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TECHNOLOGY, COMMUNICATION AND TRANSPORT

WATER CONSUMPTION STUDY OF REVERSE OSMOSIS FILTRATION AT VALIO LAPINLAHTI DAIRY

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SAVONIA UNIVERSITY OF APPLIED SCIENCES — THESIS Abstract

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Abstract

Valio Ltd has launched an energy and resource reducing project the target of which is to reduce 20% of all energy and resource consumption. Inspired of that, Valio Lapinlahti have started a pilot project of a water consumption determining and process water consumption optimization. Process water consumption optimizing project target is to reduce water consumption and set an optimal consumption level for a self-learning real time monitoring system. The monitoring system is aimed to minimize water loss caused from process errors like leakages. The monitoring system enables instant response to process errors and helps locating errors more accurately.

This thesis was commissioned by the Valio Lapinlahti plant. The target of this thesis was to chart the current level of water consumption, estimate potential water saving actions and create repeatable instructions of the charting process. The pilot target of this project was the reverse osmosis filtration process (RO) in the milk reception section at Valio Lapinlahti. Goal was to have an analysed flow measurement period, which presents current consumption level of each process sequence of the RO filtration. Actions to reduce water consumption were considered during the charting process.

Charting was done by studying the pilot target with existing materials of the target and getting familiar with the target by field investigations and making notes of the process in the control room. The target was charted by flow charts, field investigations and flow measurements. Data analysis was executed by measuring water inflow to RO filtration and connecting water data to existing sequence data. Data were presented in graphical form to observe typical water consumption level of specific process sequence and to detect any abnormalties of water consumption. Saving potential was calculated and estimated by using water footprint.

The results of this thesis were water inflow data analysis, estimation of the saving potential and instructions of the charting process. Actions to reduce water consumption were also considired. The results presented a method to investigate the current state of the water consumption.

Keywords

Milk production, dairy, water consumption, optimizing, flow measurement, data analysis, saving potential

PREFACE

I would like to thank Valio Ltd for this thesis opportunity and all the support during the thesis. I would also like to thank Savonia University of Applied Sciences for all the support.

Joni Hynynen

CONTENTS

1 INTRODUCTION

Water shortage is a global issue and a one third of the Earths population suffers from chronical water shortage. In many areas water is consumed more than new water is replaced in hydrological cycle. There are several reasons to global water shortage: the unbalanced dividing of the water supplies, urbanization, population growth and water wasting. The global climate change is a major reason of water shortage. Climate change causes radical weather conditions like aridity and heat waves which advantages water shortage. Most of the global water consumption is caused by agriculture which is 70% of total water consumption. Industries consume about 25% of water in global scale. (Keskitalo 2017, 16.)

Water shortage have appeared also in Finland. Long and hot summer have lowered ground water level even 50cm of the average level in 2018. This caused water use guidelines and water regulation in some parts of southern and western Finland. (Nissinen 2018-07-26.) Industries consume 80% of all domestic water in Finland which makes it clearly the biggest consumer in Finland (Kaatra 2011). Water saving actions should primarily focus in industry because of the scale of water consumption. Valio Ltd has launched a project which target is to reduce 20% of all energy and resource consumption, including water. Inspired by this project, Valio Lapinlahti launched the pilot project to reduce water consumption by optimizing processes and using real time monitoring with the self-learning monitoring system. The current situation of water consumption of the pilot target was studied and charted during this thesis. Reverse osmosis filtration process (RO filtration) in the milk resception section was selected to the pilot target. Subject for this thesis was accepted because the target of the project is at the right course of industries energy and resources policy.

The first phase of the water consumption study was to get familiar with the pilot target, gather information from existing materials and investigations in the field. In practice it means watching operating in the control room, asking questions about water consumption and making notes, studying flow charts and circuit diagrams, charting water pipelines in the field, general studies of an automation system and investigation of existing data collection. The target of the study was get known of existing flow meter types and locations, updating the flow chart, getting familiar with pilot target (RO) and setting up a flow monitoring system to the pilot target.

During and after the studies, potential water saving actions and new methods to reduce water consumption will be considered. The RO water reuse options will be also considered. Water saving potential was estimated and presented by water footprint calculations of Valio Lapinlahti plant and the milk reception section. Current level of the RO filtration water consumption will be monitored by using ultrasonic flow meter. Flow data is connected to existing process sequence step data to observe different sequences typical water consumption. Monitoring was executed during selected measurement period. Water inflow data and sequence data will be connected and graphically presented with measurement data managing program. Data will be analysed and reviewed for current water consumption level and any abnormalities of water consumption.

Water inflow monitoring and connecting it to sequence step data is a trial for continuous monitoring system. Goal of the project is to install the self-learning real time monitoring system to the process. Before the monitoring system installation processes will be optimized to minimum water consumption. The monitoring system will learn normal water consumption level of the process and alerts if any abnormalities are detected. This kind of system reduces significantly reaction time for abnormalities and corrective actions can be done instantly. That way water loss will be minimized and process errors like leakages will be detected quicker. Possibilities of bringing the DMA concept (District Metered Area) to the process environment is also investigated. In the DMA concept measurement target is divided in to the measurement zones, which makes easier to locate possible leakages and enables to more accurate monitoring.

2 WATER IN FINLAND

2.1 Water supplies

2.1.1 Surface water

Water supplies has always been sufficient in Finland. There are about 186 000 lakes bigger than 500m^2 where 57 000 is bigger than hectare. The total share of lake areas in Finland is about 11%- there are 34 533 km2 of fresh water contained within 303 919 km2 of land surface area. (Tilastokeskus 2018.) The Valio Lapinlahti plant is located in Northern-Savo region. Northern-Savo area is 20 952,54 km^2 where surface water area is 3718,85 km^2. Surface water covers 17.7% of whole area of Northern-Savo. (Järvi & meri wiki b n.d.) The largest lake which is entirely in Northern-Savo is lake Kallavesi (478 km^2) (Järvi & meri wiki a n.d.).

According to the latest data (2015), ecological situation of most of the fresh water supplies is good or excellent. The share of the rivers which has been rated good or excellent is 65 % and the share of the lakes is 85%. Worse than good- rating contains 35% rivers and 15% lakes. (Suomen ympristökeskus SYKE 2017-07-14.) In summary, most of surface water quality in Finland is good. However, surface water requires a treatment process before it can be used by potable water. The supplies of the fresh water ecological condition in the Northern-Savo is rated good. 90% ecological condition of the lakes and the rivers is good or excellent, but it has been estimated that approximately 20% of surface water ecological condition is turning down. (Pohjois-Savon ELY-keskus 2014-01-24.)

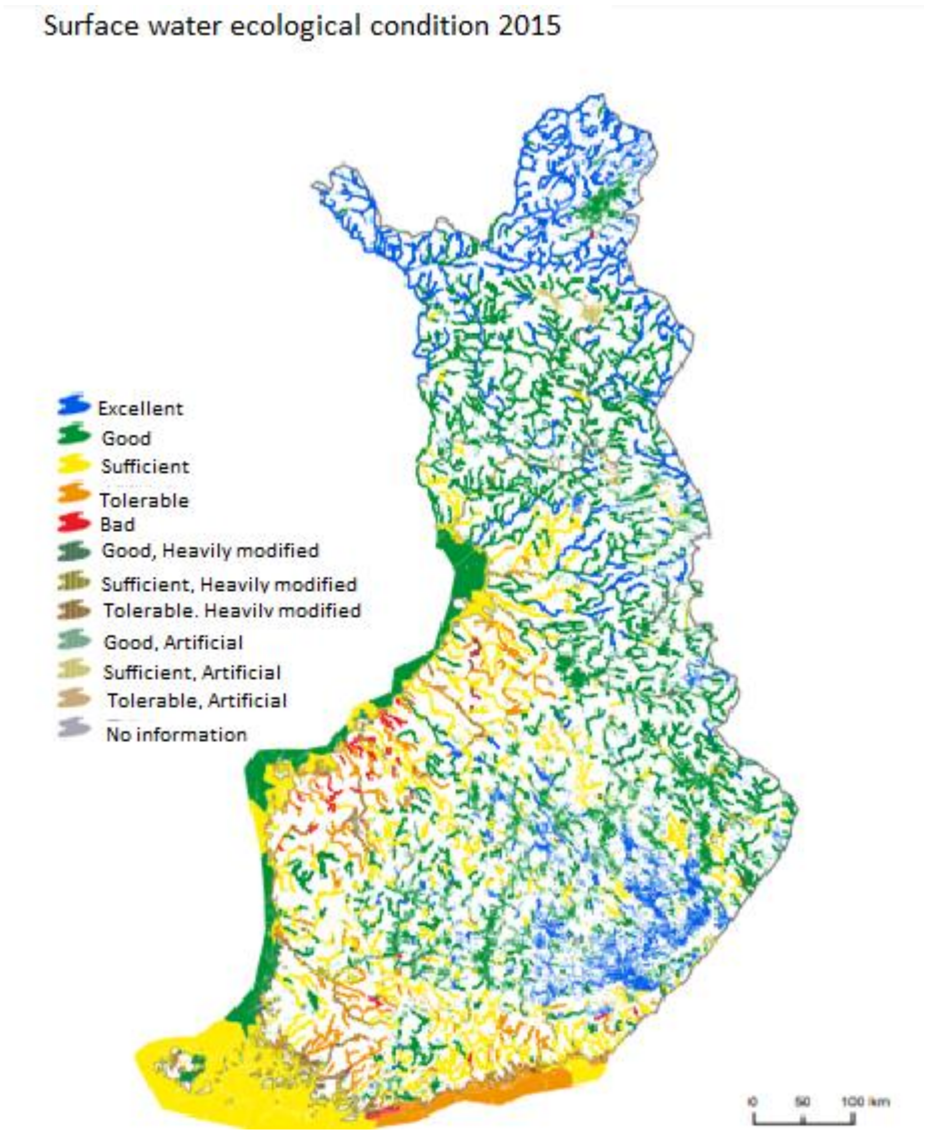

FIGURE 1 Water quality situation in the year 2015 (Based on 2006-2015 material). (Suomen ympristökeskus SYKE 2017-07-14.)

2.1.2 Groundwater

Groundwater supplies are also great. Best quality and productive groundwater areas occurs commonly in ridges which are formed by sand and gravel. Rock-bottom groundwater is mostly good quality and also good source of groundwater. Quality matters in the rock-bottom groundwater areas is result of slow flow in rocky areas. Because of that mineral level raise and acidity reduce. Harmful matter can be also dissolved to groundwater like uranium and radon containing minerals. (Geologian tutkimuskeskus n.d..)

Groundwater supplies are great. There are about 5000 groundwater areas in Finland which capacity is utilized only at 10%. (Geologian tutkimuskeskus n.d.). These groundwater areas create 5.4 million m^3 water resources every day. For suitable water access, it is estimated that groundwater is created 2,8 million m^3 in these areas. Groundwater and artificial groundwater is used about 0,7 million m^3/d which is 240 million m^3 annually. (Suomen ympäristökeskus SYKE 2018-06-15.)

Groundwater classes are good and bad. Bad class is only when content levels are over or under limiting values. Groundwater quality is usually good in Finland. There are about 3800 of 5000 groundwater areas which are suitable and important water resources. Risk areas contains 350 ground water basins. Groundwater area is classified as a risk area when monitoring reveals that ground water contains detrimental constituents and ground quality water deterioriate without restoration actions. Only 98 risk areas out of 350 are classified as bad condition. (Suomen ympäristökeskus SYKE 2018-12-18.) For example, in Pohjois-Savo has only one groundwater area in Kasurila, Sillinjärvi which quality is rated as bad. Groundwater in Kasurila has chloride value over the limit. Groundwater is polluted by de-icing salt used in the roads (Vallinkoski 2018-10-08). Groundwater areas are susceptible to pollutantse and hard to restore and because of that Finland has a strict legislation with relation to groundwater. According to law is forbidden to emit or lead any substances, energy or micro-oranisms to the important groundwater area which could reduce quality of the groundwater or can be harmful to the health (Ympäristönsuojelulaki 527/14 §17). FIGURE 2 below present groundwater situation in Finland.

