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Process Steam Source for District Heating Accumulators

A Feasibility Study

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Steam generation plays an important role in the operation of district heating accumulators. Each district heating accumulator requires a layer of steam above atmospheric pressure filling the open space above the process water within. The aim of this steam layer is to maintain a low oxygen environment within the district heating accumulators to reduce the likelihood of corrosion. Helsingin Energia's Salmisaari combined heat and power plant required a new steam generator solution to fulfil the summer requirements. The purpose of this thesis is to analyse the feasibility of different steam generation options from a technical and economic view point.

The methodology utilised involved estimating the current system parameters including power of steam required, steam consumption profile, capacity factor, energy required and available fuels. Once these parameters were defined, suitable steam generation methods were compared based on technical and economic feasibility.

The results of the above mentioned methodology showed several possibilities. The possible steam generation methods were to purchase and install a new electric resistor for the existing steam generator or purchase and install a combustion derived steam generator using light or heavy fuel oil. The third option available was to continue using the current heavy fuel oil fired auxiliary boiler for steam production and to cease the use of the district heating accumulators during the annual overhaul of the heavy fuel oil fired boiler.
The conclusions of this thesis indicate that the purchase and installation of an electric resistor is the optimal solution to this problem. The investment of a new electric resistor would be comparably low and require minimal process changes. Economically the use of an electric resistor to produce the process steam would be comparable to the heavy fuel oil boiler costs and lower than light fuel oil steam generation costs.

Keywords	Steam Generator, District Heating Accumulator, Combined Heat and Power, Feasibility Study

Dedication

I would like to dedicate this thesis to the person who sparked my interest in searching for the answer to the question “Why?”, which led to my deep interest in science.Thank you Dad.

Contents

1 Introduction

Helsingin Energia owns and operates a pulverised coal fired combined heat and power (CHP) plant located in Salmisaari, Helsinki. Included in this plant are two 10,000 m^3 district heating accumulators. In an attempt to maintain a low oxygen environment within the accumulators, a layer of steam is required in the upper part of each accumulator. Due to changes made in the process configuration of these accumulators, it became apparent that the previous steam generation system would not be sufficient for approximately two weeks of the year.

The purpose of this thesis is to determine a replacement steam generator to fulfil the requirements of the district heating accumulator system of Helsingin Energia's Salmisaari CHP plant. The steam generator in question is responsible for producing steam to create pressure slightly above atmospheric conditions within the heat accumulators to maintain a low oxygen environment. The goal of this feasibility study is to determine a new steam generation solution that fulfils the power of steam required with minimal changes to the current process and will result in a rapid payback time and a long operating life. Aspects considered will include total investment, fuel consumption, and efficiency, sensitivity to fuel and carbon emission allocation costs and payback time.

The thesis will consist of the definition of the current parameters of the system including the steam power required, and fluctuations in the steam consumption. This will be completed by calculating estimates from process data and available literature from Helsingin Energia. Once the requirements are known different available steam generation options will be compared based on fuel related costs, emission allocation costs, installation costs, investment required and payback time. After the comparisons have been made recommendations will be concluded.

2 Helsingin Energia

Helsingin Energia is an energy company based in Helsinki, Finland. Helsingin Energia is one of the biggest energy companies in Finland, with a total of 1227 workers as of

2010. The company had a turnover of 716 M€ from the same year. Helsingin Energia has a total of four electricity producing power plants (3 CHP plants) in the Helsinki gion and approximately 10 district heating plants. In 2010 the total electricity supplied was 7863 GWh (including production, shares and imports) and total district heat supply of 7850 GWh (1).

Helsingin Energia also has ownership of various other energy related companies as well as assets in several companies including the hydro power company Oy Mankala ab, Mitox Oy, partial ownership of Finestlink Oy and Vantaan Energia. Helsingin Energia also owns and operates the electrical grid in the Helsinki region (1).

This thesis was completed for Helsingin Energia in conjunction with a feasibility study carried out at the Salmisaari CHP power station.

3 Background of Study

The following chapter aims to give background information about this thesis project. The key points in understanding the topic of this thesis are district heating accumulator usage and the use of process steam in district heating accumulators. Additionally, in understanding the problem definition it is important to define the previous operation of the district heating accumulator process at the Salmisaari CHP plant, which is presented in this chapter.

3.1 District Heating Accumulator Usage

It can be said that the fluctuation of consumption of district heat has four different sources: long term seasonal change of the outdoor temperature, short term fluctuation in the weather, the fluctuation of the consumption of hot water, and the daily/weekly fluctuation in the indoor temperatures as a result of the outdoor temperature tion. These fluctuations are possible to predict based on statistical predictions and average temperatures. When operating a combined heat and power (CHP) plant the heat-to-power ratio is determined by district heat and electricity consumption demand and/or the prices of district heat and electricity (2). The demand of electricity and district heat are not directly proportional to each other. This results in difficulties optimising the production of electricity and district heat at a CHP plant (3).

The use of district heating accumulators can ease the problems associated with optimising the ratio of electricity production to heat production. Excess district heat produced is loaded into the accumulators in times of low heat consumption and the heat is then discharged into the network in times of high consumption allowing otherwise lost energy to be utilised.

The thermal losses of a short term storage accumulator constructed from steel such as those located at the Salmisaari plant are between 10 – 15 W/m^2, which leads to an annual efficiencies of over 90 % (3). The two 10,000 m^3 district heating accumulators located at the Salmisaari CHP plant have the ability to store 1,000 MWh of energy and load/discharge at a rate of 120 MW (4).

3.2 Importance of Steam to District Heating Accumulators

District heating accumulators contain their own treated process water. The water is isolated from the district heating network and is heated and cooled (loaded and charged) via heat exchangers. Although not always, the process water is usually treated by de-oxygenation and corrosion-inhibiting chemicals (3). In the upper part of a district heat accumulator is a space between the water level and the roof of the tank which increases and decreases in volume due to the volumetric expansion/contraction of water during heating and cooling. In the case of the Salmisaari accumulators this fluctuation is tens of centimetres (5). The above mentioned space is filled with a steam layer and kept at an overpressure of between 10 – 25 mbar above which eliminates the inflow of air and maintains a low oxygen environment so as not to compromise the process water quality (3). The Salmisaari accumulator's steam layer is kept at 1.02 bar (abs) (6).

In the absence of an adequate steam generator, the operational lifetime of the mulator and piping would be shortened due to corrosion. As a result of the high peratures found within the accumulators, the corrosion process is accelerated, which accentuates the problem (3).

3.3 Current District Heating Accumulator Steam Generator

The current steam generator is a 50 + 150 kW steam boiler designed and constructed in 1987. The boiler was constructed such that a 150 kW heat exchanger is inserted into the boiler and connected with a DN200 flange (see Figure 1). This heat exchanger was designed to use heat from process steam to generate steam for the district heating accumulators. Direct usage of process steam is not utilized due to the make-up of the isolated accumulator process water.

