.g. about viscosity) could change the final decision. If the consequence of the high viscosity will cost more money at a long term period, choosing another product would be better.

Considering the known information, propylene glycol seems to be a good solution.

8: Insufficient insulation

8.1 Problem explanation

The pipes at OHC (diameter of 136mm) are covered with polyurethane cell-structured foam insulation. The insulation is an essential part to prevent condensation, which leads to corrosion. For thermal insulations, there are two types of condensation, surface condensation and interstitial condensation.

8.1.1 Surface condensation

Relative humidity (%) is a term used to describe the amount of water vapour that exists in a gaseous mixture of air and water vapour. The maximum moisture value in the air at a given temperature is the saturation point or dew point. When hot air comes to a cold facility, the relative humidity increases. If it passes the dew point, it causes surface condensation. In Installations that are not well insulated, water droplets or ice can occur, which leads to irreparable damages. For this reason, the main goal is to keep the pipes surface dry. The effect of a bad insulation is shown in *figure 8.1.3, illustration 1.*

8.1.2 Interstitial condensation

Interstitial condensation is more complex and difficult to detect than surface condensation, and occurs especially in cooling installations. The moisture penetrates the insulation as a result of a pressure difference. This phenomenon occurs when there is temperature difference between the room atmosphere and pipes surface. If this happens, the water vapour diffusion will increase and result in (interstitial) condensation within the foam. This interstitial condensation slowly penetrates into the isolation. The effect of interstitial condensation is shown in *figure 8.1.3, illustration 2.*

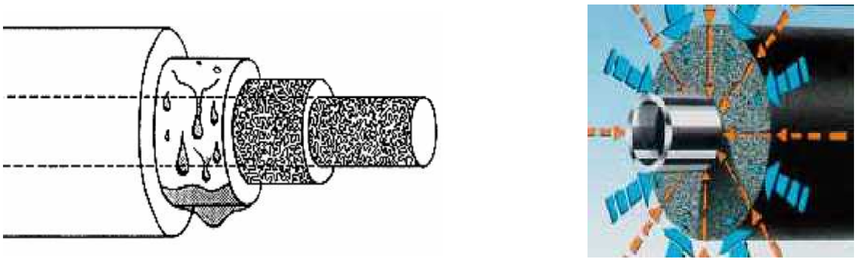

Illustration 1

Illustration 2

Figure 8.1.3: Surface condensation and interstitial condensation.

8.2 Solutions

8.2.1 Technical factors

Thermal conductivity [λ = W / (m * K)] is the most important factor for insulation. It is not a fixed value, but depends on several other factors, such as temperature, density, moisture, damage or ageing of the material. Moreover, this coefficient is important to save energy (heat loss).

The water vapour permeability [δ = kg / (m.s.Pa)] of a material indicates the amount of vapour that passes through material, depending on the area, time and pressure difference.

The vapour resistance of water [μ=no dimension] is the ratio between water vapour permeability and material air tightness. A high value of μ means that the material is more resistant to water vapour diffusion.

Each kind of insulation material has a different penetration coefficient. This coefficient is found on an experimental way. These experiments consist in knowing how the insulation is affected by a moisture condition, within in a period of time.

8.2.2 Armaflex®

According to the manufacturer's description, Armaflex® provides insulation, specialty foam and rubber solutions for a wide range of industries and supplies products for automotive, industrial, sports, leisure, packaging and a wide range of custom applications.

Armaflex® in better in quality, due to the following parameters:

Parameters	**Current insulation (OHC)**	**Armaflex® insulation**
Thermal conductivity	≤ 0.0036	≤ 0.0033
Vapour permeability	7.25×10^{-13}	7.25×10^{-13}
Vapour resistance	≥ 7000	≥ 10000
Energy saving in 10 years	18,2	20,6
Flexibility	Low	High
Microcell structure size	0,253	0,136

Table 8.2.2.1 Comparison between the current insulation and the new Armaflex® insulation.

Armaflex® provides several types or products and forms of foam. This includes a tube model and a sheet model. For a pipe diameter of Ø136mm

- Tubes foam model required: AF-1-140. Nominal insulation thickness, 10mm.
- Sheet foam model required: AF-10. Nominal insulation thickness, 10mm.

The calculations to determine the type of insulation can be found in *appendix 9.5, page 46.*

8.3 Advantages and disadvantages

Parameters	**Armaflex® insulation (tube model)**	**Armaflex® insulation (sheet model)**
Models	Defined	Universal
Tolerance	± 2	± 1
Adaptation	Depending the model	Excellent
Usability	Bad	Good

Table 8.3.1 Advantages and disadvantages table, comparison between the tube and sheet model.