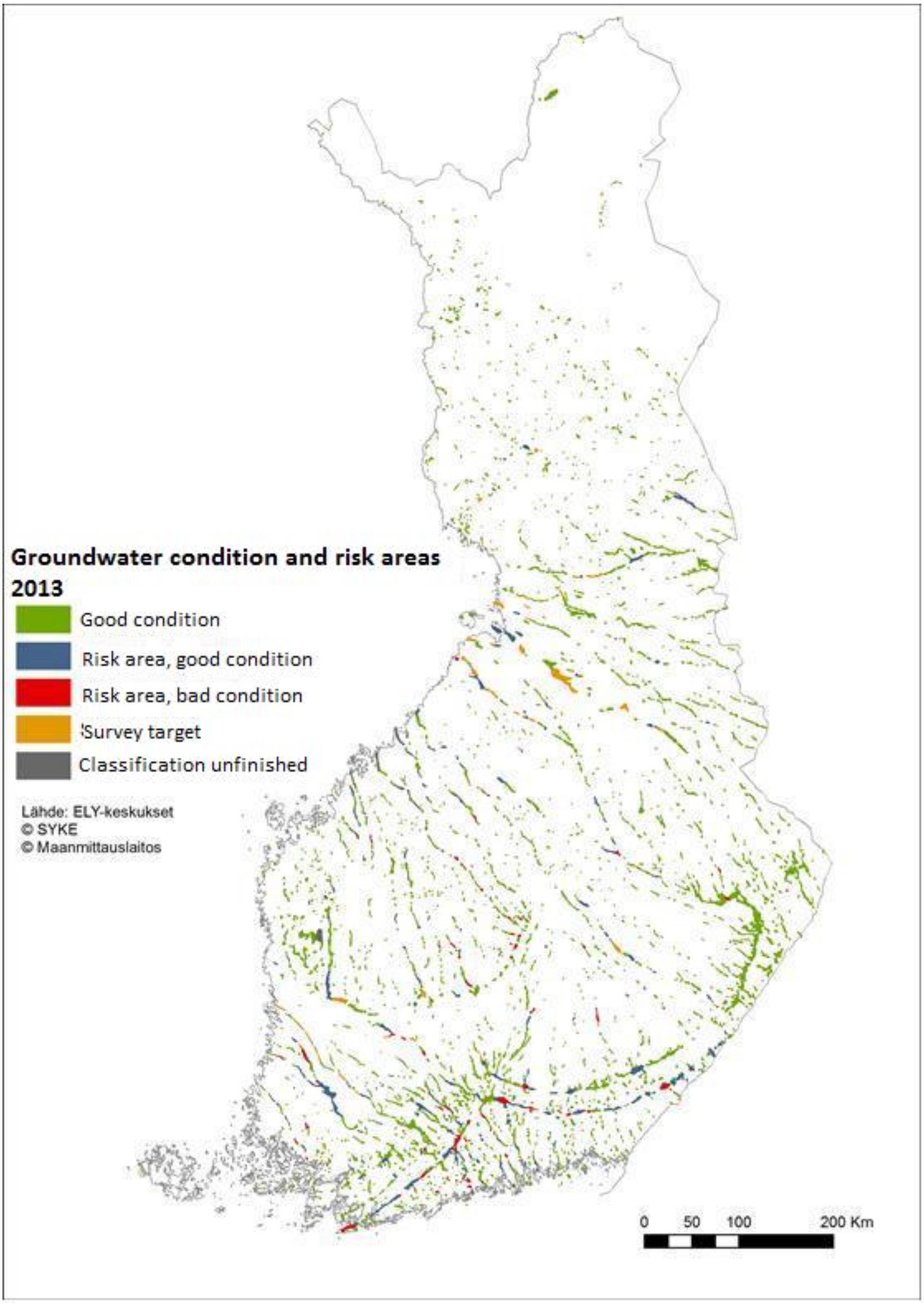

FIGURE 2 Ground water condition and risk areas 2013. (Suomen ympäristökeskus SYKE 2018-12-18)

2.2 Water consumption in Finland

With all fresh water supplies combined Finland has the biggest resources of water in the European Union (Kaatra 2011). The share of the surface water for domestic consumption treated by Finland's water supply plants is 25%. The rest of consumed water (75%) is originating from ground water resources. (Vesilaitosyhdistys n.d..)

The biggest water consumer is industry. Industry uses 80% of all used water. Only 10% of all water goes to community and rest to households (3%), irrigation (3%) and other use (4%). (Kaatra 2011.) There are several reasons why industry is usually an intensive water user. Water can also be raw material for industry products for example beverage industry. The biggest industrial water consumer is pulp and paper industry but takes most of the water straight from surface water. Food industry is the fifth biggest industrial water user. (Suomen ympäristökeskus SYKE 2017-06-14.) Water-intensive industries are shown in FIGURE 3 below.

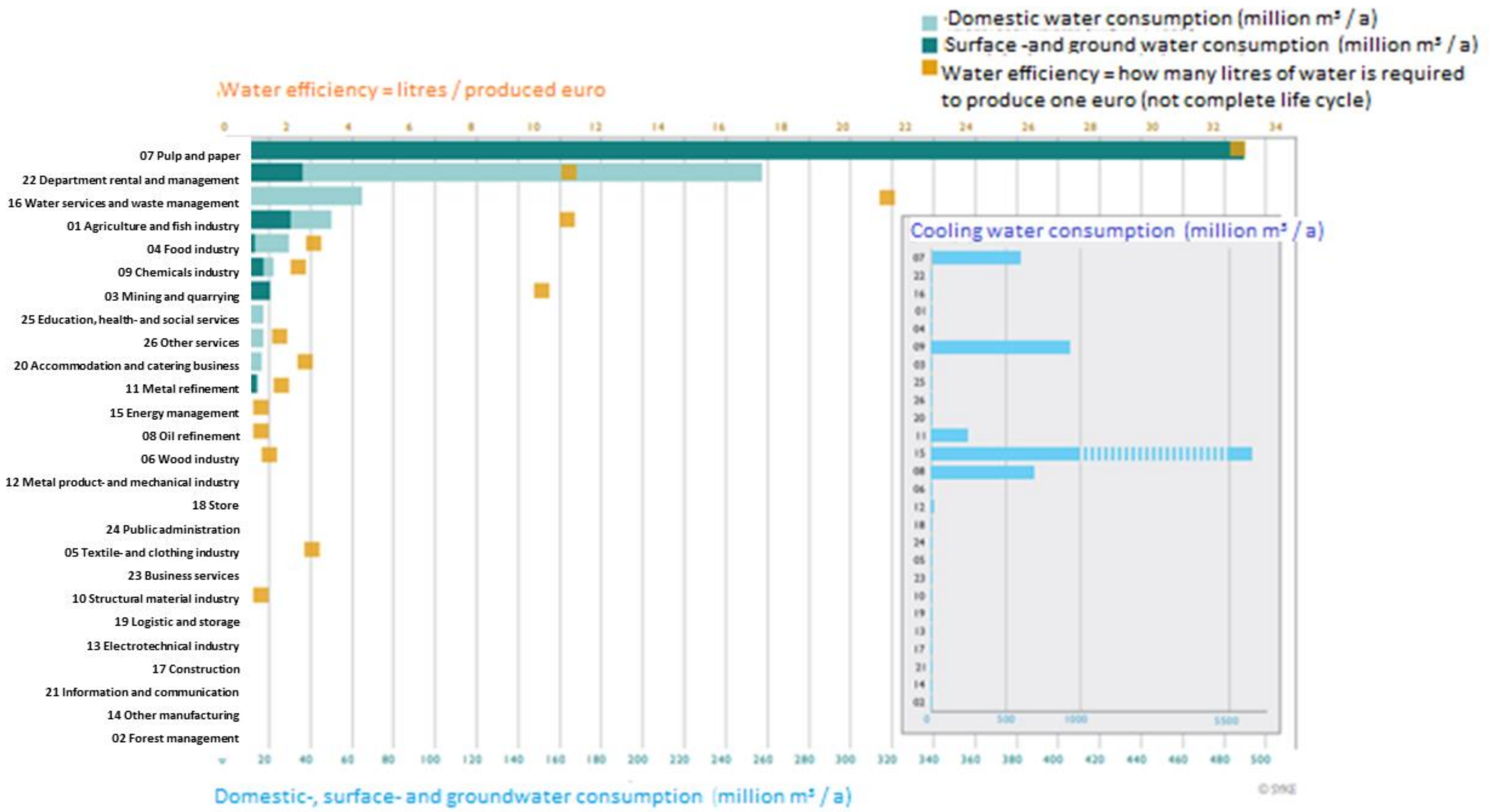

FIGURE 3 Water consumption by industry areas (2010). (Suomen ympäristökeskus SYKE 2017-06-14.)

2.3 Water shortage in Finland

Oceans and seas cover over 70% of the Earth surface. Only 3% of this water is a fresh water and 75% of the fresh water is absorbed into ice sheets and snow. Only 0.01% of all water in the Earth is an accessible fresh water. Water is a renewable natural resource but already about 33% of the population of the Earth suffers of water shortage. Major reasons for the water shortage are population growth, urbanization, water supplies irregular distribution and water wasting. Water is used more than new water appears in the hydrological cycle. (Keskitalo 2017, 16.)

The climate change raises the water shortage. Climate change has been estimated to increase radical weather occurrence like aridity and heat waves, but also floods and downpour (Ilmasto-opas.fi

2014-11-14). Even here in Finland, where is great supplies of fresh water, have turned up water shortage. The water shortage in Finland occurs mostly in the summer and in the autumn because of the long and more often appearing heat waves (Ilmasto-opas.fi 2016-07-14). This lowers ground water levels more than usual and have been affected even water regulation guidelines. In late July in 2018 ground water level were 40-50cm lower from the average level. (Nissinen 2018-07-26.)

Water distribution distances might be long in some areas, which raises cost level of the water distribution. Valio Lapinlahti water supplying comes from Pyhäsalmi which is about 100 km away from Lapinlahti (Puurunen June 2018). These long distribution distances and costs caused from it are also a motivation for industries to reduce their water consumption besides of an ecological savings.

3 VALIO

3.1 Company

Valio Ltd is owned by 16 cooperative farmer associations, including rivals. Valio acquires milk from seven cooperative associations, which attributes 80% of all milk in Finland. Annual milk production is about 1.8 million m^3. Cooperative associations include a network of approximately 5500 milk dairy farms. Valio is obliged by contract to purchase all produced milk from their cooperative associates. According to the Valio policy it is using only domestic milk for their products. (Yritysesittely 2018.)

Valio Ltd's revenue was 1708 million euros in 2017. 62% of the revenue comes from Finland, 21.8% comes from the European Union and the rest is from Russia and CIS (*The Commonwealth of Independent States*) (5.9%), USA (4.1%), Asia (4.8%) and other countries (1.4%). Valio has subsidiarys in the USA, Sweden, Estonia, Russia and China. The most important export countries are EU countries, USA, Russia and Asia countries. Valio Oy and dairy farms employ about 30 000 persons in Finland. Dairy farms receive 42.4% of revenue which is 725 million euros. (Yritysesittely 2018.)

3.1.1 Background information

Valio was established on 4th of July 1905. Valio was initially founded by 17 cooperative dairies and the full name was Voinvienti-osuusliike Valio. It was originally a butter export company and headquarters were in Hanko in years 1905-1918 before it was moved to Helsinki. In 1910s Valio started exporting also cheese and milk. Valio started to sell in homeland in 1910s and homeland sell got more profitable than export in 1920s. (Perko 2005, 12, 14, 15.)

Valio started to consolidate and centralise their operations in the late 1940s. From the beginning business was scattered to cooperative dairys (Perko 2005, 18). Now business is centered to several specific locations, for example in Lapinlahti in 1959. After 1980 to 21st century dairy industry has experienced many radical changes like milk production reduction, consumer habit changes and dairies change to refinement plants. (Perko 2005, 16.)

Valio has contract with all their milk suppliers that it buys all milk produced and refines it even when there is and adverse market situation. Every farmer which produces milk for Valio is also co-owner of Valio. In a nutshell the financial success of the Valio group is directly proportional to farmers financial benefit. (Perko 2005,16)

Company has a long research history. Valio has many covered trademarks as Gefilus, Eila and Mifu. Valio owns overall 350 patents. Artturi Ilmari Virtanen, who was the director of the Valio's research and development department almost 50 years, won chemistry Nobel-prize in 1945 for inventing AIV-fodder. (Yritysesittely 2018.)

3.1.2 Responsibility

Valio Ltd is operated by ISO-14001 environment certificate and ISO-9001 quality certificate (Valio.fi 2015-10-13). Valio has three years environment plans which set a main theme for developing processes to more ecological. (Puurunen 2018-12-10). All Valio plants have an environmental permit excluding the Vantaa plant. All plants prepare also annual environmental report which includes amount of received milk, amount of used water and amount of waste water. (Puurunen June 2018.)

3.2 Valio Lapinlahti

3.2.1 History of Valio Lapinlahti

Valio Lapinlahti was established on 28th of September 1959, when the first milk load was received in the powder factory L1 (Valio Oy Lapinlahti 2018). Valio Lapinlahti was called Kuivamaito Oy at that time. Kuivamaito Oy was a company owned by Valio Meijerien Keskusosuusliike and other cooperatives. Kuivamaito Oy dehydrated surplus milk, which was left from other refinement, to milk powder. (Valio Oy 2009-10-09.) The plant of the Lapinlahti was a third powder plant owned by Kuivamaito Oy. The second powder factory L2 was build in 1970. At the seventies started whey powder manufacturing, which is nowadays one of the most important products for Valio. Half of the raw materials was whey in 1980 when before main product was milk powder. (Valio Oy Lapinlahti 2018.) Kuivamaito Oy produced also butter during years 1974-1998.

Lapinlahti built a cheese factory after twelve years of powder manufacturing. The cheese factory was founded by cooperative operators and the factory was named as Osuuskunta Yhteisjuustola. Since 1971 the cheese factory started to produce Emmental type of cheese and three years later production expanded to Edam cheeses. (Valio Oy Lapinlahti 2018.) The cheese factory produces raw material to the powder factory which is whey. In cheese manufacturing whey is separated from milk and then used as a raw material in the powder factory. Kuivamaito Oy commit to refine all the whey which is a coming as a by-product of cheese production. (Valio Oy 2009-10-09.) That is one of the most important matter why cheese factory was started in Lapinlahti.

Valio Lapinlahti have had many big investments in the 21st century. Most significant was in 2014 when powder factory L4 was built - dedicated formula milk production. Factory L4 has the newest technology and hereby it is the most modern factory, together with the Riihimäki snack plant in Valio. Other big investments were commited in 2013: finished boiler plant, 2015: finished laboratory-, canteen- and office building LRT and formula milk packaging section. (Valio Oy Lapinlahti 2018.)

3.2.2 Present situation

Today Valio Lapinlahti is the biggest plant in the Valio group measured by amount of received milk. In 2017 Valio Lapinlahti received about 450 million litres of milk. That amount is 25% of all received milk by the Valio group in Finland. Valio Lapinlahti products are milk powders, whey powders, formula milk powders and cheeses. 45% of Valio milk and whey powders are produced in Lapinlahti and correspondingly share of cheeses are 40%. Manufactured products total amount was 63 million kg: cheese products 23 million kg and powder products 40.7 million kg of the whole amount. About 75% of all production in Lapinlahti goes to export. (Valio Oy Lapinlahti 2018.)