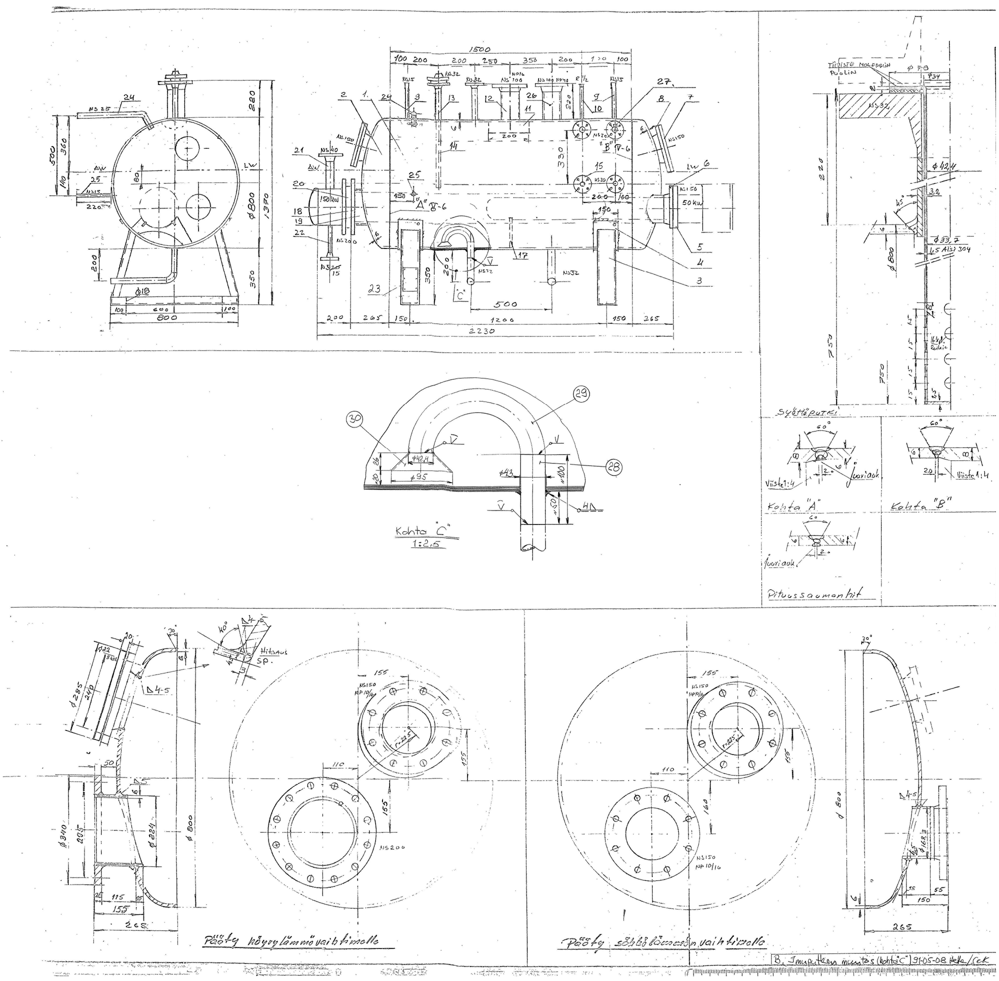

Figure 1. District Heating Accumulator Steam Generator.

Located at the other end of the boiler is a 50 kW electrical resistor inserted via a DN150 flange (see Figure 1). This electrical resistor is used to produce steam for the accumulators when they are not in use for four months of the year in the summer.

The boiler is equipped with a water level monitoring system, a water level control system, an internal pressure monitoring system and a pressure control system.

The water level monitoring system is based on three electrodes inserted into the boiler water. The three electrodes are responsible for stopping and locking the heat source and signalling an alarm if the level is at risk of boiling dry, stopping the heat source and sounding a low water level alarm, and signalling an alarm if the water level is too high (7).

The water level control system is based on a local electro-hydraulic control system which uses a hydraulic actuator to control the water level by opening and closing the feed water valve. The pressure inside the steam boiler, which is representative of the pressure inside the accumulators, is measured and then controlled by adjusting the temperature inside the boiler. This is achieved by either controlling the steam flow to the 150 kW heat exchanger or by controlling the power of the 50 kW electric resistor, which both increase steam production and pressure (6).

3.4 Previous Operation of the System

The previous operation of the district heating accumulators was reliant on the main process of the Salmisaari CHP plant. The accumulators were loaded and discharged through the district heating pipelines of Boiler 1. When Boiler 1 was under overhaul during four months in the summer, the district heating accumulators were not in use.

During the time of Boiler 1 usage, the heat for the steam generator was taken from the main process steam chamber through the auxiliary process steam chamber (see Figure 2). In the event that Boiler 1 was on standby the process steam was generated in Boiler 5 using heavy fuel oil. During standby, the heat to generate steam for the accumulators was taken from Boiler 5.

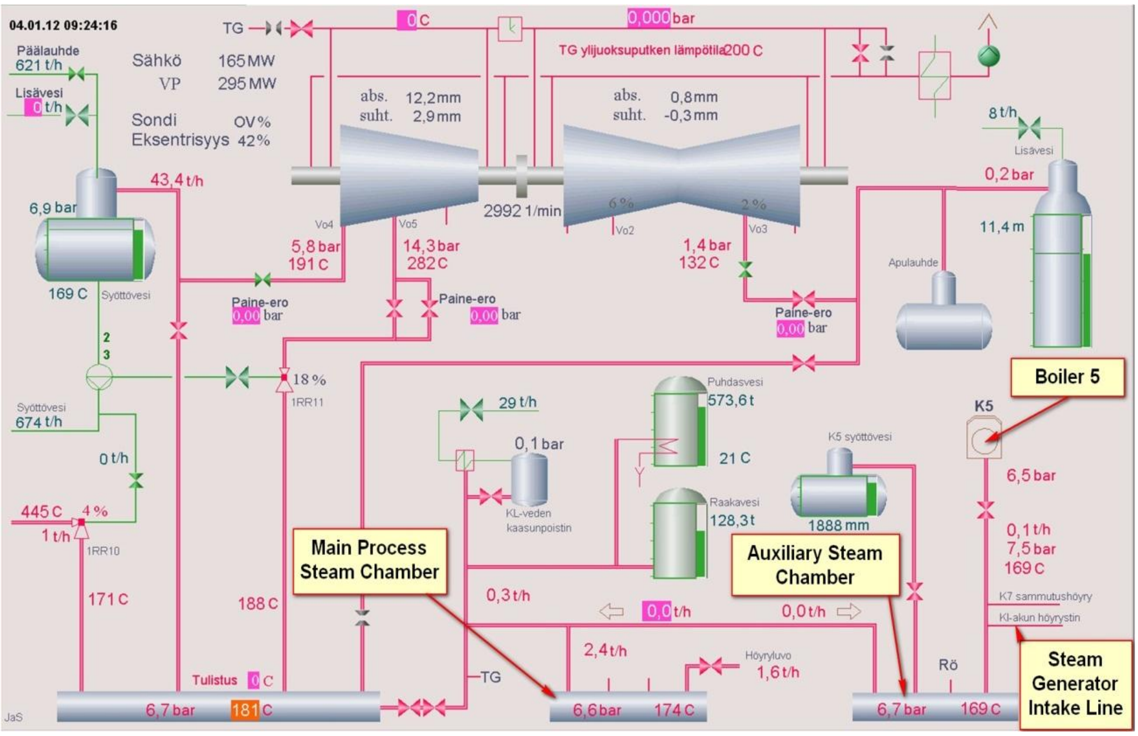

Figure 2. Process Steam Control Room Screen

3.5 Problem Definition

In the summer of 2011 modifications were made to the pipe network of the district heating accumulators, which enable their usage during overhaul of Boiler 1 and certain district heating equipment (2). The modifications were completed such that the mulators could be loaded from the district heating network through Boiler 7 district heating pipelines (5).