8.4 Economic overview

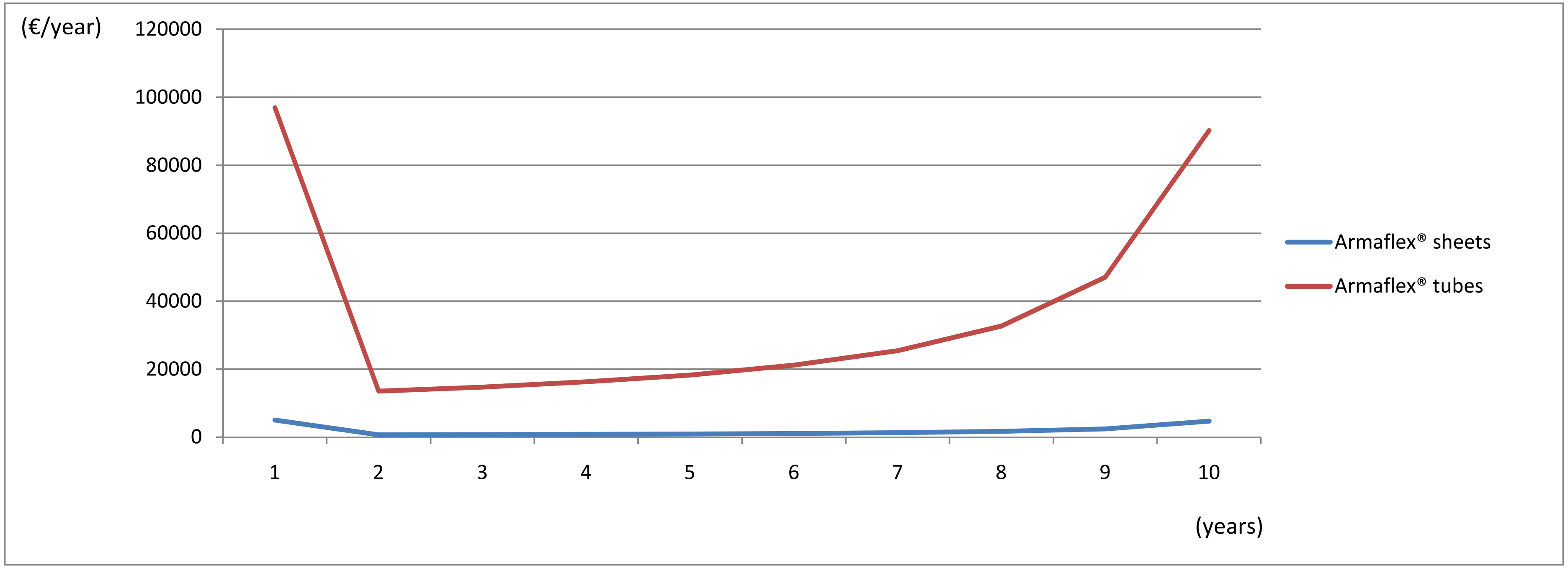

Table 8.4.1 Costs versus time for each solution.

The table above illustrates the two options to insulate the system, sheets or tubes model. This graphic was made in order to get an idea about which option is the best for the corrosion problem. For the calculations, see in *appendix 9.9, page 51*. The conclusion is, after approximately 1,5-2 years, using an Armaflex® sheets model would be a better option because the quantity of money in the investment will be less and the efficiency to prevent the heat loss will much better.

8.5 Conclusion and suggestions

Concerning the problem with insufficient insulation two solutions were found to avoid corrosion outside and the best solution is the Armaflex® sheets model.

For the following parameters: model, tolerance, adaptation and usability, the Armaflex® sheet model is a better solution. Moreover the Armaflex® sheets will be the best choice concerning the costs.

9: Appendixes

9.1 Thickness measurements

Measurements	measure 1	measure 2	measure 3	average	total average
Measurement 1	1,9	3,5	2,0	2,5	2,03 (mm)
Measurement 2	2,0	2,0	1,9	2,0	
Measurement 3	1,9	1,9	2,5	2,1	
Measurement 4	2,0	3,0	1,9	2,3	
Measurement 5	1,9	3,0	2,0	2,3	
Measurement 6	1,9	1,9	1,9	1,9	
Measurement 7	2,4	2,5	2,6	2,5	
Measurement 8	2,0	2,0	1,9	2,0	
Measurement 9	3,0	3,2	2,2	2,8	
Measurement 10	2,0	2,0	1,9	2,0	

Table 9.1.1: Measurements in the first room

Measurements	measure 1	measure 2	measure 3	average	total average
Measurement 1	1,9	2,0	2,0	2,0	2,4 (mm)
Measurement 2	2,6	2,3	2,2	2,4	
Measurement 3	2,2	3,2	2,1	2,5	
Measurement 4	2,1	2,1	2,0	2,1	
Measurement 5	2,7	2,6	2,6	2,6	
Measurement 6	2,6	2,5	2,7	2,6	