Valio Lapinlahti's revenue is 250 million euros. About 20 million euros in year goes to investments, for example the latest powder factory L4 was a significant investment in 2014. The total number of employees in Lapinlahti is 284 (19th of October 2018) where 190 staff was employed in production, 45 in maintenance and 31 in laboratory. Rest of employees are working in the research and development sector and cooperative work. (Valio Oy Lapinlahti 2018.)

Lapinlahti receives most of the milk in Valio, but it is also the biggest producer of waste water. Total volume of waste water in 2017 was 1.48 million m^3 when second highest was at Seinäjoki with 1.1 million m3 (Ympäristötiedosto 2017.) The high waste water volume of the Lapinlahti and Seinäjoki is explained by the specifics of products made. Lapinlahti and Seinäjoki produces most of the powder of the Valio and the powder is made by dehydrating the milk. The liquid which is leftover by dehydrating process goes to waste water treatment plant. Waste water volume therefore correlates with received milk. Roughly 3000m^3 litres of water is received in a day and 4000m^3 is going to the waste water treatment plant.

4 WATER CONSUMPTION IN VALIO

4.1 Corporation level

Water consumption is high compared to the total national water consumption in Valio. Valio used 1.6% of all delivered water by water supply plants in 2016 (Ympäristönäkökohdat 2017). The main priorities of the Valio in the environmental field nowdays are to reduce water consumption in production plants. Water consumption is dependent on the particular production plant. Specially, it depends what product specific plant produces and how often equipment is required to be washed.

FIGURE 3 shows that the food industry is only the fifth highest water consumer of different industry areas. However, the plants of the Valio consume a significant amount of water. The total consumption of water in Valio in 2017 was 4 613 886m^3 (Ympäristötiedosto 2017). The total water consumption of the food industries was about 35 million m^3 in year 2010. Comparing the total water consumption of the Valio to FIGURE 3 shows that about 13% of food industries water consumption comes from Valio. Comparing these two volumes is an estimation because Figure 3 is from year 2010 and Valio water use from 2017.

4.2 Valio Lapinlahti and other plants

Valio has many plants over Finland which are manufacturing different types of dairy products. Some of the plants are bigger than the others and they receives different amounts of milk. These are major reasons for differences in the water using. Main reason is the strict correlation with received amount of milk. When there is more milk to refine then there is more water usage. Secondly, type of production has a major effect on water usage. Products manufacturing differ in requirement on extensive and frequent equipment washing cycles. It depends on product type and even recipe for a product. Washing cycles are the main reason for high water consumption. Some products also requires added water as a raw material.

Lapinlahti and Seinäjoki plants are the biggest water users, but they also receive the biggest amount of milk (Ympäristötiedosto 2017). Received milk correlates with the water consumption. These plants products same type of products. Seinäjoki products also butter and greases and Lapinlahti products formula milk powder. Lapinlahti received about 89 000 m^3 water monthly and Seinäjoki 72 000 m^3. Received amount of milk in Lapinlahti was about 37 000 tons and Seinäjoki 34 000 tons in 2017. Difference between the received milk is not that big as difference in water consumption with these two plants. Difference between received milk is only about 9% when correspondingly consumed water is about 24%. This is explained by equipment washing cycles. Lapinlahti needs to wash more often and with more water than Seinäjoki. Washing cycles are required to ensure food safety. Washing cycle and flushes consumes significant amount of water but there are possibilities to do optimization with these actions

4.3 Milk reception

The milk reception consumed about 197 000 m^3 water in 2017. It was about 18 % of the total water consumption in that year. The total consumption of water was about 1 071 000 m^3 during that year. (Kunnanvesi 2017.) The milk reception is a significant water user in Valio Lapinlahti and like most of the processes in Valio Lapinlahti washes consumes the most of the water. Approximately 50 % in the water usage of the milk reception is caused by CIP-centers (Cleaning in place). The milk reception has two CIP-centers: one for the milk reception which includes for example silo and tank washes and second for the standardizing line. Silos, tanks and production lines are specified to be washed at least in every 24h. Especially process pipes are major water consumer because of the size of the pipes. The milk reception has pipe sizes from 28 mm to 120 mm. To achieve required cleaness in the pipe, flow velocity must be high enough. The flow and the size of the pipe have a correlation between each other and this way it is possible to determine the right volume of the water in each flush. (Pyykkönen 2018-12-03.)

Reverse osmosis (RO) filtration consume about 15 % of the milk reception water usage which is roughly 30 000 m3 annually. RO filtration currently uses about 60-70 m^3 water in each washing cycle flushing. RO filtration was implemented in the summer 2016 and it was optimized for production. An equipment washing program was not actually never optimized. With the right water pressure and washing interval it might be possible to reduce water consumption in the RO. (Pyykkönen 2018-12-03.)

The major reasons of the water consumption in the milk reception are washes and water flushes. There are possibilities to reduce water consumption if production periods are long and continuos and washing intervals are optimized long enough. Required water pressure also needs to be pay attention to. Because equipment must be clean and washes requires always certain amount of water it is impossible to go below a certain level of water consumption. (Pyykkönen 2018-12-03.) Received milk and water consumption in the milk reception have also a strong correlation between each other. Water consumption and received milk data had a correlation 0.94 between 2006 – 2017 which indicates that these parameters correlates almost perfeclty. Received milk amount raised 131 357 m^3 from year 2006 to 2017 and correspondingly water consumption raised 75 876 m^3. (Ympäristötiedosto 2006-2017.)

5 PROJECT BACKGROUND

5.1 Milk reception and standardizing line process in Lapinlahti plant

Milk reception and standardizing process is described in this chapter. The milk reception is the first step in a milk refining plant. In the milk reception raw milk is received from the tank truck. Then laboratory samples are taken from freshly received milk. Raw milk is transported to the raw milk silos to wait for the standardizing process. The milk reception and the standardizing processes are shown in FIGURE 4.

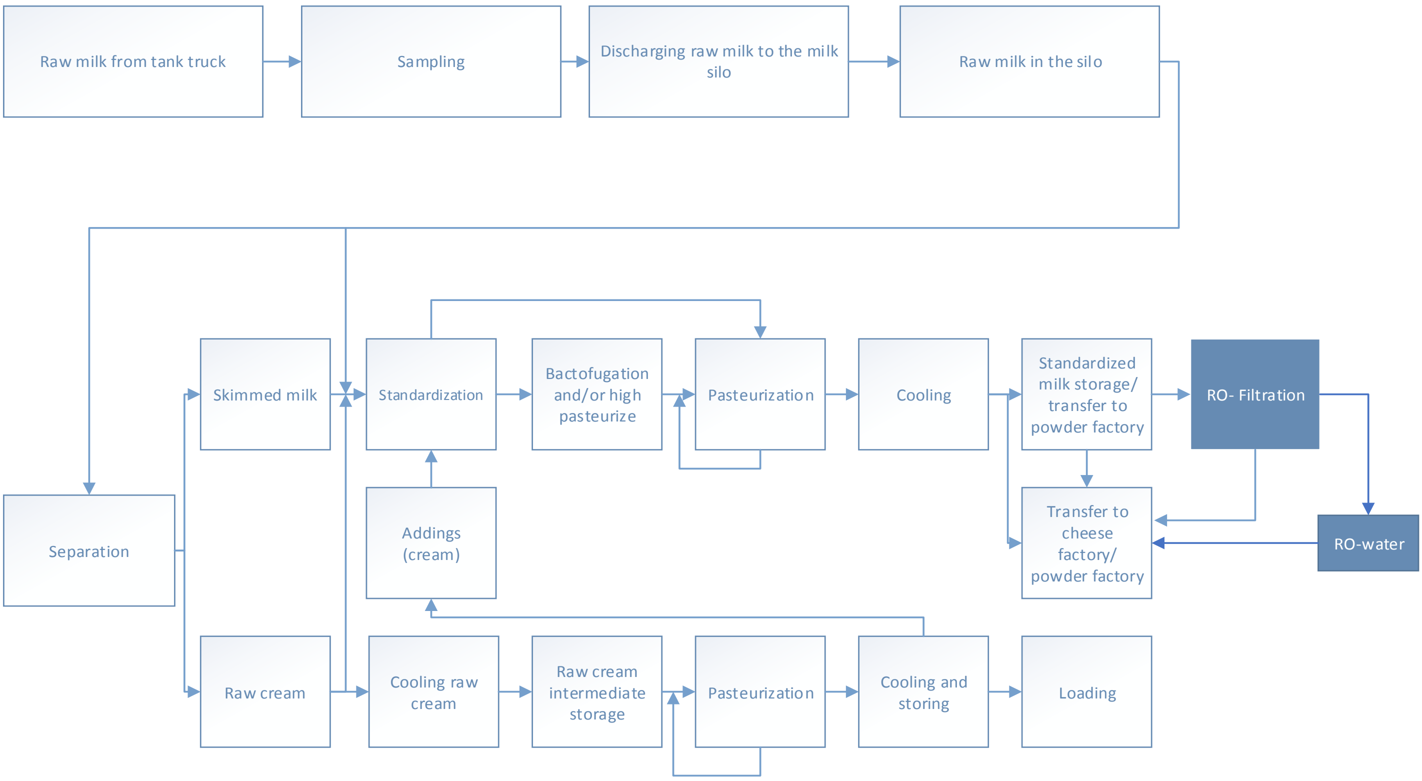

FIGURE 4 Milk reception and standardizing process flow chart (Valio toimintajärjestelmä n.d.).

In the standardizing process no-fat milk and cream is separated from each other in the separator. Milk is separated with a high speed circulation and centrifugal force separates light particles (no-fat milk) to the outer circular orbit and heavier particles (cream) in the inner orbit. (Milkworks n.d..) After separation milk is standardized by adding cream back to the no-fat milk. In this way milk is set to the required fat percentage. At this stage food additives are added if needed. Food additives depends on what kind of receipe is used for production. Raw cream goes through the cooling process and it is stored in intermediate storage to wait for further processing.

When milk is standardized to the required fat-level, it goes to bactofugation and/or high heat pasteurization ELS treatment (Extended Shelf Life). Bactofugation principle is the same as in the separation process but the separated particles are harmful microbes (Pyykkönen 2018-12-03)**.** In the ESL treatment the milk is heated up to 125-135 °C for 0.5-2.5 seconds. This heat treatment increases milks shelf life. (Valio.fi 2018-12-07.) After bactofugation and the ESL treatment milk goes to the pasteurization. In the pasteurization the temperature is lower but pasteurization time is longer than in the ESL treatment. In the pasteurization milk is heated up fast at least to +72 °C and immediately cooled down to +6°C. The pasteurization treatment removes bacteria and microbes from milk because these substances can be harmful for the health. (Valio.fi 2018-12-07.) Cream is also pasteurized before further processing.

After the standardizing process both cream and milk are cooled and stored into the silos. Milk and cream are transported from the storage silos to the powder factories (milk) and to the cheese factory (milk and cream) to produce cheese and milk powders. Whey comes from the cheese factory as a by-product. Whey is separated from the cream and used to whey and formula powder.

5.2 RO filtration

Reverse osmosis (RO) is a membrane filtration technique, which is operated to separate water from liquid which contains a dry substance. The RO filtration concentrates liquid and raises a dry substance level higher. In this case the liquid is a milk which dry substance level is raised up. The RO filtration makes it easier to dry milk to the powder when its dry substance is already higher than naturally. Drying capacity increases because there is less water to dry. The RO filtration produces water as a by-product, which is possible to reuse. (Kalvosuodatinkoulutus 2016.)

The membrane filtration is categorized by its filtration ability. The RO filtration dissolution potential is less than 0,001 µm. RO technique is the most effective membrane filtration technique. Membrane let through only water when all the components of the milk are filtrated. Fraction which flows through the membrane is a permeate which is water. Fraction which will not go through membrane is a retentate which is consended milk. Water which flows through membrane is at least valid process water and it is possible to reuse in the factory. (Kalvosuodatinkoulutus 2016.) Valio reuses currently all RO water in L3 factory. RO water is used in the demineralization process for regeneration of the ion exchange pillars and washing the filtration equipment.

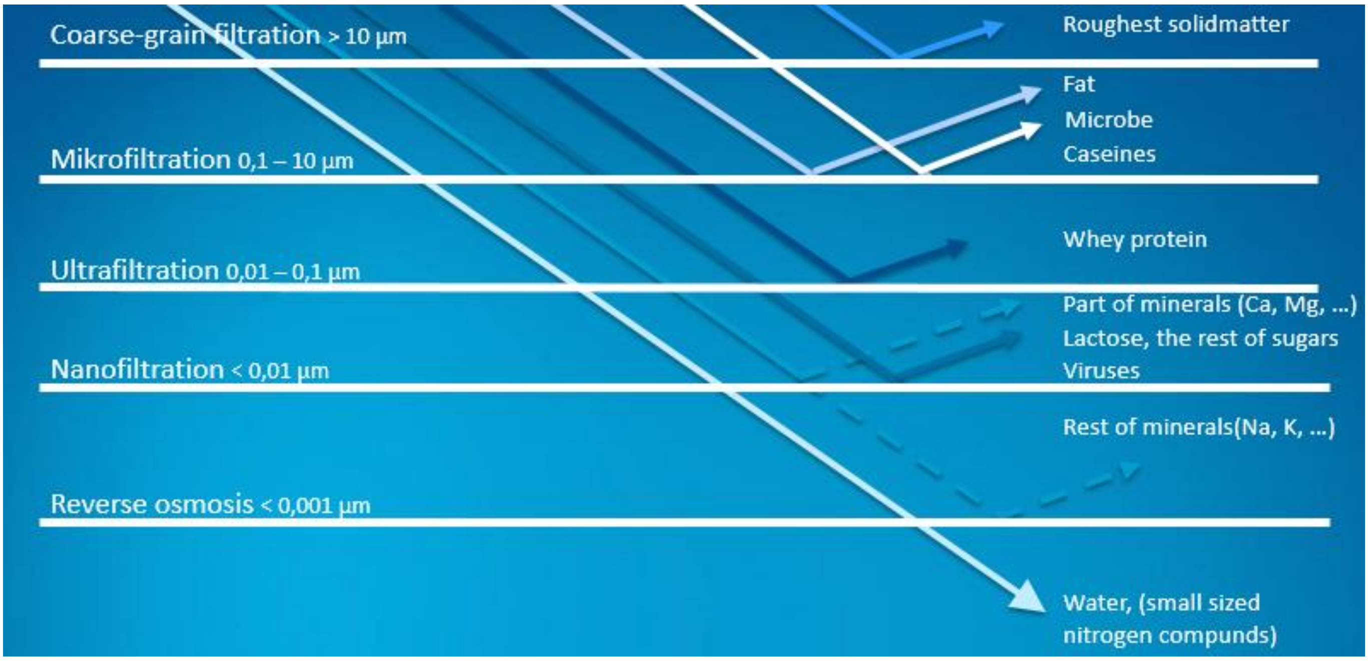

FIGURE 5 Permeability of different types of membrane filtration (Kalvosuodatinkoulutus 2016).