During operation of the system, it was noted that the 50 kW electric resistor alone cannot produce enough steam to maintain the required pressure during loading and discharging of the accumulators. This problem leads to a high risk of the accumulators corroding inside.

Over the years since the initial installation and commissioning of the district heating accumulator system, the prices of fuels relevant to the production of steam have risen considerably (see Figure 3). The choice of steam production method will also include a choice of energy source. The costs of fuel type account the large majority of annual costs relating steam production.

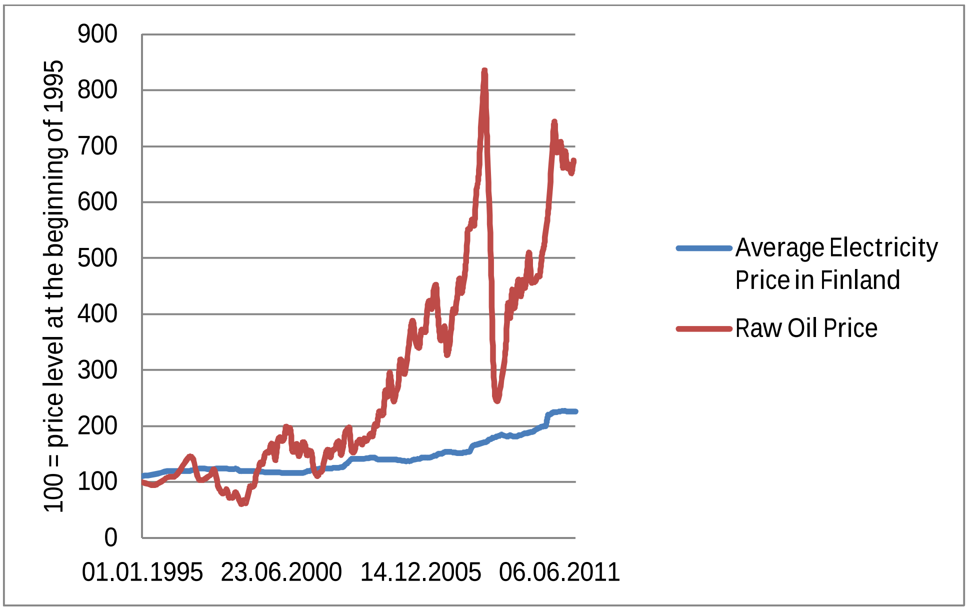

Figure 3. Energy Price History (8; 9).

4 Review of Steam Generators

The previous chapter provided the relevant background knowledge to understand the thesis problem in general. The current chapter gives a more in depth understanding of the technology behind the production of process steam in industrial processes, which is central to the technical problem solving presented in this thesis.

4.1 Steam Generators General

Steam generators, also known as packaged boilers, are self-contained boilers with power ranging from 9 to 33000 kW and higher (10). Most commonly, steam generators use oil, gas or electricity as fuels to produce steam. The benefits of steam generators are low investment costs, fast installation, small size and standardized units. Some negative aspects include, lower efficiencies compared to larger boilers and smaller maintenance intervals (11). In the case of the topic of this thesis, the power required is a mere 120 kW of steam with varying production requirements, for which a package boiler is an optimal solution.

4.2 Steam Generation Options

The options available are considered based on power source/fuel. The various options are taken from steam generators available on the Finnish market and compared based on the required characteristics of this thesis project. Steam generators are usually either fire tube boilers or water tube boilers.

Fire tube boilers consist of a vessel containing water to be vaporised and tubes conducting the hot flue gas from the combustion process within the water. The thermal energy is conducted through the pipes into the water. Fire tube boilers can contain two pass, three pass and four pass patterns where the hot flue gas will be passed through the water two, three or four times to ensure maximum transfer of heat. Figure 4 demonstrates a two pass design. Due to the inherent larger volume of water within the vessel fire tube steam generators are suited for applications with rapid and larger fluctuations in power load (12; 13).

Figure 4. The Working Principle of a Fire Tube Boiler (14).

Water tube boilers are essentially the opposite to fire tube boilers. Water is passed through tubes which are exposed to the hot flue gases and combustion process in the boiler (see Figure 5). Higher efficiencies are possible with water tube boilers along with higher pressures. Water tube boilers are attractive to certain applications due to their ability to generate high pressure-, dry-, and high- energy steam (13).

Figure 5. Water Tube Steam Generator Manufactured by Clayton Steam Systems (10).

4.2.1 Oil Fired Steam Generation

Steam generation from oil can be achieved either with heavy- or light- fuel oil. Also both fire tube and water tube boilers are available. The generators/boilers which are heavy fuel oil fired are generally larger fire tube boilers such as the auxiliary boiler cated at Salmisaari power plant. Boiler 5 at Salmisaari is a 7.7 MW fire tube boiler which uses no. 4 heavy fuel oil (15). The efficiency of heavy fuel oil steam boilers is somewhat lower than that of other fuel fired steam generators. Boiler 5 had an age yearly efficiency of 79 % in the years 2006 - 2011. One benefit of a larger steam boiler is that the steam power coming into the steam generator can be regulated down to the accuracy of the control valve and actuator.

Many smaller steam generators on the market are suitable for burning both light fuel oil and/or gas. The smaller steam generators are more commonly water tube boilers running at efficiencies of between 90 – 95 %. Smaller boilers below 300 kW have ON/OFF firing steps and larger models can be fired at 50 % or 100 % power (10).

4.2.2 Gas Fired Steam Generators

Steam generators using gas as a fuel source are common. Both fire tube and water tube steam generators are available fired by gas. Efficiencies of gas fired steam erators are usually between 90 – 97 % depending on the presence of an economizer (16). The firing steps of gas boilers are usually ON/OFF with a power below 300 kW after which 50 %/100 % is possible (10). Some steam generators can be fired with both gas and light oil simultaneously. The installation of a gas fired boiler includes gas pipeline installation, steam and process water piping, flue gas piping, valves, actuators, relevant electrical equipment, and some automation.