Table 9.1.2: Measurements in the second room

9.2 Lifetime of various objects in at OHC.

Building-related objects	60 year
Boiler, burner, pumps	15 year
Insulation	10 year
Pipe radiators	30 year
Glycol	10 year
Thermostatic valves	10 year
Heater	25 year
Heat exchangers	15 year

9.3 Annuity table

Lifetime (years)	Interest, r (%)							
	3%	4%	5%	6%	7%	8%	9%	10%
1	1,0300	1,0400	1,0500	1,0600	1,0700	1,0800	1,0900	1,1000
2	0,5226	0,5302	0,5378	0,5454	0,5531	0,5608	0,5685	0,5762
3	0,3535	0,3603	0,3672	0,3741	0,3811	0,3880	0,3951	0,4021
4	0,2690	0,2755	0,2820	0,2886	0,2952	0,3019	0,3087	0,3155
5	0,2184	0,2246	0,2310	0,2374	0,2439	0,2505	0,2571	0,2638
6	0,1846	0,1908	0,1970	0,2034	0,2098	0,2163	0,2239	0,2296
7	0,1605	0,1666	0,1728	0,1791	0,1856	0,1921	0,1987	0,2054
8	0,1425	0,1485	0,1547	0,1610	0,1675	0,1740	0,1807	0,1874
9	0,1284	0,1345	0,1407	0,1470	0,1535	0,1601	0,1668	0,1736
10	0,1172	0,1233	0,1295	0,1359	0,1424	0,1490	0,1558	0,1627
15	0,0838	0,0900	0,0963	0,1030	0,1098	0,1168	0,1241	0,1315
20	0,0672	0,0736	0,0802	0,0872	0,944	0,1019	0,1095	0,1175
25	0,0574	0,0640	0,0710	0,0782	0,0858	0,0937	0,1018	0,1102
30	0,0510	0,0578	0,0651	0,0726	0,0806	0,0888	0,0973	0,1061
40	0,0433	0,0505	0,0583	0,0665	0,0750	0,0839	0,0930	0,1023

9.4 Flow calculation

To calculate the flow, the speed and area of the pipes inside must be known.

Q = Flow (m^2/s)
A = Area (m^2)
V = Speed (m/s)
D = Diameter pipe (m)

$A = \frac{1}{4} * \pi * D^2$	Area
$Q = A * V$	Flow

$D = 136$ mm (1)
$A = 9.503318*10^{-3}$ m
$V = 1$ m/s (1)
$Q = 9.503318*10^{-3}\ m^2/s$

$1\ L/s = 10^{-3}\ m^2/s$.

$Q = 9{,}503318$ L/s

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(1) See paragraph 8.1.
(2) Value is given by the supervisor.

9.5 Thickness calculation

h = Heat transfer coefficient $\left(\frac{W}{mk}\right)$
Hr = Relative humidity (%)
K = thermal conductivity of the insulation $\left(\frac{W}{m^2k}\right)$
t_{int} = temperature interior (K)
t_{ext} = temperature exterior (K)
t_{dp} = temperature of dew point (K)
t = thickness of the insulation layer (mm)

Calculation dew point temperature:

$$\mathrm{t_{dp}} = \left(\left(\left(\frac{\mathrm{H_R}}{100}\right)^{0.1247}\right)\cdot(109.8+\mathrm{t_w})\right)-109.8 = ((0.4^{0.1247})\cdot(109.8+295.7))-109.8$$

h = $9\frac{W}{mk}$
Hr = 40%
K = $0.033\frac{W}{m^2k}$
t_{int} = $269K$
t_{ext} = $295K$
t_{dp}= $281.4K$

Calculation the thickness:

$$\boxed{t = \frac{K}{h}\cdot\frac{t_{dp}-t_{int}}{t_{ext}-t_{dp}}}$$

t = 3.2 mm

9.6 General calculation for the economy overview

For the economic calculation, a period of ten years has been chosen. To have the total cost per year of each solution, two multiplications are executed in order to calculate capital cost and operating cost. The capital cost is the investment cost multiplied by the annuity factor (for each year) Operating cost is the investment cost multiplied by a value based on experience (2% of the investment cost).

a = annuity
I = investment
Cc = Capital cost (€/year)
Oc = Operating cost (€/year)
Tc = Total cost (€/year)

Cc= I * a	Capital cost
Oc = I * 0,02	Operating cost
Tc = Cc + Oc	Total cost

The first year matches with the estimated lifetime. E.g. if the lifetime is 10 years, the annuity factor for the first year is 0,1295, for the second year, it is 0,1407 etc.

For the first year of each solution, the investment cost is added to the capital cost. Then, for each year, an addition is executed to have the total cost.

Lifetime (years)	**Annuity (for interest of 5 %)**
1	1,0500
2	0,5378
3	0,3672
4	0,2820
5	0,2310
6	0,1970
7	0,1728
8	0,1547
9	0,1407
10	0,1295

Table 9.6.1: Annuity for a period of 10 years.