The osmosis effect means that liquid flows through the semipermeable membrane to the direction where component content level is lower. The semipermeable membranes let through only small sized compounds like water. Minerals and other components are not able to go through the membrane and water flows to the more concentrated side of the membrane. Water behaves in this way because it is trying to equalize the concentration level of the liquid. Pressure, which affect to the membrane when water is not able to transfer to the more concentrated side without adding external pressure, is called osmotic pressure. Reverse osmosis means a situation, when the input side has a higher pressure than the osmotic pressure. When the pressure is higher than the osmotic pressure, water flows through the membrane and the input is concentrated. In this case concentrated input is milk. Concentrating begins in about 5 bar pressure. RO filtration process pressure is now about 15 bar in the milk reception. (Kalvosuodatinkoulutus 2016.)

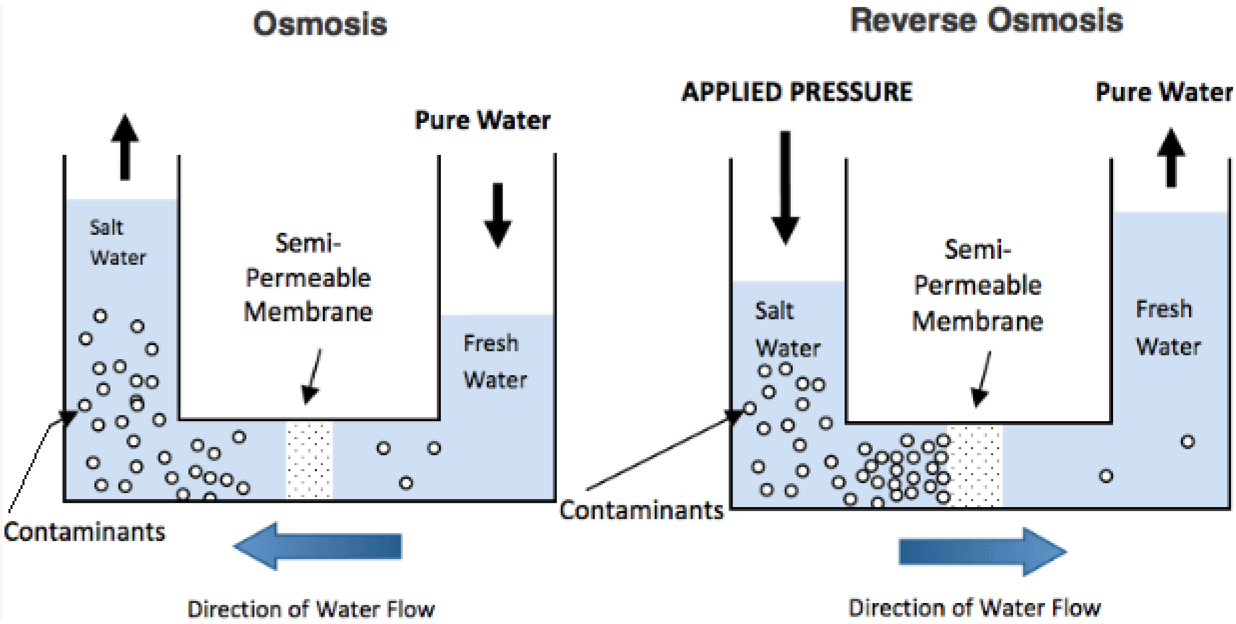

FIGURE 6 Osmosis and reverse osmosis principle (Techdracula n.d.).

5.3 Water flow measurement in the milk reception

At the beginning of the project there were 12 existing flow meters mounted on the water pipes. Most of them are electromagnetic type flow meters. Electromagnetic flow meter measure induced voltage by conductive fluid – measurement principle is based on Faraday's Law of induction (Proline Promag 50 n.d., 97). Voltage is generated by the fluid in motion which is water. Flow meter generates a magnetic field and flow through the meter sensore generates voltage and transmitter converts it to velocity and then flow rate. (Emerson Electric Co. n.d.) Magnetic flow meters which are used in Valio are produced by Endress Hauser and the type is Promag 50 (Proline Promag 50 n.d., 1). Electromagnetic flow meters have several advantages – they are accurate, reliable and wide ranged to measure process industries water pipe flows. Promag 50 proper function demand conductivity 5µS/cm and it provides flow rate range up to 9600m3/h and process pressures up to 40 bar (Promag 50/53 n.d.). Measurement uncertainty for Promag 50 is below 0,5% (Proline Promag 50 n.d., 100). Promag 50 is scaled from 0m^3/h to 50-120m3/h and the ouput is 4-20 mA signal. Locations of the flow meters are represented in the Appendix 2.

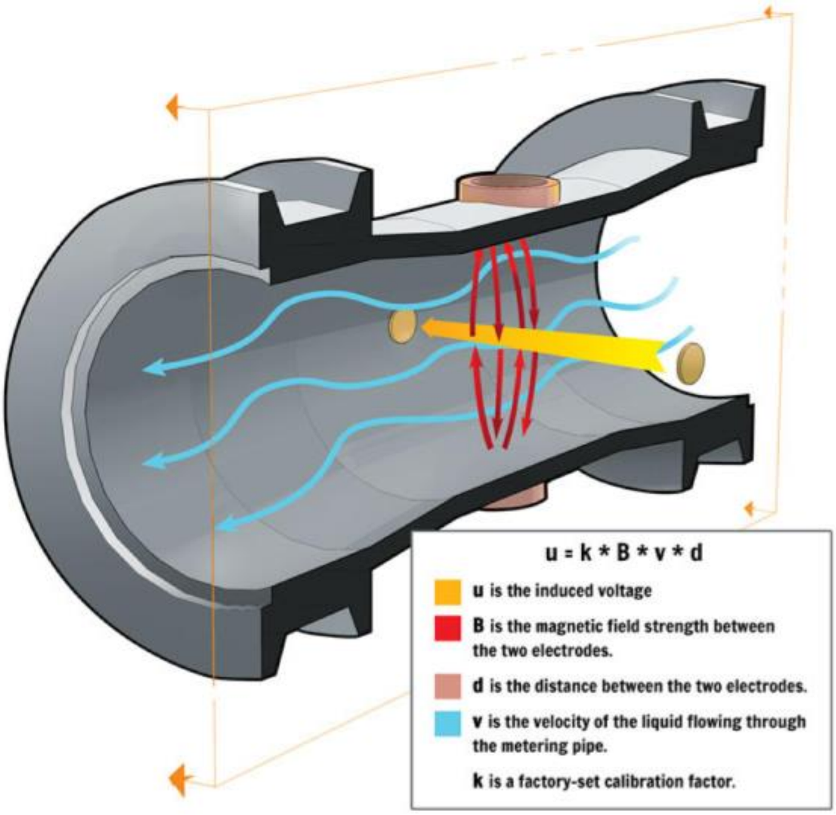

FIGURE 7 Principle of electromagnetic flow meter (Process automatic n.d.).

5 of 12 existing flow meters are magnetic switch. This kind of electromagnetic detectors operates only by on-off principle (MAGPHANT DTI200 n.d., 2). It shows whether there is flow or not. This kind of meters are not accurate and flow or quantity of water is not known. Flow detectors were used in the location where flow measurement was not required by production process. Water consumption in these locations is low. Magnetic switch meters type is MAGPHANT DTI200. It is produced by Endress Hauser. (Endress+Hauser n.d., 1).

The bulk meter located at the main pipeline, which is supplying water to milk reception, is a turbine type of meter. This type of meter works by turbine which is rotated by water flow. Turbine sends a pulse when full rotation is detected. One rotation has a specific value dependent on the type and size of the meter. This way it is possible to calculate the flow by pulses. This kind of meter is reliable and inexpensive but is not such as accurate as electromagnetic flow meter. Turbine meter type in milk reception is MEINECKE WPD 100 produced by Meinecke (Meinecke WPD 100 2011). All the flow meters are listed and the properties are summarised in Appendix 1.

FIGURE 8 Cross-section of turbine flow meter (Meinecke 2011, 1).

Almost all the water pipelines connected to the process equipment have a flow measurement. Pipeline to the RO filtration is an exception. This specific pipeline to the RO is without any kind of flow measurement. Because the RO is the target under investigation in this project, it was decided to purchase a new flow meter. The selected flow meter was an ultrasonic flow meter produced by Flexim – model is FLUXUS F-501. Detailed information about ultrasonic flow measurement is given in Chapter 6.2. The flow chart of the milk reception water pipelines, measurement points- and types, line capacity and pipe sizes are presented in the Appendix 2.

5.4 Automation system descprition

Automation system in the milk reception is a Honeywell Experion® PKS (Process Knowledge System) which is a distributed control system (Honeywell n.d.). DCS (Distributed control system) controls whole process operations, in this case milk reception, when PLC (Programmable Logic Controller) controls a single processes. DCS and PLC runs sequences which operates processes in the factory. (Kippo and Tikka 2008, 55) More information about sequences is provided in the Chapter 5.5. The automation system chart is presented in the FIGURE 9.

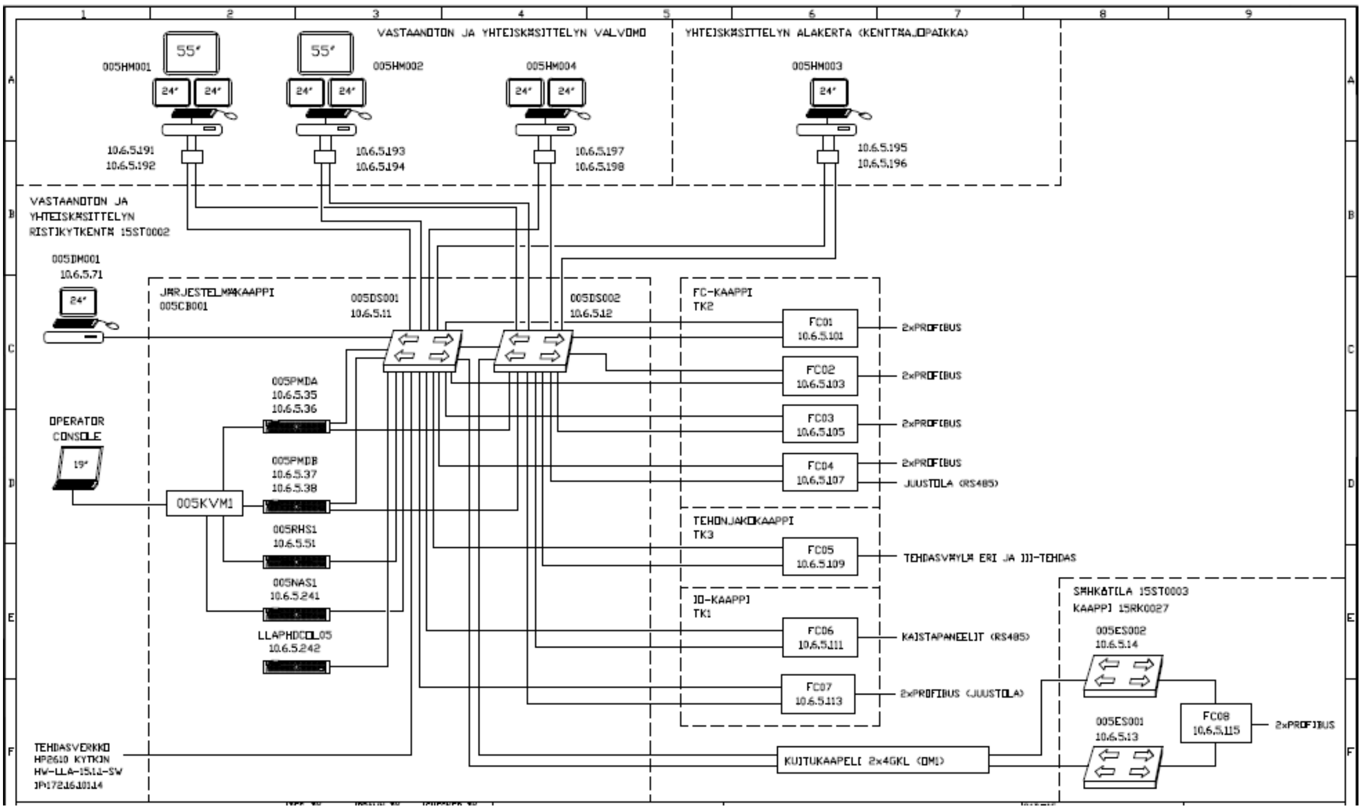

FIGURE 9 Milk reception automation system chart (Automation system chart n.d.).