4.2.3 Electrically Powered Steam Generators

Electrically powered steam generators are usually designed similar to fire tube steam generators; however, in the place of the fire tubes there are electrical resistors. Benefits of these type of steam generators include higher density of firing steps, rapid load response time, flexibility of energy source option (fossil or renewable electricity), lower investment due to reduced need for fuel and flue gas piping, and in this thesis project, the lack of need to construct a new pressure vessel and an automation system. Negative aspects of electrical resistor steam generators can be summed up as follows: poorer total energy efficiency of the process (losses from electrical production and transmission to site), higher operation costs for non electrical producing plants and processes due to Finnish taxing regulation, and requirement of high voltage electrical connections.

5 Research Methodology

Thus far the thesis content has provided the adequate background information about the thesis project problem itself along with a review of the technical aspects of smaller scale industrial steam production. The present chapter explains the methodology employed to analyse the various steam production approaches.

5.1 Estimation of Parameters

Estimating the steam power required for the district heating accumulators was not possible directly and subsequently had to be calculated from other system parameters. The selected method to estimate the steam consumption was to use hourly average readings of the flow rate, temperature and pressure of the district heating steam line shown in Figure 2 connecting the main steam chamber to the auxiliary steam chamber. Based on Equation 1, where P = power [W], $\dot{m}$ = mass flow [kg/s] and h = enthalpy [kj/kg], the steam power was estimated on an hourly basis.

$$P = \dot{m} \cdot h \tag{1}$$

The enthalpy was estimated from an enthalpy-entropy diagram for steam (see annex 1). The standard deviation of the temperature and pressure for the time interval selected were 3 °C and 0.6 bar respectively. Constant temperature and pressure ensured a relatively constant enthalpy of 2768 kj/kg. The data selected to estimate the steam power required was from 1/11/2011 – 1/12/2011. Figure 6 represents the results of power estimation.

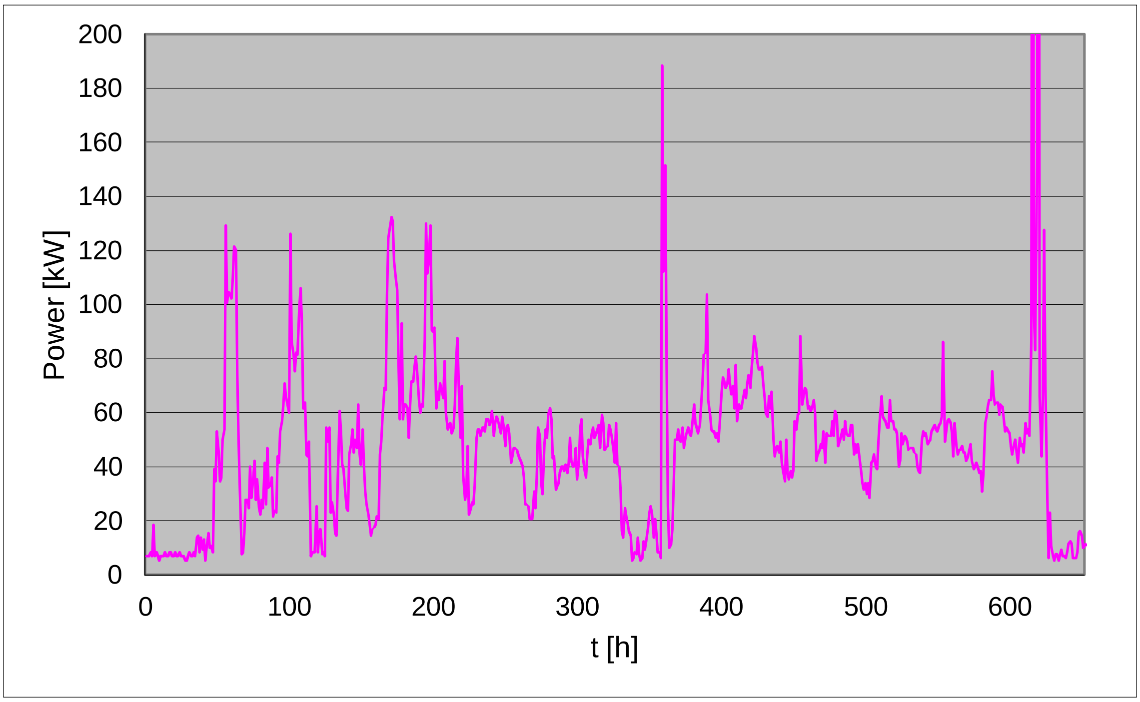

Figure 6. Steam Demand Estimation of the District Heating Accumulators.

Consumption of steam rises when the accumulators are discharged of energy and the volumetric thermal contraction of the water increases the volume above the process water and requires more steam to maintain the 1.02 bar (abs) pressure therein. Additionally the temperature of the water is lower which increases the amount of steam condensing onto the surface of the process water which also

The time interval used to compare the different steam production options was the estimated summer downtime for 2012 of 2670 h leading to a capacity factor of 0.30. This estimate was made by applying linear regression to the Boiler 1 downtime data of the past 25 years and extrapolating for the next year. The Boiler 5 operational hours were slightly modified. As Boiler 5 requires approximately two weeks of standstill for maintenance each summer, the time interval was 2334 h corresponding to a capacity factor of 0.27. This time signifies the time when the main boiler at Salmisaari is under yearly maintenance and is the intended time for operation of the various steam production methods.

When determining the efficiency of the methods to be compared, certain assumptions were made. Due to the fact that the required power estimate already includes the losses resulting from the steam generator now in use, the efficiency of it was not included when comparing Boiler 5 and the electrical resistor. The other steam production methods analysed use the efficiency as quoted by the manufacturer for steam production. The efficiency of Boiler 5 was taken from using the average annual efficiency from previous years. The efficiency of the electric resistor was taken as 100 %. The assumption regarding the efficiency of the electric resistor does not account for the efficiency of the electricity production method. However, as electricity consumed by Salmisaari CHP plant during standstill is purchased from the Nordpool electricity market, this extra energy is already accounted for in the price already.

5.2 Fuel and Emission Cost Estimation

The fuel and emission costs play an important role in the determination of the most feasible steam generation option as the two parameters determine the largest part of the annual costs. The estimation of the annual costs related to fuel purchasing and emission allocation value was completed by assuming linear growth between given forecasts and extrapolating. The current fuel prices and carbon allocation values were acquired from the Helsingin Energia Energy Business Development department. The fuel prices and carbon allocation value for the year 2017 were also provided by the Energy Business Development department. From the above mentioned estimates, a linear growth was assumed to estimate the annual cost for the years falling between the years 2013 - 2017 and onwards (see Figure 7).