9.7 Economical values and calculations (O_2 level)

9.7.1 Hire a Niprox® system:

- Hire a mobile Niprox® system (per week) (1) = 1029,41 € (incl. 1,25 VAT)
- Hire a mobile Niprox® system (per year) = 4117,65 € (incl. 1,25 VAT)

9.7.2 Buy a Niprox® system:

- Investment Niprox® system = 7429,88 €
- Maintenance (per year) = 148,60 € (2)

9.7.1 Costs table

Years	**Buy Niprox®**	**Hire Niprox®**
1	8293,97744	4117,65
2	864,097444	4117,65
3	864,097444	4117,65
4	864,097444	4117,65
5	1110,76946	4117,65
6	1193,98412	4117,65
7	1298,00244	4117,65
8	1432,48326	4117,65
9	1612,28636	4117,65
10	1864,90228	4117,65

Table 9.7.1: Costs table for a period of 10 years (in €).

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(1) The estimated need of the Mobil Niprox® system is four weeks per year.

(2) Maintenance costs are approximately 2% of the investment costs.

9.8 Economical values and calculations (glycol)

Total amount of liquid within the in pipes is 20.000 litres.

9.8.1 Propylene glycol:

- 0,9 €/L (1)
- 1,5 €/L = price by the company (estimated)
- Volume mass = 1,04 kg/L
- 0,9 x 1,04 = 0,94 €/L
- Percentage within the mix = 40%
- 1,5€/L x (0,4 x 20.000) = 12.000 €

9.8.2 Ethylene glycol:

- 0,55 €/L (1)
- 1,0 €/L = price by the company (estimated)
- Volume mass = 1,1 kg/L
- 0,55 x 1,1= 0,61 €/L
- Percentage within the mix = 40%
- 1,0 €/L x (0,4 x 20000) = 12.000 €

9.8.3 Thermera®:

- Estimated price is 3 €/L x 20.000= 60.000 €

9.8.4 Temper®:

- Estimated price is 4 €/L x 20.000 = 80.000 €

This price covers the temper density (2) the market prices of potassium formate (3) and potassium acetate (3)

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(1) http://www.icis.com
(2) http://www.temper.se
(3) http://www.alfa.com

9.8.5 Costs table

Years	**Ethylene glycol**	**Propylene glycol**	**Temper®**	**Thermera®**
1	9196	13794	91960	68970
2	1285,6	1928,4	12856	9642
3	1397,6	2096,4	13976	10482
4	1542,4	2313,6	15424	11568
5	1736	2604	17360	13020
6	2008	3012	20080	15060
7	2416	3624	24160	18120
8	3097,6	4646,4	30976	23232
9	4462,4	6693,6	44624	33468
10	8560	12840	85600	64200

Table 9.8.1: Costs table for a period of 10 years (in €).

9.9 Economic values and calculations (insufficient insulation)

Total length of the pipes network: 240m

9.9.1 Investment costs for sheets:

- Armaflex® Adhesive 520 = connection for 140 meter/L
- 0,5 L = 100 NOK
- Amount of Armaflex® Adhesive 520 needed = 2L (280m)
- Adhesive 520 = 100 x 4 = 400 NOK

- AF-10mm sheets = 227,70 NOK/m2
- Price/m = 0,562 (1) x 227,70 = 127,63 NOK/per meter of pipe
- 240 x 127,63 = 30631.2 NOK

- Installation costs = 0.2 x (30.631 + 400) = 6206.2 NOK

I= 400 + 30631.2 + 6206.2 = 37237.4 NOK

9.9.2 Investment costs for tubes:

- Insulation tape (3mm x 50mm x 15m) = 230 NOK
- Units necessary to cover all the installation: 240m / 15m = 16 Units.
- Total price of Tapes: 16 x 230 = 3680 NOK

- Model: AF-1-140 = NOK 207,60/m
- Total price tubes: 240 x 207,60= 56052 NOK

- Installation costs = 0.2 x (3680 + 56.052)= 11946,4 NOK

I = 3680 + 56.052 + 11.946,4 = 716.784,4 NOK = 84327,93 €

Used change rate: 1 € = 8.5 NOK.

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(1) Factor given by Armaflex®.

9.9.3 Costs table

Years	**Armaflex® sheets**	**Armaflex® tubes**
1	5035,81267	96934,9569
2	704,008409	13551,4998
3	765,340589	14732,0908
4	844,634336	16258,4263
5	950,65139	18299,1622
6	1099,60097	21166,3118
7	1323,02534	25467,0363
8	1696,27546	32651,7759
9	2443,65189	47038,1208
10	4687,5335	90230,8865

Table 9.9.3: Costs table for a period of 10 years (in €).