5.5 Sequence step system description

Process sequences are installed programs at PLC/DCS (Programmable Logic Controller) automation system. PLC/DCS runs a certain part of the whole processes. (Kippo and Tikka 2008, 54.) There are many PLC's in one factory section. PLC/DCS are operated via PCS's (Process Control Station). PCS run measurement, adjustment, logic and control actions which are linked with PLC/DCS. (Kippo and Tikka 2008, 54-55.) Milk reception has eight (8) PCS's to operate different processes. PLC/DCS runs all the time its own logic and it runs it at ordered "route". The route is where the signal goes in PLC/DCS. It reacts to changes in the process and when wanted value or limit has achieved, it will find "other route" to run. In other route logic order to do some changes in the process, for example open some valves or start pumps. After that there is a new limit to reach before next change happens. All the changes, actions and adjustments based on process measurements like flow, temperature, electrical conductance or time elapsed (process duration). (Kippo and Tikka 2008, 55.)

Almost all processes at the Valio Lapinlahti are based on process sequences. In this project the RO filtration sequences in the milk reception section are under investigation. Process proceeds by sequences and sequences proceeds by steps. Only one step at time can be active. Step proceeds to the next one when the step condition is obtaining status "true". It will not proceed until every condition in the active step is set to be "true". (Kippo and Tikka 2008, 58.) There are usually some extra measurements like time or temperature if something goes wrong in the process and the process need to abort.

To describe a process automation, a generic example will be used. The process will be about filling a tank with 1 m^3 of water. “Step 1” is closing the valve V2 from tank to a sewer and opening the valve V1 in water pipe to the tank. When operator close the valve V2 and open the valve V1 from control room, step condition is true. Transition to “Step 2” happens and the pump P1 start running. Now water is flowing to the tank. “Step 3” has a sequence measurement. Step condition is to fill $1m^3$ water in the definite time. When $1m^3$ is reached in time, automation process proceeds to “Step 4” which is closing the valve V1 and stopping the pump P1. If process status does not reach $1m^3$ in time, it proceeds to “Step 5” which is abort a process and the valve V2 in the tank is opened drain into the sewer. In other words, after “Step 3” there are two options from two actions: reach the ordered quantity of water and close the valve and pump or time switch-off and close the valve and the pump and drain water into the sewer. This example of a process automation outline is represented in FIGURE 10.

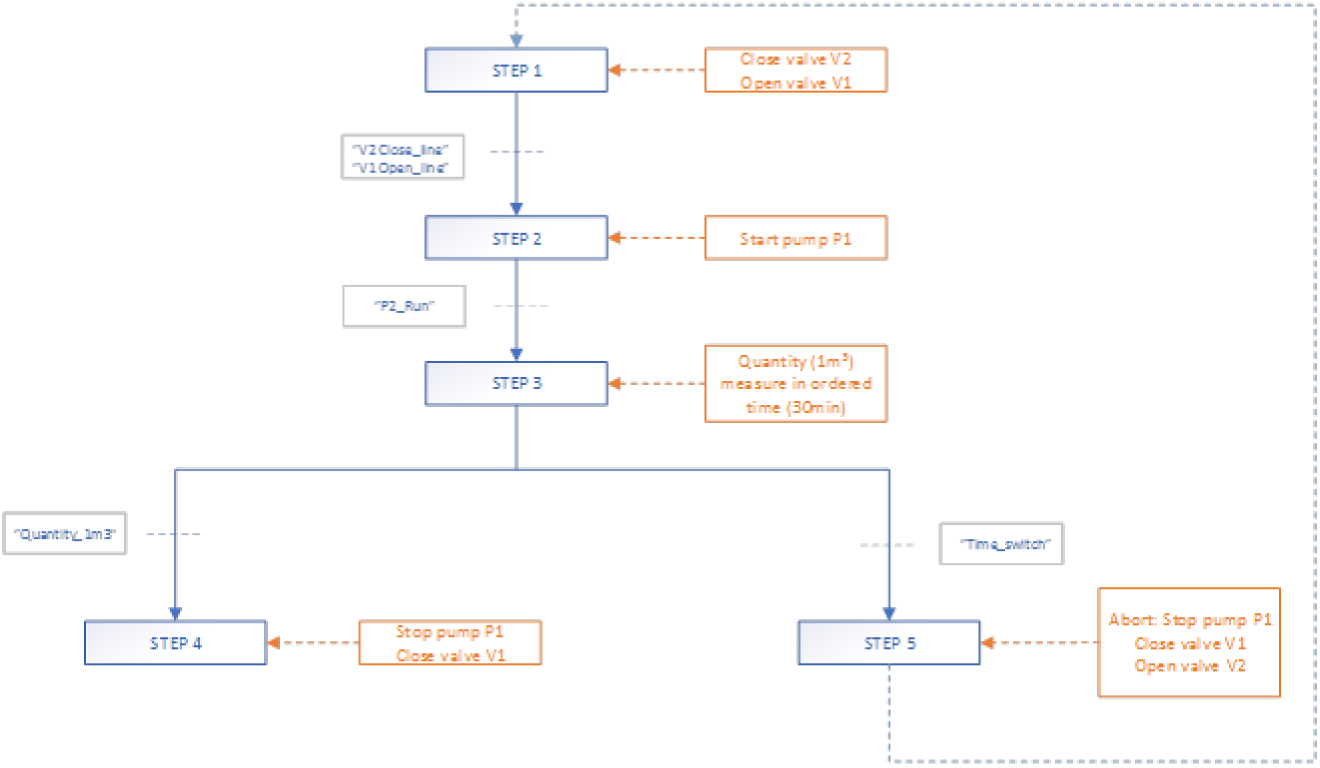

FIGURE 10 Example of a simple sequence automation step system

In the real applications, process sequence charts are significantly more complicated, but the principle is always the same. In this project, investigation focuses only on those sequences, which consumes water. If there is some abnormal water consumption, actions and conditions are checked in specific sequence and find out where is the error. Naturally, if there is any consumption during sequence when there should not be it need to be investigated.

6 REVERSE OSMOSIS FILTRATION WATER CONSUMPTION STUDY

6.1 Target and reasons of the water consumption optimization

The target of this thesis was to find and test a systematic way to audit water balance in an industrial process to asses the potential for reducing water consumption in the milk reception at Valio Lapinlahti, more specifically in the RO filtration section. The thesis was the first phase of the water consumption optimizing project. The RO filtration was selected as a pilot target in the project. The RO filtration water consumption was measured and analysed to detect a normal level of water consumption. Effort was made to select a representative time period. If there were any abnormal water consumption, reasons for that were investigated. Data analysis showed which sequences uses most of the water and these sequences were investigated more thoroughly. To facilitate analyses data was pre-processed and presented in the chart. This pre-charting was done for an automated measurement system which learns processes normal water consumption. It calculates by algorithm the normal consumption and alerts when water consumption is too high compared to the sequence currently active. Water use optimizing should be done before an automated measurement is installed to reach the optimal level of water consumption.

This thesis includes pre-charting phase of the optimization project. In this phase all water flow meters were investigated and listed, flow chart of water pipes was prepared and pilot target (RO filtration) water flow was measured. In addition to previous conclusions and possible suggestion to reduce water consumption were made and saving potential were estimated by water footprint calculations based on plant's water balance data.

6.2 Measuring water consumption

The flow rate for most of the water pipes connected to the process equipment is currently measured. There are eight (8) flowmeters and five (5) flow detectors mounted in the water pipes. Inline flow meter types are electromagnetic meters and for bulk metering a turbine meter is used. Some meters are used as flow detectors, so they are used as magnetic switches. Some locations are not measured, for example RO filtration. RO filtration has an internal flow measurement, but it is not able to connect to the automation. Meter and meter types are shown in the flow chart (Appendix 2)

The main pipe flow meter (bulk meter) type is a turbine meter. This meter is reliable for a general volume flow measurement, but accuracy is low for low flows (Meinecke WPD 100 2011, 2-3). The meter sends a pulse in every 0.1m^3 flow and the maximum measurement uncertainty is 2%. In 2017 the milk reception average water usage in month was 16 427 m^3 (Kunnanvesi 2017) and if measurement uncertainty is 2% that means possible 328.5 m^3 unmeasured flow. Correspondingly annual water consumption in 2017 was 197 119 m^3 (Kunnanvesi 2017) and with 2% uncertainty that means about 3942 m^3. In this scale water amount is significant. These are very rough estimations calculated with maximum uncertainty.

5 of 13 of the meters are magnetic switches which reports only if there is flow or not. These detectors report constantly small flow and when there is an actual flow detector records a maximum value. Detectors are used to detect flow, not measure flow rate. Reason to have this kind of detectors is in these positions flow is not expected to be high. This detector type is MAGPHANT DTI200. (MAGPHANT DTI200 n.d 1)

Other meter type is an electromagnetic flow meter. 6 of 13 meters are this kind of meters. Electromagnetic meters are accurate and reliable. These meters measurement uncertainty is below 0.5% so measurement is accurate. These meters are selected for these locations because water consumption is high and there are more factors to cause possible leakages. Meter type is PROMAG 50. (PROLINE PROMAG 50 n.d. 1)

6.2.1 Ultrasonic flow meter

The ultrasonic flow meter model is Fluxus F-501. Meter is clamp-on meter, which means it can be mounted on the pipe. Clamp-on meter will not need pipe modifications if there is a vertically or a horizontally straight pipe which length is a length of the device. Device need to be installed in a place where pipe cross-section is always full. (FLUXUS F 501 2015, 18)

The ultrasonic flow meter measurement principle is a transit time difference correlation. The meter has two transducers which both are sending and receiving signals. Signals are sent and received in and against the flow. If the medium in the pipe moves, it causes the signal displacing with the flow. The signal displacing causes distance reduction if the signal goes flow direction. Correspondingly distance increases it if the signal goes against flow. Differences in the signal transit distances causes differences in the transit time and the transit time is proportional in average velocity. The flow velocity of the medium, which is water, is calculated as follows (FLUXUS F 501, 12.):

$$v = k_{Re} \times k_a \times \frac{\Delta t}{2 \times t_{fl}}$$

with:
v= flow velocity of the medium
k_{Re}= fluid mechanics correction factor
k_a=acoustic calibration factor
Δt= transit time difference
t_{fl}= transit time in the medium

Volumetric flow rate V means the volume of the medium which runs through the pipe per unit time. Volumetric flow rate is calculated from flow velovity v and cross-sectional of the pipe area A (FLUXUS F 501, 12.):

$$V = v \times A$$

Mass flow rate m means the mass of the medium that runs through the pipe per unit time. The mass flow rate is calculated from the volumetric flow rate V and the density ρ (FLUXUS F 501, 12.):

$$m = V \times \rho$$

This meter was chosen because its accuracy, price and mobility. This particular ultrasonic flow meter has ± 0,5% measuring accuracy (FLUXUS F 501 n.d.). The clamp-on meter transfer to other location is easy to realise and this benefit is important further in the project when other objects are measured.

6.2.2 Pressure measurement

Pressure meters are installed next to the bulk flow meter and in the process equipment, including the RO filtration. Pressure is measured because the flushes requires a certain pressure to clean properly pipes and process equipment. The RO filtration a requires certain pressure level to achieve reverse osmosis and this way water flow through a membrane. If pressure is not high enough, reverse osmosis will not operate properly and water just flows straight without going through the membrane and flush it. Pipe flushes requires also enough pressure to achieve demanded flow rate to clean the pipes. (Pyykkönen 2018-12-03.)

Pressure in the system is constantly monitored because during periods of high water demand, available pressure might not be enough for some processes. Pressure shocks due to burst operation of pumps and valves are problem too and requires a special equipment for pressure monitoring. Pressure shocks can damage equipment or even water pipe support.

6.2.3 Ultrasonic flow meter connection to automation

Fluxus F-501 ultrasonic flow meter is directly connected to Valio's SCADA. The flow meter sends data directly to the Honeywell PHD (Process History Database). The flow meter sends a raw 4-20 mA analogue signal which has a 0-100m^3 range. The flow meter interval for value reading is 1 second. Data is retrieved from PHD with SQL-query (Structured Query Language) with MMC-reportage software. The data is aggregated and saved in 1 minute interval.

6.3 Concept of a district metered area

District metered area (DMA) in water distribution system (WDS) means dividing district in to the measurement areas where all the water pipes have a shut-off valves. DMAs are used to managing water network and reduce water loss. Every pipe where water is taken has flow meter to measure all the water use in the specific area. In this way it is possible to divide water usage in certain area and all water consumption is captured. This method also enables to investigate more accurate consumption because there are less water users in the smaller area. All results combined gives a detailed water balance of those areas. (Alvisi and Franchini 2013, 1.)

The DMA method is used in big scale by cities. Data which is acquired from a DMA system can be used in real time monitoring. This simple idea and economical savings what DMA provide has made it a popular way to control water consumption worldwide. The method makes possible to detect a single leakages and background leakages in the water system. (Puurunen 2015, 7.) The same idea can be used in the process industry to capture all water flows which are used in the process and when there should be less water use or no use at all.