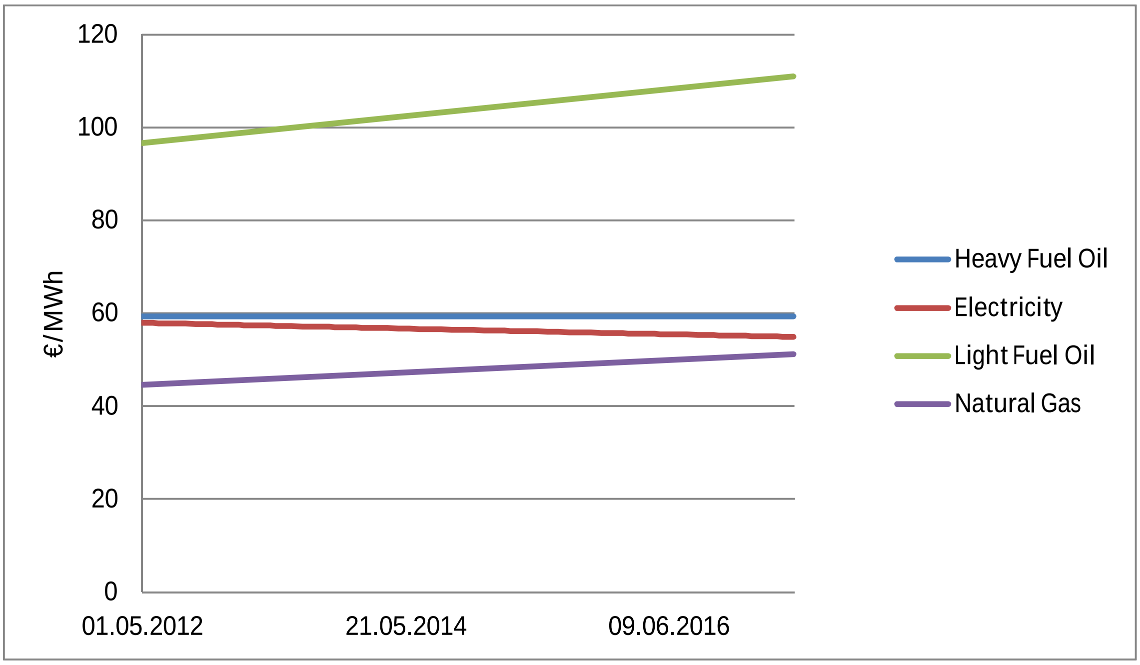

Figure 7. Energy Price Forecast.

To estimate the costs for the carbon allocation value, estimates are needed to nominally determine the tonnage of CO_2 emitted. In this thesis, the $kgCO_2/MWh$ emission factors were taken from the government owned Motiva Oy according to the fuel/energy source. The defined emission factor for heavy fuel oil is defined as 279 $kgCO_2/MWh$ (17). The emissions of carbon from the purchased electricity are already accounted for in the price of electricity and therefore are not directly discussed in this thesis (18).

5.3 Calculation Methodology

The estimation of the total costs resulting from the steam production for the district heating accumulators was completed in a combination of calculations, assumptions and use of other's estimates. When determining the investment of the project itself, prices were taken either from manufacturers of products or estimated by employees at Helsingin Energia (19).

The total annual energy consumption calculation was completed the in the same fashion for each of the compared steam production methods. The baseline power consumption was obtained by analyzing data of the steam flow rate for the main process steam feed line from a two month period to calculate the power based on temperature, pressure and enthalpy diagrams using Equation 1 as explained above. An hourly average was taken from this data and taken as the hourly average consumption.

The efficiency of the electric resistor was taken as 100 % as there are no losses from the electric resistor itself. The efficiency of Boiler 5 was calculated by taking an average of the annual efficiency for the years 2006 – 2011. The losses resulting from the system itself were not considered in the comparison due to the fact that they are practically the same for all options.

Redefining the system to the steam generator and the accumulators and conducting an exact separation of the different energy consumptions was not conducted as it would most likely be minimal energy consumption difference and out of the scope of this thesis. The main area where the differences would lie would be in the automation and control. The electrical resistor has the ability to react and heat up much faster producing more power due to the firing steps (See Figure 8). The steam from boiler 5 reacts slower to drops in pressure within the steam generator vessel (see Figure 6). The reaction time for the other generators would not differ extensively from the above mentioned options. Differences may lie in the dead-time and overshoot of the automation systems behaviour resulting in excess energy use.

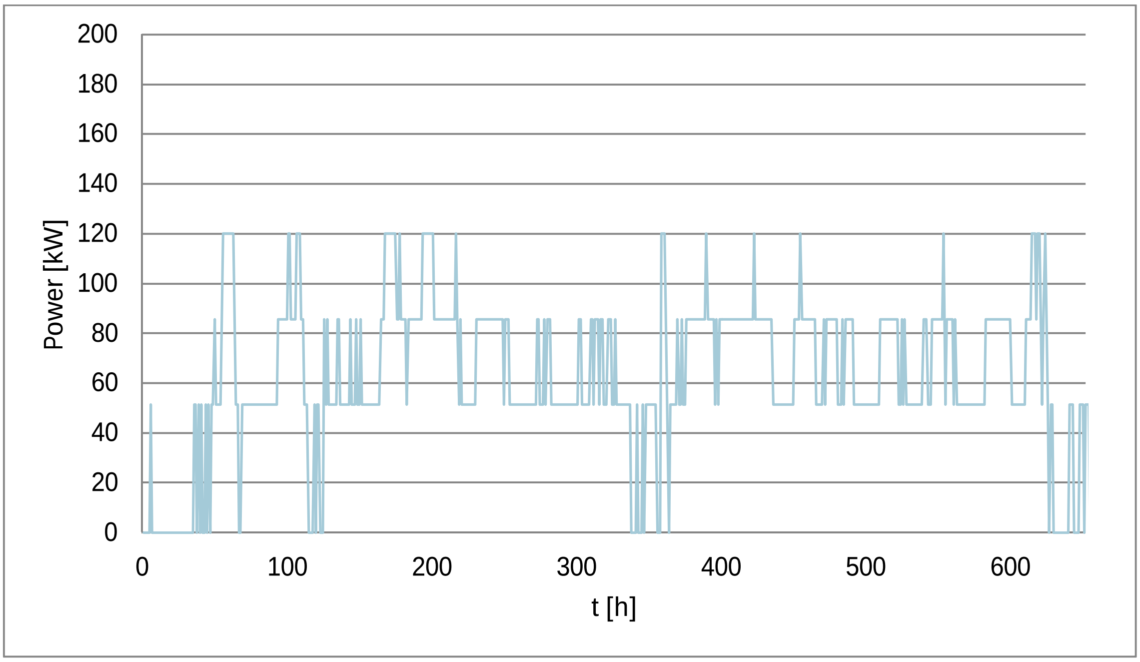

Figure 8. A Comparison of Power Curves of Boiler 5 and a 120 kW Electric Resistor

The investments were estimated for the electrical resistor in detail as it is seen as the only feasible option. A rough investment amount for the other steam generator options was estimated. The continued use of Boiler 5 requires no investment. The investment for the electric resistor and other steam generators can be broken down into the following parts: feasibility study and design costs; installation costs; supervision and reporting; and materials purchased. The design and installation parts of the investment are split into the process and machine part and the electrical part. The same division is also made for the purchasing of materials. The estimation of cost and time required for the design and installation were gained via consulting with experienced professionals employed by Helsingin Energia. The required materials were estimated based on inspection of the site and consultation with manufacturers and experienced professionals employed at Helsingin Energia.

An estimate was required of the additional turnover gain from the use of the district heating accumulators for two weeks during the summer. A direct estimation of District heating energy saved and sold at market prices would not be feasible in this case to estimate the additional turnover gained from the accumulator usage. The savings gained from using district heating accumulators is slightly more complicated.

During the summer time Helsingin Energia produces all its electricity and heat needs at their Vuosaari combined cycle CHP plant. The heat-to-power ratio of the plant can be altered to run the plant off-design to either meet the demand of electricity or heat (20).

The district heating accumulators can, for example, be charged during the night when the power plant runs off-design to produce more heat when the electricity prices are lower and during the times of higher electricity prices the plant can run off-design to meet the electricity demand while still meeting the heat demand by discharging the accumulators into the network. Additionally, the accumulators can be charged at times of low heat consumption and discharged at consumption peaks to smooth and balance the operation of the plant closer to its design point.

As a result of the difficulties in defining what is the magnitude of the savings gained from the accumulators and where the savings are made, an estimate was obtained from Helsingin Energia's Energy Business Development department.

The annual energy costs were calculated using the fuel cost estimations from Helsingin Energia's Energy Business Development department and creating a linear growth from present to 2017 the estimates. The total cost of energy was calculated according to equation 2, where C_{fuel} = total annual fuel costs [€/a], E_a = annual energy consumed [MWh/a], and c_f = cost per unit energy [€/MWh].

$$C_{fuel} = E_a \cdot c_f \qquad (2)$$

The annual emission costs were calculated in a similar fashion to the annual fuel costs. Helsingin Energia's Energy Business Development department provided estimates for EUA price for 2017 which enabled the creation of a linear price model until the said year. The emission factors were gained from Motiva Oy. The calculations followed equation 3, where $C_{emission}$ = total annual cost of emission allocations [€], CEF = Carbon Emission Factor of the fuel/energy source [$kgCO_2$/MWh], c_{CO_2} = Carbon Emission Allowance value [€/$kgCO_2$] and E_a = annual energy consumed.

$$C_{emission} = CEF \cdot c_{CO_2} \cdot E_a \qquad (3)$$

The payback time was calculated using Microsoft Excel with the following iterative method (where $L_{month\ X}$ = the loan amount at month X, i = interest rate and p = profit from accumulator usage):

$L_{month\ 1} = L_{initial} * (1+i) - p/12$

$L_{month\ 2} = L_{month\ 1} * (1+i) - p/12$

$L_{month\ 3} = L_{month\ 2} * (1+i) - p/12$

$L_{month\ 4} = L_{month\ 3} * (1+i) - p/12$

.

.

.

$L_{month\ N} = L_{month\ N-1} * (1+i) - p/12$

Payback = COUNTIF($L_{month\ 1}$: $L_{month\ N}$,">=0")/12

6 Results

The following chapter assesses the results after carrying out the above defined methodology. The results are discussed on the basis of steam generator fuel type as in the review of steam generator chapter. Steam production methods which were evidently not practical for consideration are discussed in less detail.

6.1 Electrically Powered Steam Generator

According to the findings, the cost of fuel accounted for all of the electric resistors annual costs as other minor cost such as maintenance are not included in this thesis (see Figure 9). The cost of electricity for the steam generator is higher than that of electricity used in the main boiler process at Salmisaari, due to the fact that the steam generator is located in the boiler hall of Salmisaari's 170 MW district heating boiler. Electricity producing plants are entitled to tax free auxiliary electricity when the plant is on standby. The boiler in question is only for thermal energy production; thus, it must pay the tax related to the electricity. If the steam generator was located in the main boiler hall, the electricity would be tax free (21).

The current estimated average electricity price for 2013 would be 41 €/MWh + 17.03 €/MWh (Tax). This would lead to energy costs of 7,620 € for the year 2013, which is slightly higher than heavy fuel oil, about 1000 € higher than natural gas usage and considerably cheaper than light fuel oil usage.

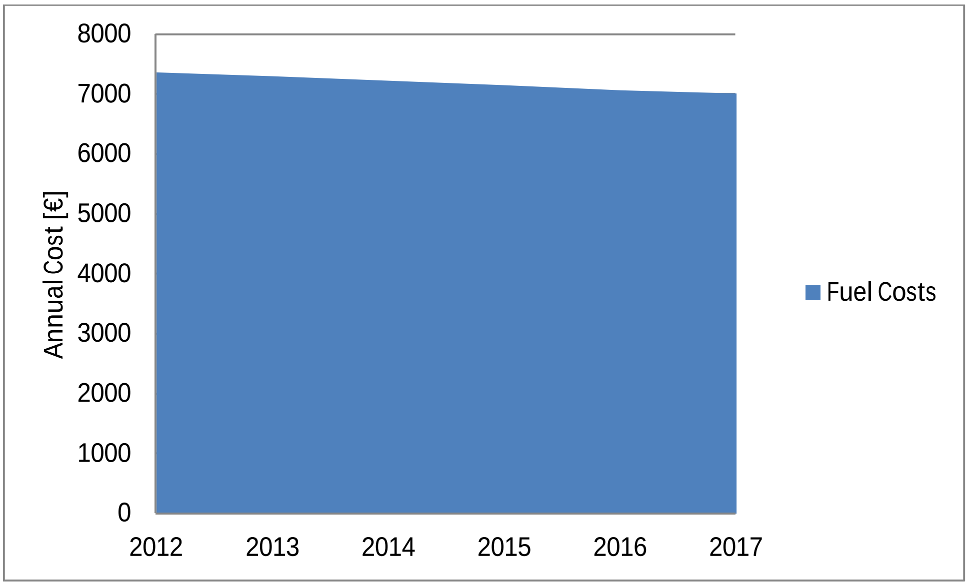

Figure 9. Electric Resistor Annual Cost Accrued from Fuel

The investment required for the purchase and installation of a new electric resistor can be divided into design, installation and product purchase. The design phase includes the feasibility study, the design for electrical connections, and the design for the installation of the resistor into the pressure vessel. The installation phase contains the installation of the electrical connections of the resistor and the installation of the resistor itself. The acquisition of materials includes electrical cable, electrical cabinet, and the electrical resistor.

The investment of the design phase totals approximately 7,800 € including six weeks (240 h) of work for one person for the feasibility study 1 week (40 h) for one person to create the machine installation diagrams for the machine, and 2 weeks (80 h) for one person to complete the electrical diagrams. The installation phase would cost 13,200 € derived from, two workers working for two weeks (240 h) completing the electrical installations and one worker taking one week (40 h) to install the resistor itself. The materials required total 17,890 €. The individual prices of the materials are electric resistor 2,890 €, electrical cable 10,000 €, and electrical cabinet 5,000 € (See Table 1 for total costs).