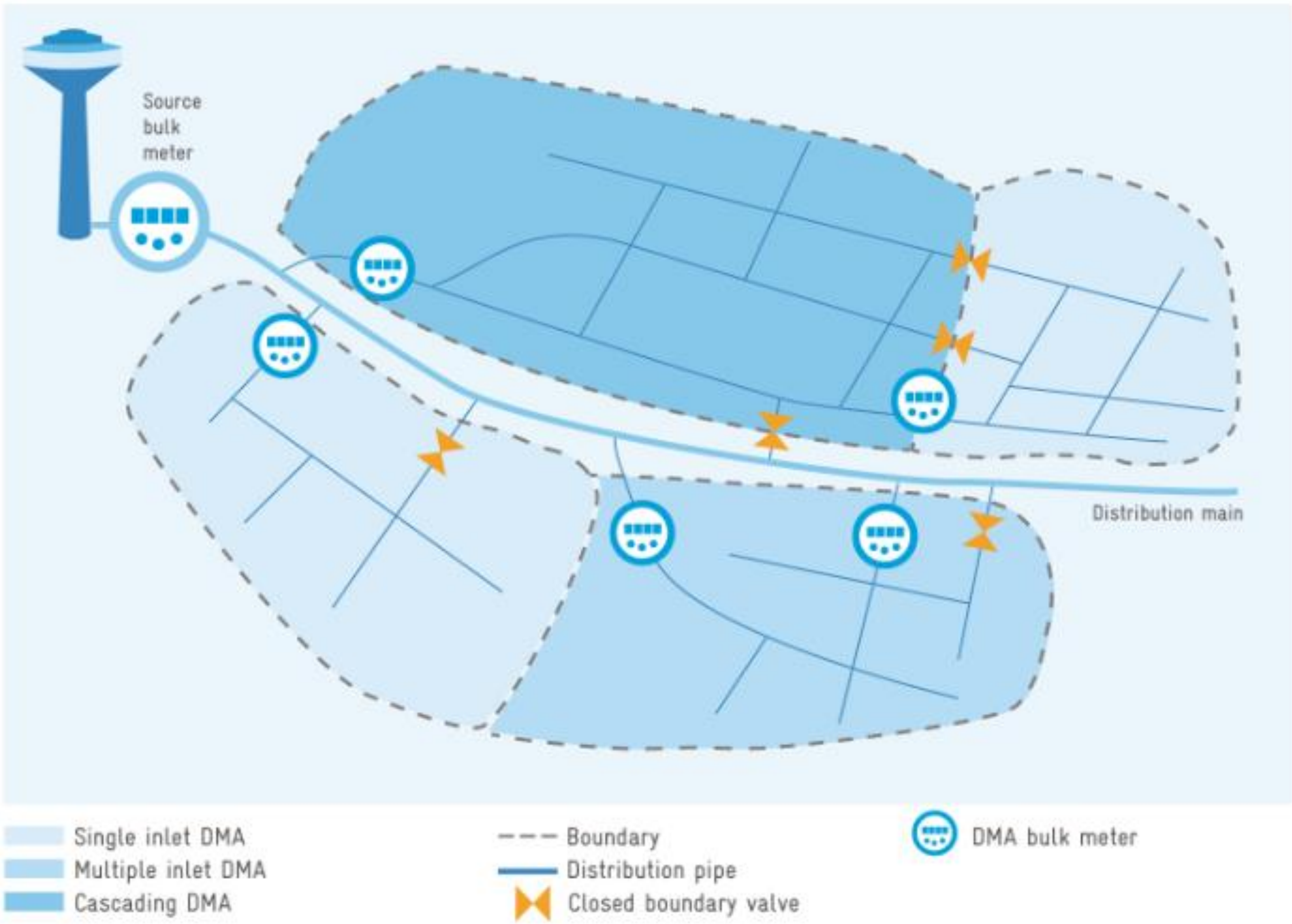

FIGURE 11 Example of DMA (Waterloss reduction n.d.).

Benefits in the DMA method if it is applied to process industry is to divide different parts of process into own specific areas. This way it is possible to see differences in water consumption in each measured area. There is not any unmeasured flow. The water balance has an exact information of water usage and could connect it to different actions, in this case to the process sequences. Using a regular timestamp, flow measurement and process sequence steps of specific area are known it is possible to accurately connect water consumption into the exact moment. Sequence step present what was running in the process at that moment and water flow data shows how much water were used during that. Process can be divided as many measurement areas as needed. Water balance and data is easier to manage.

Disbenefits of the DMA concept are possible pipe modifications which are mostly shut-off valves and flow meters. Shut-off valves and/or flow meters are necessary to add in each pipe where water is taken in the area. Depending of the measurement target pipe modifications brings expenses, except targets where is already required valves and flow meters to apply the DMA concept.

6.4 Water saving potential

Possible ecological and economical savings were calculated by a water footprint. The water footprint means how much water is used to produce specific unit of product (Water footprint network n.d.). In this project water footprint was not calculated by products but instead received milk (m^3) was compared to used water (m^3). The water footprint was calculated by received milk because different products uses different volume of water and milk. Therefore, it is required to calculate them separately. Other reason was that all the milk is received through the milk reception and standardizing process. Because the milk reception was the target of the project, there was no necessity to calculate water footprint by product.

Calculated variables were following: used water, received milk and waste water discharged volume. Inflow water and received milk are separated into total plant volume and the milk reception volume. The milk receptions waste water discharge was calculated approximately by using multiplier which come from:

$$\frac{Total\ waste\ water\ m^3/a}{Total\ water\ m^3/a}$$

Valio Lapinlahti plant waste water balance is a special case because there is more waste water discharged than water is received. In 2017 ratio between the waste water discharge and the water inflow in Valio Lapinlahti were 1.38. All the parameters used in the calculations are monthly from the year 2017 (Ympäristötiedosto 2017, Kunnanvesi 2017). Water m^3 price is current price.

The water footprint was calculated separately for the whole plant and for the milk reception. Saving potential was calculated by 0.25 m^3 steps of water reduction. This way is calculated how much would 0.25 m^3 drop of water usage per milk m^3 affect to ecologigal and economical savings. Water cost correlates directly to the water consumption. The waste water cost is by a contract and it is not included in calculations. The waste water volume from milk reception is a rough estimation. The waste water volume in different water usage level is calculated by multiplier. The calculations is presented in the Appendix 3. Discussion about saving potential are in the Chapter 7.2.

6.5 Water use analysis using flow measurement and automation sequence data

Data analysis of water use was carried out using Excel and Matlab software. Firstly, data of water use were downloaded by SQL query (Structured Query Language) formulated in MMC reporting software in Valio. Water flow data was received directly from the flow meter. Water flow data was exported in xlsx. format from MMC. Sequence steps were received from Honeywell Uniformance PHD (*Process History Database*) in xlsx. -format. After this data was modified in Excel and all parameters were separated into their own columns. For example, timestamp in original data is in one column. After modifications year, month, day, hour and second have own columns. These modifications are important for further analysis. Sequence steps were in their own file.

After the data was prepared to the analysis, it was imported to the Matlab analysis software. In the Matlab it is important that every parameter is in separate columns. This way input matrix in the Matlab is created properly. Next phase, after water use and sequence matrix creation, is to create a program to combine these parameters timely in to the same format. Because both data are from the different sources, timestamps are not matching perfectly. Interval of the water use data is one minute, but sequence number is collected when it changes (Milk reception volume, RO filtration volume, RO wash volume and RO total volume). Differences between the timestamps are not big, only some seconds, but in the process those seconds can mean a lot. Some sequence steps might last only few seconds. Interval of the water use data was 1 min, but sequence steps were irregular. In the combination of the data the water use data timestamp was set to closest timestamp in the sequence data. No data were deleted in the timestamp harmonization. Used Matlab code is presented in Appendix 4.

After combining the data, the sequence steps and the water use data was illustrated in graphical form by using basic line diagram. In Figure 12 all four sequences are presented in the same figure with water use. With this figure it is possible to investigate water use during each sequence steps.

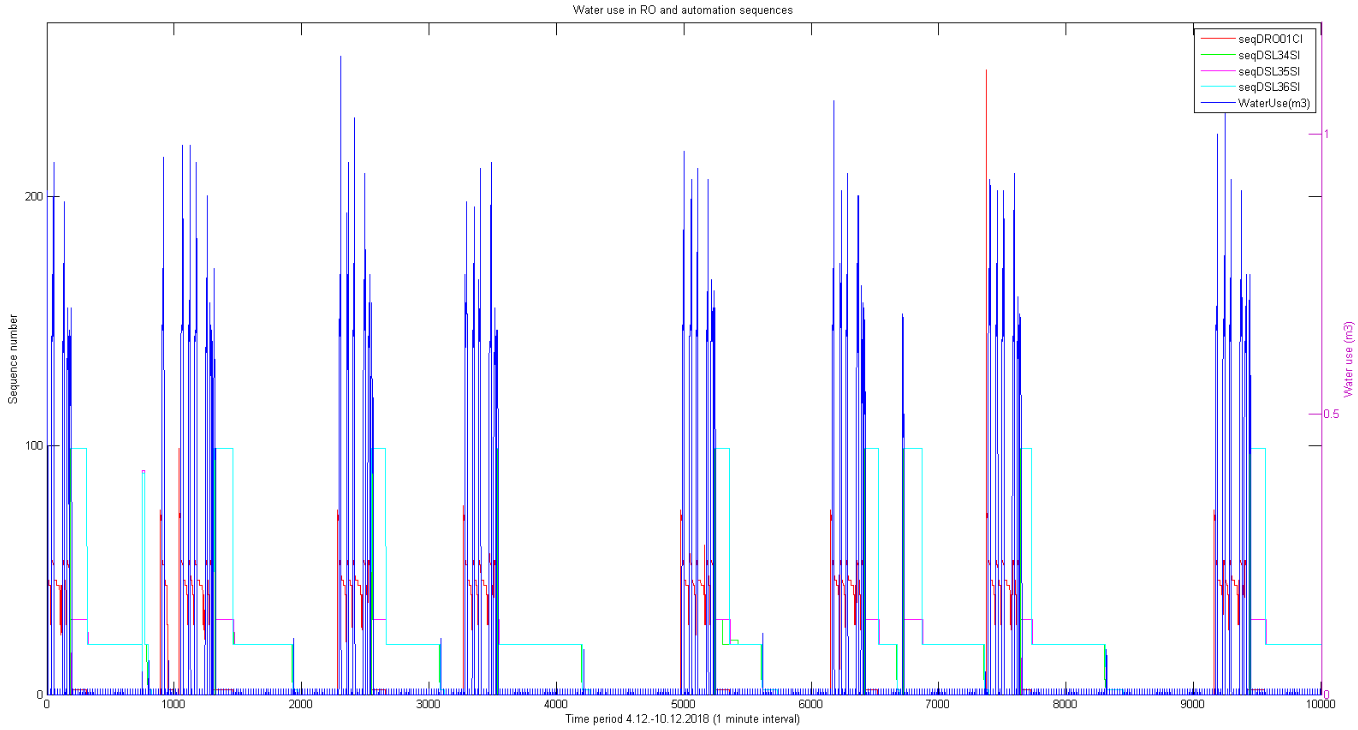

FIGURE 12 Reverse osmosis filtration process during 4.12.2018-10.12.2018. Water use in blue and other colors are sequences. X- axis is time in minutes, left Y-axis is a sequence step number and right Y-axis is water use in m^3.

7 RESULTS AND DISCUSSION

7.1 Data analysis results

Inspected measurement data period was 4th of December-10th of December 2018. Water was consumed 543m^3 during this period, which is about 15% of total milk reception consumption. It is estimated that water consumption of the RO filtration is about 10% of total milk reception water consumption, but water consumption was higher during measurement period.

Currently water data and sequence step data are not from the same software or database and therefore timestamps of these two data were not exactly matching. Created Matlab code was used to combine these datasets to nearest second. Combining data to the nearest second allows to compare these two datasets although there were few second differences. This little timestamp error will not have effect on to the data review.

The data analysis reveals that water is consumed mostly during the washing sequence DRO01CI.OST. During the sequence DRO01CI.OST water was used only during flushing sequences. Flushing sequence step numbers are 52 "flushing" and 54 "end of flushing". Flushes are repeated five times during each washing cycle. Only expection was found in X-axis value 1000. There are six flushes and time interval between the first flush and the rest of the flushes is longer than in normal situation. DRO01CI.OST is represented in red in the Figure 12. Some consumption was noticed during sequence "permeate to the RO equipment" DSL36SI.OST. Water is consumed during step 99 "ending". This is explained by ending flush, which flushes pipes and equipment empty. DSL36SI.OST is represented in cyan in the Figure 12.

Water consumption during the measurement period is a normal consumption. One abnormal consumption was detected. During the whole timeperiod there was detected a low regular flow. Flow meter recorded 0.01 m^3 (10 L) flow in every 20 min. There is a chance for a small leakage somewhere in the process. Flow meter records flow rate in 0.01m^3 intervals so it might leak all the time and every 20 min meter records a 0.01 m^3 flow. If the meter records a true leakage it consumes water about $0.01m^3 \times 3 \times 24 \times 365 = 262.8m^3$ in the year. It could be an error in the ultrasound caused by electromagnetic pulse, for example from pumps, but it is impropable because of its regularity.

Data analysis presents that RO filtration process has a similar working pattern. There might be some differences in the pattern, but these differences are mostly caused by production recipes and a different washing program. If there are any errors in the process, it is possible to notice these abnormal situations from this kind of data analysis and graphical presentation. Moreover, this kind of graphical presentation of water use and sequence steps allows a detailed examination of the actions which have affect to water use and provides method to find solutions for reduction of water use.

7.2 Water saving potential results

There are possible savings in the milk reception RO filtration. The RO filtration washing program is not optimized properly and pressure difference between retentant and permeate sides is not high enough to effect reverse osmosis. Because of this water is not going through the membrane to the retentate side and water flows through the permeate side. This affects long and high volume flushes because conductivity will not reduce that effectively compared to when water runs through the membrane. Conductivity is a main parameter to end the flushing sequence. A rough estimation of possible reduction of the water flushes is about 50% when compared to other similar applications of the RO filtration (Pyykkönen 2018-12-03). This is a major annual reduction if it is achieved. Optimizing production and washing interval is also a major target of development. Production should run as long as possible and process equipment should be washed with a longer interval than currently.