The investment required for the purchase and installation of the new electric resistor would be paid back in 2 years and 4 months (2.3 a) assuming a 5 % interest and linear growth in the price of electricity and carbon emission allocation value (see Figure 10). The rapid payback time is a result of the additional 35,000 € gained from the use of the district heating accumulators for two weeks in the summer. After the payback time, the additional income would be approximately 25,000 € - 27,500 € per year.

Reason		Weeks	Persons	€/h	h	Cost
Feasibility Study		6	1	65	240	15600 €
Design						
	Mechanical	1	1		40	
	Electrical	2	1		80	
				65	120	7800 €
Installation						
	Mechanical	1	2			
	Electrical	2	2			
				55	240	13200 €
Supervision and Reporting		1	1	65	40	2600 €
					Sub-total	39200 €
Acquisition		Cost/product	no. of products			Cost
Electric Resistor		2890,5	1			2890,5 €
Cable		10000	1			10000 €
Cabinet		5000	1			5000 €
					Sub-total	17890 €
					Total	62800 €

(Total price contains an additional 10 % buffer)

Table 1. Costs Accrued from Electric Resistor Purchase Installation

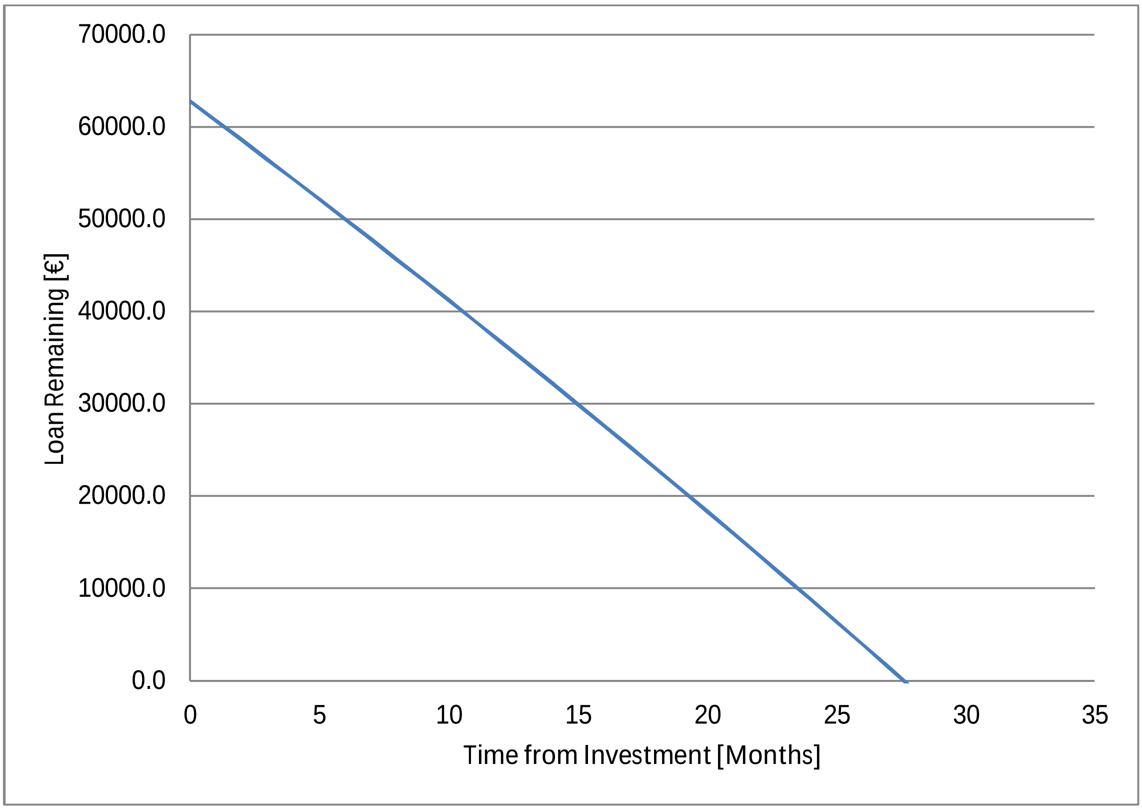

Figure 10. Investment Payback of the Electric Resistor.

6.2 Gas Fired Steam Generator

The results for the purchase and installation of a gas powered steam generator were not studied in detail due to the non-compatibility of natural gas for this application. There is no natural gas supply to the Salmisaari plant. In addition, the purchase and installation of a steam generator which involves combustion increases the required design, installation and material costs substantially.

As with the other steam production options assessed, the costs of fuel account for the largest percent of the annual costs with the use of a natural gas system. The fuel costs for the initial year would be approximately 6150 €, which is less than any other steam production option. Assuming a similar growth rate to that of the other energy forms, the cost after in 2017 the annual fuel costs would grow to 7200 €.

The emission costs associated with the use of natural gas would be considerably lower than the those from the use of light fuel oil and the use of Boiler 5. The emission factor for natural gas is 202 $kgCO_2$/MWh, compared to that of heavy fuel oil at 279 $kgCO_2$/MWh and light fuel oil 267 $kgCO_2$/MWh. The annual costs for the initial year of operation would total approximately 191 €, and in the year 2017 the approximation would be 226 €.

Along with the lack of a natural gas supply to the power plant, the relatively high investment is a drawback. When installing a combustion driven steam generator, the required changes to the process are significantly greater. The pipelines for the connecting water supply, outgoing steam, incoming fuel, outgoing flue gas must be redesigned and installed. The redesign and installation would definitely include the addition of new valves and actuators for controlling the process; and in addition, the requirement of a new automation system for this process would be required. The cost of the steam generator itself would cost between 20,000 € - 25,000 € (10). The total investment would likely fall between 150,000 € - 200,000 € with a payback time between 7 and 11 years. This investment is more than three times that of the electric resistor investment.

6.3 Light Fuel Oil Fired Steam Generator

A light fuel oil fired steam generator was also not studied in depth due to the obvious high annual fuel costs. The main key figures are as follows: The annual fuel costs for the initial year of 2013 the operation would likely be around 13,250 € and the carbon allocation costs for the initial year would likely total approximately 480 €. At a total annual cost for the initial year of over 13,725 €, the light fuel oil option is clearly not worth pursuing as the other prices are much lower. The total investment would be a similar amount to estimated for the natural gas option of between 150,000 € - 200,000 € with a payback of 10 - ∞ years depending how high the fuel price rises. The oil price at which the operation of the system would not produce any turnover would be approximately 250 €/MWh.

6.4 Use of Process Steam from Heavy Fuel Oil

Using the heavy fuel oil fired Boiler 5 located at Salmisaari power plant for steam production during standstill and discontinuing the use of the district heating accumulators while Boiler 5 is under maintenance is one option to be considered. The results for this alternative are have both benefits and drawbacks.

The fuel costs related to the heavy fuel fired steam production option were lower than the costs of electricity; however they were higher than the cost of natural gas for the initial year. The fuel costs for the first year would be approximately 6610 €. This is slightly lower than the electric resistor fuel costs. The growth rate of heavy fuel oil price was predicted not to rise much leading to a total annual cost price of 7240 € in the year 2017 (See Figure 11 for the growth trend).