Another target of development is a flushing volumes and investigation of streching current washing cycles to longer interval. Currently it is quality assurance factor to wash equipment in selected interval, which is at least in every 24h. If it is possible to reduce washing load and flushing volume and still clean equipment to the required level it would have a major effect to reducing water consumption and in the other hand economical savings in the long run.

Lastly, when the normal consumption is found after the process is optimized, water consumption real time monitoring and alerts from abnormal consumption reduces water consumption even more. Monitoring helps to notice abnormal consumption instantly and if it is divided in sections by DMA concept, leakage or process error is located faster. Normal consumption should be connected to every sequence and sequence steps which uses water. There should be also information about sequences where water consumption should not be at all.

Used water, waste water and economical savings were calculated by a water footprint. The water footprint was calculated by water m^3 / received milk m^3. Water footprint expresses how much water is used per received milk m^3. These calculations were both made for the milk reception and for the whole plant. The water footprint was not calculated for each product, which would be important information for further in the project. At this point there were lack of required information and calculations would be too wide to involved in this thesis. Information which was used in the calculations are from year 2017. The water footprint were calculated for each month and average of the year. Average of the year was a used parameter to estimate the saving potential.

Calculations showed that Lapinlahti's plant water footprint is 2.36 m^3 and milk reception is 0.43 m^3. The milk reception is easier to calculate because all milk in the plant is received through the milk reception and standardizing line. If water footprint is calculated for example for cheese factory it will have more factors like milk used in different products.

Starting point of the calculations was that if the footprint is 2.25 m^3 in the whole plant and 0.4 m^3 in the milk reception how much it would cause water, waste water and economical savings. Next steps in the calculations was -0.25 m^3 drops of water use. Economical savings were calculated by price of the water m^3. Water price correlates strictly to consumed water. Waste water treatment price have variable and fixed cost by a contract. Waste water price depends on solid matters, amount and fixed cost. Waste water price was not calculated beacuse of contract matters. Waste water amount was calculated by a multiplier which is ratio from water use m^3/waste water m^3= 1.38.

Calculations shows that even the first stage from 2.36 m^3 to 2.25 m^3 would bring potential savings in total water use and on this account also economical savings. Water savings would be about 47 000 m^3 and economical savings about 41 000€ annually. Drop would be 0.11 m^3 water to 1 m^3 of milk. The first steps to achieve first stage of the water reduce calculations are the optimization of the washing cycle processes in the plant and RO-water re-use in the process more than currently it is used. Optimization of the washing cycle main points are optimization of the washing cycle interval and water volume optimization of the flushes. All stages and savings is presented in Appendix 3.

7.3 Instructions to repeat water consumption study

This thesis contains water consumption study for the RO filtration process. Using created procedure, similar kind of study could be also done to the other process units at the plant. The principle of the created water consumption study is presented in the Fgure 13 and in the following text.

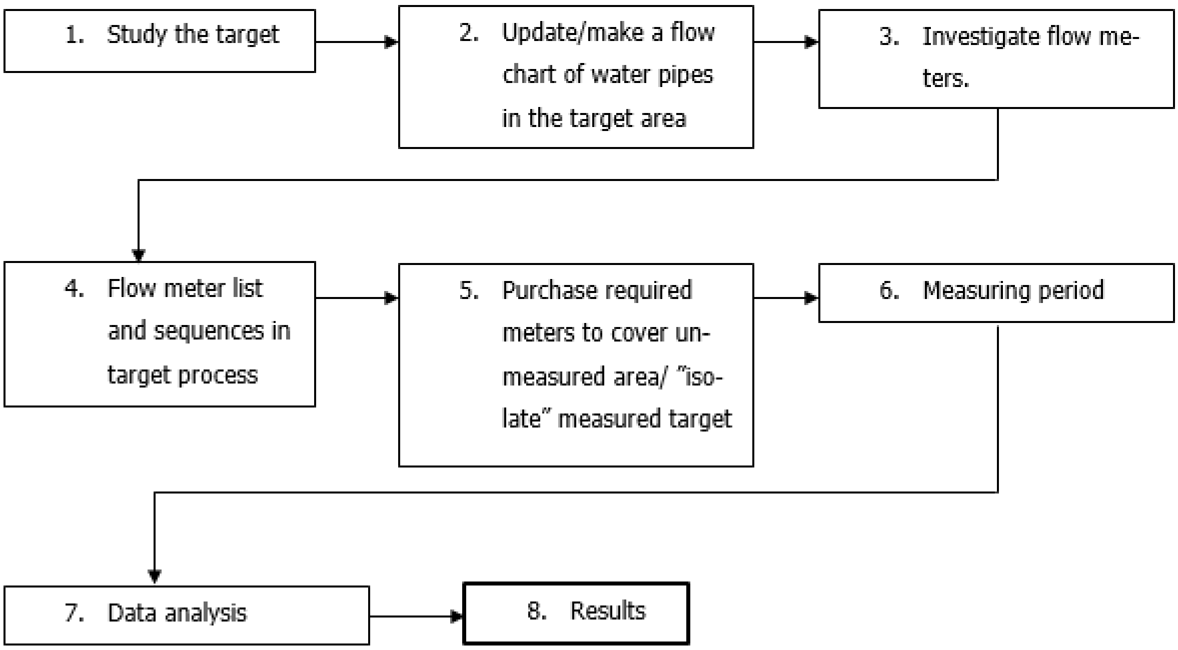

FIGURE 13 Steps of data-based water used analysis

1. Firstly, the target should be studied. Watching in the control room and getting familiar with the process in question. Get to known the process in the field is also important. This way a general view of the process is made. Writing notes of the current situation is also important.
2. If there is a flow chart of the water pipes already, it should be confirmed that it is updated by tracking pipes in the field and comparing them to the exceeding flow chart. If there has been some changes it should be updated to the flow chart. If there is no flow chart of the target it should be done. Notable information in the flow chart are water pipes, pipe size, maximum flow, flow and pressure meters and water consumption objects after particular flow meter.
3. The flow meter type, model, accuracy, location, range, scale and water user of particular flow meter should be investigated. Note also if there is unmeasured areas in the target.
4. List all the flow meters and write down things listed in item 3 above. Write down is meter accuracy sufficient enough or not. If known list also the share of the total volume of water (%), average daily flow (m^3) and maximum flow (m^3/h). Investigate sequences of the target process. Secure that sequence history data is collected to the PHD (Process History Database)
5. If there are unmeasured areas, purchase suitable flow meter to the area. Make sure that the target area is "isolated". All possible water inflow is under measurement or the water pipes is shut off by a valve. If there is inflow which is not measured take it into account.
6. Collect flow data and sequence step data from specified measuring period.

7. Analyse data for example with Excel and Matlab. Connect sequence data to the flow data (if not in the same file). Inspect data for abnormal water consumption and process trend.
8. The results of the study are information of used water during the time period, abnormal water consumption, process trend and process errors. Investigate any abnormalities.

8 CONCLUSIONS

In this thesis the target was to chart a background of the water consumption in the RO filtration process in the milk reception of Valio Lapinlahti plant. The target of the study determine current water consumption of the RO filtration and investigate the process sequences which are consuming water. The main phases of the study were: 1. The flow chart creation of the target (the milk reception) and investigation of current flow meters, 2. the inflow monitoring of the pilot target (RO filtration) and 3. the analysis of the water data. The results of the study are the manual of the charting process, the observation of the water data analysis and the saving potential estimation by water footprint. This thesis is the first phase of the optimizing project of water consumption in the Valio Lapinlahti plant.

The manual of the study is reproducible and it is possible to put into practice for other targets. On this account the manual is a tool to repeat the charting process in different processes. The manual presents the charting process step by step and shows how the charting process proceeds. The water data analysis contains conclusions of the current water consumption and specific sequences which consumes water significantly in RO filtration.

The water inflow data and the sequence data were collected from the RO filtration during selected time period. Flow measurement did not exist in the water pipeline connected to the RO filtration and Fluxus F-501 ultrasonic flow meter was selected for the water pipeline. This specific flow meter was selected because of its accuracy, price and mobility. The sequence data were collected already to the Honeywell Uniformance PHD. Datas were processed by Excel and Matlab to graphical form. The figure of the momentary water consumption and sequence steps presented the maximum water consumption and main sequences which causes water consumption. The figure also presented any abnormalities of the water consumption. Graphical examination presented that water is consumed mostly during the flushes as expected. Only abnormal consumption was a small regular flow (0.01m^3/20min) which could be a leakage. Consumption during the measurement period was 543m^3 which was 15% of the total consumption of the milk reception. The data analysis showed that graphical examination of water inflow connected to the sequence steps enables a detailed investigation of water consumption.

Saving potential was calculated and estimated by a water footprint principle. The water footprint expresses water consumption for manufacturing a unit of a specific product. In this thesis the water footprint was used to compare water consumption to received raw milk (m^3). The water footprint was calculated by the total water consumption of the plant and by water consumption of the milk reception. Water and economical savings were calculated by a different water footprints per milk m^3. Waste water volume was also estimated with a different water footprints. The water consumption charting and the saving potential calculations reveals that there are potential saving possibilities for water consumption and therefore also for economical savings.

The main targets of the development of the RO filtration were the washing cycles and flushes as expected. The washing cycle interval should be optimized as long as possible. Water amount used for washing load is also a potential water saving target. Flushes of the RO filtration is propably the first stage to optimizing. Pressure of the flushing water is not high enough to affect reverse osmosis effect between permeate and retentate side and that is why water will not flow through the membrane. Conductivity will not get low enough to switch off sequence because pressure is not high enough to clean the filtration equipment. By optimizing the pressure it is possible to reduce as much as half of the current water flushing consumption. RO water is currently used only in the L3 plant. RO water is pure water if the membranes work properly. The targets of the RO water reuse should be investigated more closely to find new applications for it.

This study revealed that flushing and washing cycles are a potential water saving target in the whole plant. Intervals of the washing cycles and flushing optimizing is useful in several locations in the plant. Challenges are production planning and washing cycles combining for long enough. Production intervals of a specific product depends of a several factors and washing cycles are not always at optimal intervals. Flushing is also a major water consumer and should be optimized. Water consumption of the other processes were not investigated but same kind of challenges also appears in different production units.

After the main consumers of water are optimized, project should proceed into the next phase which is a self-learning monitoring system. The monitoring system learns process water consumption and alerts if there occurs any abnormal water consumption. Before the monitoring system can be installed water consumption requires a charting and optimization to optimal level. The advantages of the monitoring systems are real time monitoring and alerting of any abnormalities in water consumption. Real time monitoring provides quick response for abnormal water consumptions.

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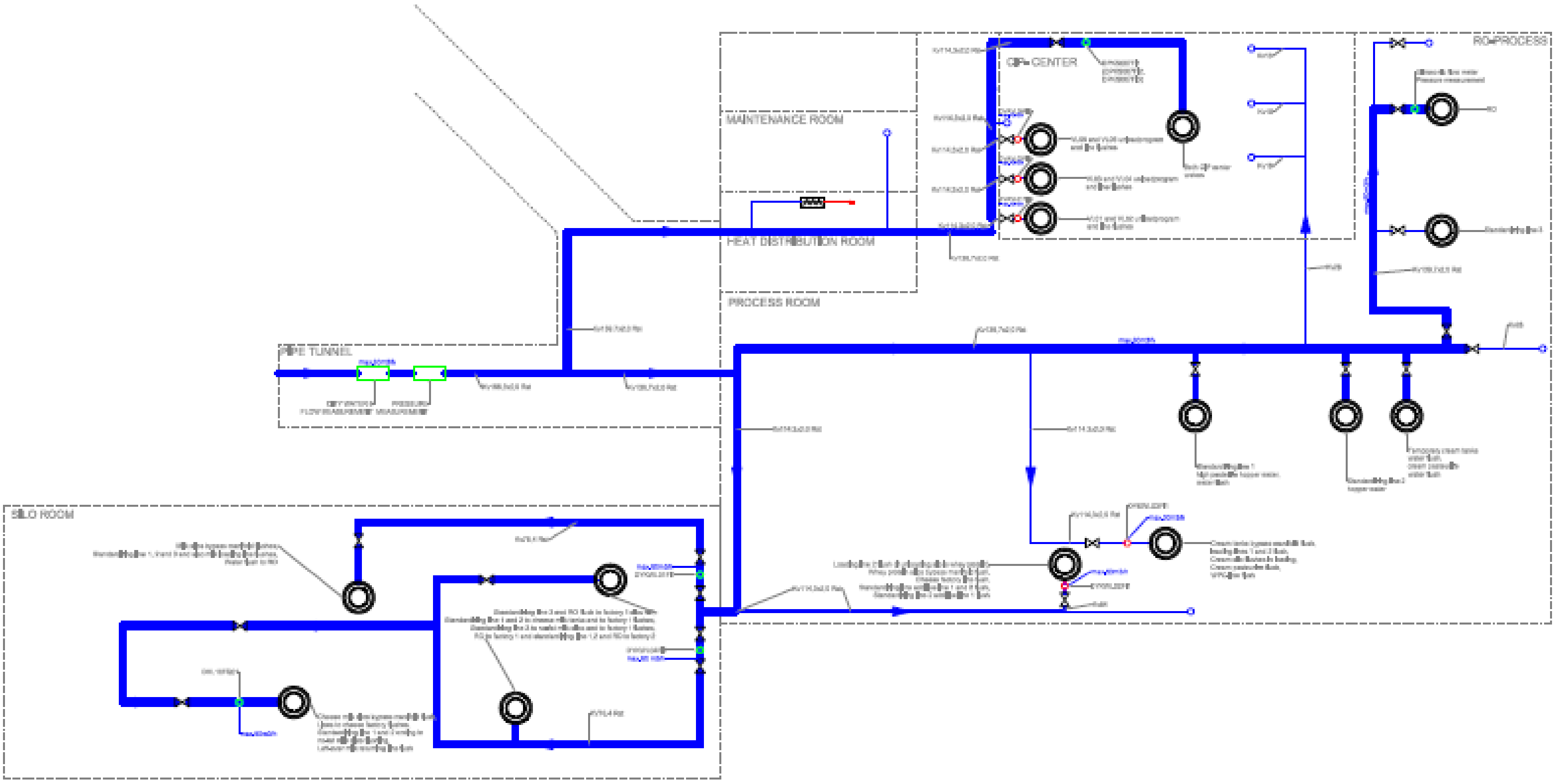
APPENDIX 1: FLOW METER LIST

Milk reception flow meter list 10.7.2018

Position	Meter	Range (L/H)	Metertype	Pipe size	Measurement uncertainty	Sufficient accuracy
DVAKYVEMI1 (KUNNANVESI 9)	MEINECKE WPD 100	0-60000 L/H	Turbine meter	168,3x2,0 Rst	< 2%	$1m^3$
DVAVL01FI2	MAGPHANT DTI200	0-40000 L/H	Magnetic switch	114,3x2,0 Rst	Inaccurate	$1m^3$
DVAVL03FI2	MAGPHANT DTI200	0-40000 L/H	Magnetic switch	114,3x2,0 Rst	Inaccurate	$1m^3$
DVAVL05FI2	MAGPHANT DTI200	0-40000 L/H	Magnetic switch	114,3x2,0 Rst	Inaccurate	$1m^3$
DYKWL01FI1	PROMAG 50	0-60000 L/H	Electromagnetic	114,3x2,0 Rst	< 0,5%	$1m^3$
DYKWL03FI1	MAGPHANT DTI200	0-30000 L/H	Magnetic switch	114,3x2,0 Rst	Inaccurate	$1m^3$
DYKWL02FI1	MAGPHANT DTI200	0-50000 L/H	Magnetic switch	54 Rst	Inaccurate	$1m^3$
DYKWL04FI1	PROMAG 50	0-60000 L/H	Electromagnetic	114,3x2,0 Rst	< 0,5%	$1m^3$
DHL10FQ01	PROMAG 50	0-50000 L/H	Electromagnetic	76,4 Rst	< 0,5%	$1m^3$
DPKS007FI1	PROMAG 50	0-120000 L/H	Electromagnetic	114,3x2,0 Rst	< 0,5%	$1m^3$
DPKS007FI2	PROMAG 50	0-50000 L/H	Electromagnetic	114,3x2,0 Rst	< 0,5%	$1m^3$
DPKS007FI3	PROMAG 50	0-60000 L/H	Electromagnetic	114,3x2,0 Rst	< 0,5%	$1m^3$
(COMING)	FLUXUS -F-501	0,01-25 m/s	Ultrasonic	?	< 0,5%	$1m^3$

Position	Measurement targets	Water usage	Share of total water volume (%)	Average daily flow (m^3)	Maximum flow (m^3/h)
DVAKYVEMI1 (KUNNANVESI 9)	Milk reception	City water flow meter.	100	590	60
DVAVL01FI2	VL01 ja VL02	VL01 ja VL02 unload program and line flushes	?	?	40
DVAVL03FI2	VL03 ja VL04	VL03 ja VL04 unload program and line flushes	?	?	40
DVAVL05FI2	VL05 ja VL06	VL05 ja VL06 unload program and line flushes	?	?	40
DYKWL01FI1	Milksilos, Standardizing line 1-3, RO	Milk silos bypass manifold flushes, standardizing line 1, 2 and 3 flushes, milk loading line flushes, water flush to RO	?	?	60
DYKWL03FI1	Cream tanks, loading line 1-2, cream pasteurize, WPC-line	Cream tanks bypass manifold flush, loading lines 1 and 2 flush, cream silo flushes in loading, cream pasteurize flush, WPC- line flush	?	?	30
DYKWL02FI1	Loading line 2, whey protein silos, standardizing line 1-2	Loading line 2 flush, whey protein silos bypass manifold flush, cheese factory line flush, stamdardizing line additive line 1 and 2, standardizing line 2 additive line 1 flush.	?	?	50
DYKWL04FI1	Standardizing line 1-3, Silos S4-S7, cheese milk silos, no fat milk silos	Standardizing line 3 and RO flush to factory 1 silos 4-7, Standardizing line 1 and 2 to cheese milk tanks and to factory 1 flushes, Standardizing line 3 to no-fat milk silos and to factory 1 flushes, RO to factory 1 and standardizing line 1,2 and RO to factory 2	?	?	60
DHL10FQ01	Cheese milk silos, lines to cheesfactory, standardizing line 1-2, returning line	Cheese milk silos bypass manifold flush, Lines to cheese factory flushes, Standardizing line 1 and 2 ending to no-fat milk silos flushing, Left-over milk returning line flush	?	?	50
DPKS007FI1	Milk reception CIP-Centers	Milk reception CIP-Centers cold city water	?	?	60
DPKS007FI2	Milk reception CIP-Centers	Milk reception CIP-Centers collecting water	?	?	50
DPKS007FI3	Milk reception CIP-Centers	Milk reception CIP-Centers warm water	?	?	60
FLUXUS F-501	RO-equipment	RO-equipment	?	?	?

APPENDIX 2: FLOW CHART OF MILK RECEPTION WATER PIPES



APPENDIX 3: WATER FOOTPRINT CALCULATIONS

2017 Month	Milk reception water consumption m3	Total water consumption m3	Milk ton	Milk m3	Milk reception water €/mont	Total water €/month	Milk reception waste water m3	Total waste water m3	water l/milk l milk reception	water l/milk l total
1	15 565	87 588	38 513	39 283	13 542	76 202	21 500	126 966	0,40	2,23
2	15 101	82 046	36 010	36 730	13 138	71 380	20 860	115 867	0,41	2,23
3	18 535	98 692	39 962	40 761	16 125	85 862	25 603	130 520	0,45	2,42
4	15 108	86 086	35 737	36 452	13 144	74 895	20 869	120 691	0,41	2,36
5	16 360	91 394	39 041	39 822	14 233	79 513	22 599	126 769	0,41	2,30
6	18 258	90 043	41 158	41 981	15 884	78 337	25 220	126 403	0,43	2,14
7	17 940	95 353	39 980	40 780	15 608	82 957	24 781	130 943	0,44	2,34
8	16 484	82 481	36 860	37 597	14 341	71 758	22 770	123 582	0,44	2,19
9	17 015	93 431	36 724	37 458	14 803	81 285	23 503	123 665	0,45	2,49
10	15 784	84 302	35 109	35 811	13 732	73 343	21 803	118 514	0,44	2,35
11	13 831	90 437	31 276	31 902	12 033	78 680	19 105	111 532	0,43	2,83
12	17 138	88 839	35 440	36 149	14 910	77 290	23 673	123 533	0,47	2,46
Total	**197 119**	**1 070 692**	**445 810**	**454 726**	**171 494**	**931 502**	**272 287**	**1 478 985**		
Average	**16 427**	**89 224**	**37 151**	**37 894**	**14 291**	**77 625**	**22 691**	**123 249**	**0,43**	**2,36**

waste water multiplier	1,38
water/m3	0,87 €

TOTAL

water/milk ratio	water m3/a	water €/a	saving to current situation
2,25	1 023 134	890 127 €	**41 376 €**
2	909 452	791 224 €	**140 278 €**
1,75	795 771	692 321 €	**239 181 €**
1,5	682 089	593 418 €	**338 084 €**
1,25	568 408	494 515 €	**436 987 €**
1	454 726	395 612 €	**535 890 €**

water/milk ratio	waste water m3/a
2,25	1 413 291
2	1 256 259
1,75	1 099 227
1,5	942 194
1,25	785 162
1	628 129

MILK RECEPTION

water/milk ratio	water m3/a	water €/a	saving to current situation
0,4	191 205	166 349 €	**5 145 €**
0,35	181 349	157 774 €	**13 719 €**
0,3	171 494	149 199 €	**22 294 €**
0,25	161 638	140 625 €	**30 869 €**
0,2	151 782	132 050 €	**39 444 €**
0,15	141 926	123 475 €	**48 018 €**

water/milk ratio	waste water m3/a
0,4	264 119
0,35	250 504
0,3	236 890
0,25	223 276
0,2	209 661
0,15	196 047

APPENDIX 4: MATLAB SCRIPT

```
orig_data = data; %aikaleima ja vesimäärä
sequence = seqDRO01CIOST; % vaihda tähän aina positio jota olet muokkaamassa
orig_sequence = sequence; %tähän positiokohtaisesti aina aikaleima ja sekvenssinumero

% aikaleimat matlabin ymmärtämään muotoon --> datetime -funktion
for i=1:length(data)
    dates(i) = datetime(data(i,1),data(i,2),data(i,3),data(i,4),data(i,5),data(i,6));
end

dates = dates';

for i=1:length(sequence)
    seq_dates(i) = datetime(sequence(i,1),sequence(i,2),sequence(i,3),se-
quence(i,4),sequence(i,5),sequence(i,6));
end

seq_dates = seq_dates';

% seq2 = [];
% loytyi2 = [];
% for i=1:length(dates)
%     for j = 1:length(seq_dates)
%         if datenum(dates(i,1)) == datenum(seq_dates(j,1))
%             break;
%         else
%             seq2(i,1)=NaN;
%             loytyi2(i,1)=NaN;
%         end
%         loytyi2(i,1) = 1;
%         seq2(i,1) = sequence(j,7);
%     end
%
% end

% kuvaaja vesimäärästä ja sekvenssistä
figure; hold on;
plot(seq,'-r');
yyaxis right;
plot(data(:,8));
axis([0 length(data) 0 1.2]);


%%%%%%%%

% for i=1:length(datas)
%     dates_s(i) =
datetime(datas(i,1),datas(i,2),datas(i,3),datas(i,4),datas(i,5),datas(i,6));
% end
%
% dates_s = dates_s';
%
% sequences = seqDRO01PR;
%
%
% for i=1:length(sequences)
%     seq_dates_s(i) = datetime(sequences(i,1),sequences(i,2),sequences(i,3),se-
quences(i,4),sequences(i,5),sequences(i,6));
% end
%
% seq_dates_s = seq_dates_s';
```

```
% num_dates_s = datenum(dates_s);
% num_seq_dates_s = datenum(seq_dates_s);

num_dates = datenum(dates);
num_seq_dates = datenum(seq_dates);

% V = num_dates_s;
% N = num_seq_dates_s;

% Päivämääräämien etsintä molemmista datoista (vesi ja sekvenssi)
V = num_dates';
N = num_seq_dates;

Nmat = repmat(N,[1 numel(V)]);
 [minval,indices] = min(abs(Nmat-V),[],1);
 closestvals = N(indices);

 % haetaan sekvenssikoodi vesidatan mukaiseen aikasarjaan
 for i = 1:length(indices)
     % vaihda tähän position mukainen muuttujan nimi
     seqDSL34SI_Value(i,1) = sequence(indices(i),7);
 end



%  yhdistetään positiokohtaiset data vesidatan kanssa kuvaajan piirtämistä
%  varten
data_seq = [data(:,[1:6 8]) ...
             seqDRO01CI_Value ...
             seqDSL34SI_Value ...
             seqDSL35SI_Value ...
             seqDSL36SI_Value ];

% käännetään rivijärjestys ylösalaisin
% viimeisin ajanhetki on datan lopussa
data_seq = flipud(data_seq);

% figure;
% plot(data_seq(:,8:12));

% % piirretään kaikki sekvenssit samaan kuvaajaan, toimii vain Matlabin
% uudessa versiossa
% figure; hold on;
% plot(data_seq(:,8),'-r');
% plot(data_seq(:,9),'-g');
% plot(data_seq(:,10),'-m');
% plot(data_seq(:,11),'-c');
% %plot(data_seq(:,13),'-y');
% ylabel('Sequence number')
% yyaxis right;
% plot(data_seq(:,7),'-b');
% axis([0 length(data_seq) 0 1.2]);
% legend('seqDRO01CI','seqDSL34SI','seqDSL35SI','seqDSL36SI','WaterUse(m3)');
% title('Water use in RO and automation sequences');
% ylabel('Water use (m3)');
% xlabel('Time period 4.12.-10.12.2018 (1 minute interval)')

% Kaksi y-akselia sisältävän kuvaajan piirtäminen
% Toimii Matlab R2013 versiossa

figure; hold on;
x = 1:length(data_seq);
[AX,H1,H2] = plotyy(x, data_seq(:,8:11), ...
                    x, data_seq(:,7),'plot');
```

```
set(AX(1),'YLim',[0 270]);
set(AX(2),'YLim',[0 1.2]);
set(AX(1),'XLim',[0 length(data_seq)]);
set(AX(2),'XLim',[0 length(data_seq)]);
set(H1(1),'Color','red');
set(H1(2),'Color','green');
set(H1(3),'Color','magenta');
set(H1(4),'Color','cyan');
set(H2,'Color','blue');
%plot(x, data_vrk(:,5),'r');
set(get(AX(1),'Ylabel'),'String','Sequence number')
set(get(AX(2),'Ylabel'),'String','Water use (m3)')
title('Water use in RO and automation sequences');
xlabel('Time period 4.12.-10.12.2018 (1 minute interval)')
legend('seqDRO01CI','seqDSL34SI','seqDSL35SI','seqDSL36SI','WaterUse(m3)');


% figure;
% subplot(5,1,1)
% plot(data_seq(:,8),'-k');
% subplot(5,1,2)
% plot(data_seq(:,9));
% subplot(5,1,3)
% plot(data_seq(:,10));
% subplot(5,1,4)
% plot(data_seq(:,11));
% subplot(5,1,5)
% plot(data_seq(:,12));
```