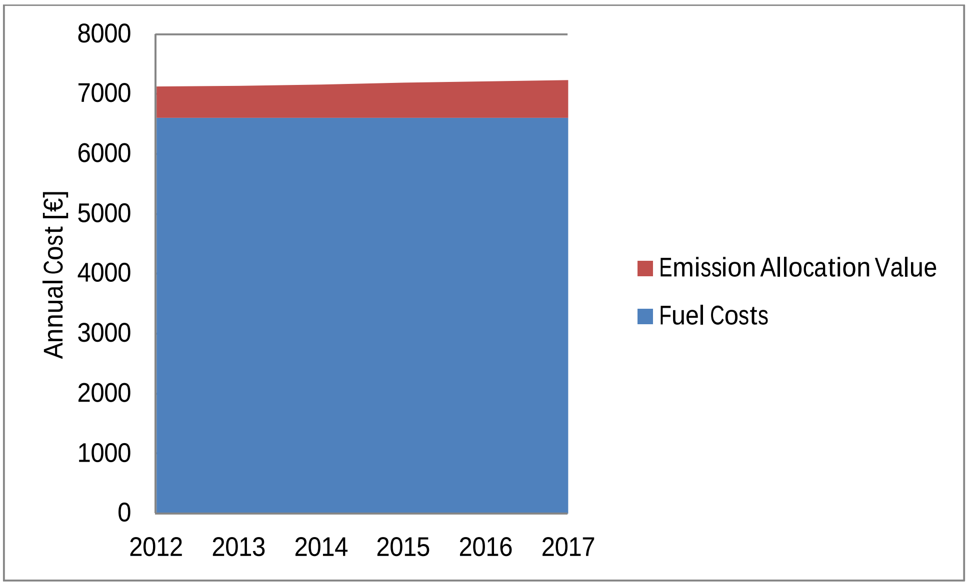

Figure 11. The Forecast of the Annual Cost of Boiler 5 Usage

The emissions resulting from the combustion of heavy fuel oil in Boiler 5 are an area of concern with this comparison. When comparing Figure 11 and Figure 9, it can be seen that the carbon emission allocation costs are greater for Boiler 5. The carbon emission factor for heavy fuel oil is 279 $kgCO_2$/MWh (17). The relatively high emission factor means higher costs per year. The costs for the emission allocations for the initial year of 2013 would be approximately 540 €, and for the year 2017 the prediction would be approximately 630 €.

The greater concern when considering the emissions from burning heavy fuel oil are the emissions of sulphur into the atmosphere. The emissions of sulphur from heavy fuel oil are dependent on the sulphur content of the fuel before combustion (22). The sulphur content of no. 4 heavy fuel oil, which is used in Boiler 5, is usually between 1 % and 3 % (23). The emissions of sulphur from boiler 5 are roughly 1100 mg/m^3n (3 % O_2) as recorded by the power plant. Current PINO legislation defines the limit value of sulphur emissions for boilers of the size 1 MW – 49 MW to be 1700 mg/m^3n (3 % O_2); however, beginning on 1st January 2018 the limit value will be reduced to 850 mg/m^3n (3 % O_2) (24). This is a point of importance when considering the long term feasibility of steam production for the district heating accumulators. If Boiler 5 usage would continue either a more expensive low sulphur fuel would have to be used, or investment in sulphur removal plant for the boiler. Both options increase the cost of continuing the use of boiler 5.

7 Conclusions

In studying the feasibility of the various steam production methods available on the Finnish market, the best option became quite clear. All the different methods had positive and negative aspects when applying them to produce steam for the district heating accumulators. It must be mentioned that the major driving force behind the decision making of this thesis project was of a financial nature.

The installation of steam generators requiring a combustion process were all poor options due to the required extra investment in process design and installation. Another hindering factor was the higher prices for the light fuel oil option. The price of gas was lower than those of electricity, light fuel oil and heavy fuel oil, however, the difference was not large enough to justify the large investment.

The heavy fuel oil fired Boiler 5 is an eliminated possibility for several reasons. The loss of extra income (35,000 €/a) as a result of the discontinued use of the district heating accumulators is the strongest argument against the option. Additionally, the changes in emission limit values for the boiler in the year 2018 indicates the use of the boiler is not a long term solution and must be taken into consideration. The emissions of carbon are substantially higher than other considered options; however, the forecast of the rise in carbon allocation value used in this thesis indicate it does not playing a decisive role in the annual costs.

The benefits of the continued use of Boiler 5 are of course the lack of any investment required. Also the relatively low price of heavy fuel oil no. 4 is a financial benefit for the option. However when considering Figure 3 the price of heavy fuel oil will most likely not stay low. The final conclusions to be made with regard to the continued use of boiler 5 as a steam source for the district heating accumulators is that it should not be considered further.

The electrical resistor steam production option is a poor choice as a source of steam for the district heating accumulators for energy efficiency related reasons. However it can be concluded that it is the best available option considering the mid to long term operation of the process.

The evidence against the installation and operation of an electrical powered steam generator in this case are mainly due to energy related issues. The fact that the process itself requires heat to produce steam, and electricity is used to create the heat is a very poor idea from a process point of view. About one third of the electricity purchased for the consumption of this process is produced via a thermal power production process which includes losses from the combustion process, losses from the energy transformation (thermal to kinetic then kinetic to electric), and losses from the transfer of electricity through the grid. Even the renewable non-thermal and nuclear electricity purchased for the process includes the losses of the transfer of the electricity through the grid. The total energy efficiency of the process is very low for a heat production process.

The benefits of choosing the electrical resistor as a steam production source for the district heating accumulators are mainly dependant on the investment aspects of the option. The relatively low investment and rapid payback time are the main positive aspects of the electrical resistor. The investment was estimated to be less than half the estimated costs of the other compared options, Boiler 5 excluded. The ability of the district heating accumulators to function throughout the summer without a larger investment mean the option is beneficial to Helsingin Energia.

After the installation of the electric resistor there are two possible operation strategies available, which both have their pros and cons. The electric resistor can either be utilised only during the standstill of Boiler 5 or during the whole Boiler 1 standstill duration when steam from the main process steam chamber is not available. If the electric resistor was to be operated for the entire standstill time, the benefit would be the reduction in atmospheric emissions per unit of steam energy generated; however, the cost of each unit of steam energy produced would be slightly higher. Operating the electric resistor only during the two weeks of Boiler 5 overhaul would result in higher atmospheric emissions but slightly lower operating costs.

From a financial view point, Helsingin Energia should use the electric resistor for the entire Boiler 1 overhaul period. From an environmental point of view, Helsingin Energia should use the electric resistor for the entire standstill duration. Most likely, however, a replacement boiler will be installed before the new PINO emission limits become valid in 2018. The optimal solution would be to consider a more financially and environmentally feasible solution for the installation of the auxiliary boiler and utilize the thermal energy requirements from it. The electrical resistor is a suitable back-up system when the auxiliary boiler is under maintenance or in standstill mode.

8 References

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Enthalpy-Entropy Diagram for Steam