Experimental Study to Reduce CO Emissions in Skellefteå Kraft's 16 MW Bubbling Fluidized Bed Boiler

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Abstract

Skellefteå Kraft has had high CO emissions problems in a bubbling fluidized bed (BFB) boiler in Malå. Statistical emissions data from 2013 to 2019 shows plant average emissions of 1230 ppm. This exceeds the recommended 440 ppm (6 % O2) that Naturvårdsverket proposes (Naturvårdsverket, 2005). The aim of this project was to identify and map the cause of the BFB boilers high CO yield with the help of a literature study as well as practical experiments to reduce CO, and; furthermore, suggest possible changes that can be implemented to resolve this problem.

A literature study was conducted to gain a better understanding of possible causes of high CO in fluidized bed combustion of biomass. The results from the literature study showed that bed agglomeration, airflow symmetry, biomass moisture content, biomass particle size and biomass bed distribution all are common factors that can cause high CO emissions.

Based on the literature study, statistical data from 2013 – 2019 and employee operator experience a series of tests, calibrations and experiments were conducted on the boiler. The following methods were used; Boiler statistical data analysis; Primary, secondary and tertiary airflow mapping; Pneumatic boiler feed system test (biomass bed distribution) and a bed material change test.

From the statistical data analysis, it was found that sudden load variations had a minor contribution to the CO emissions. However, load variations were not the biggest contributing factor to high CO emissions in the boiler in Malå. The primary, secondary and tertiary airflow were measured and mapped, uneven airflows between left and right were found. By calibration of even air distribution in the primary systems CO levels were slightly reduced by 14 %. The primary air calibration improved left to right boiler air distribution from a 5 % difference to only a 0.7 % difference.

A series of 11 tests was conducted on the pneumatic boiler feed system to obtain optimal fuel distribution. The test series that consisted of maximum parameters for transport air, spreading air and casting air obtained the lowest CO emissions levels of 350 ppm. An increase in airflow of transport air in the pneumatic boiler feed system resulted in more even biomass bed distribution and increased airflow in the lower secondary zone. This resulted in a dramatic CO emission decrease by 63 %. A 45 °C temperature increase was also noticed in the secondary zone, a decrease in temperature before super heater 2 and a decrease in temperature before super heater 1. The change in transport air caused combustion of flue gasses to occur a lot lower in the furnace.

This was clearly also documented through visual images taken inside the boiler with a special camera while the boiler was in operation. The images taken inside the boiler before and after the adjustments clearly showed that an increase of lower secondary air moves combustion closer to the boiler bed and reduces the CO emissions. The images also showed that uneven combustion was occurring in the boiler, as more violent and turbulent combustion was occurring on the right side of the boiler. This was an interesting finding as the measured airflow distribution was even in the boiler. This suggests that there is a major leakage in the air distribution pipes on the left side of the boiler. By reducing the airflow to the right section and increasing airflow to maximum on the left, an even airflow distribution was obtained resulting in a more even combustion throughout the entire boiler.

An increase in bed material change frequency from 1 time (3 % regeneration of total bed mass) to 3 times (9 % regeneration of total bed mass) resulted in a CO emission decrease by 20 %. During the
bed material change test bed agglomerates were observed which may explain the possible emissions improvement as the bed material was changed more frequently.

All different tests were conducted independently of each other. The change that resulted in the highest CO reduction was the increase of transport air to the secondary zone. Emissions were reduced by a total of 68 % as the transport air was set to maximum flow, the sand was changed three times and the primary airflow from left to right was even. The proposed adjustments will likely also increase the boiler efficiency and reduce the maintenance of super heater 1, super heater 2 as well as the economizer. The boiler produces around 400 ppm at 6 % O2 after the changes have been implemented. This is significantly lower compared to the original operation settings that during 2013 to February 2019 have produced a CO emission of 1230 ppm (on average). The significant CO decrease in Skellefteå Kraft’s boiler has opened opportunity to operate the boiler with lower excess air which ultimately decreases exhaust heat losses. If Skellefteå Kraft were to succeed in operating the boiler at 3 % O2 excess, a sum of 255 kkr could be saved annually.

The following recommendations are given in order to achieve low CO emissions:

- Increase the bed material change frequency.
- Clean pneumatic airflow system during summer stop annually.
- Ensure airflow symmetry within the boiler is achieved annually.
- Increase airflow to lower secondary zone.
- Use recommended airflow for pneumatic boiler feed system.
- Invest in a buffer tank to reduce load variation by Setra Sawmill.
- Reduce secondary air nozzle size to increase combustion air in the middle of the boiler.
- Increase the feed port ramp angle to increase biomass casting length in the boiler.
- Investigate left side secondary air flow (possible leakage suggested)
1 Table of Contents

Acknowledgments ............................................................................................................. 1
Abstract ............................................................................................................................... 2

2 Introduction ...................................................................................................................... 1
  2.1 Background .................................................................................................................. 1
  2.2 Project Aim ................................................................................................................ 3

3 Literature review .............................................................................................................. 3
  3.1 Bubbling fluidized bed (BFB) technology ................................................................. 3
  3.2 Carbon monoxide (CO) ............................................................................................. 4
  3.3 Common performance problems .............................................................................. 5
    3.3.1 Moisture content ................................................................................................. 5
    3.3.2 Biomass size ....................................................................................................... 5
    3.3.3 Biomass fuel distribution .................................................................................... 5
    3.3.4 Airflow symmetry .............................................................................................. 6
    3.3.5 Load variations .................................................................................................. 6
    3.3.6 Bed agglomeration ............................................................................................ 6

4 Method & Performance ..................................................................................................... 7
  4.1 Restrictions .................................................................................................................. 8
    4.1.1 Biomass particle size .......................................................................................... 8
    4.1.2 Biomass humidity .............................................................................................. 8
  4.2 Boiler background ....................................................................................................... 8
  4.3 Boiler statistical data analysis ................................................................................... 10
  4.4 Airflow mapping ....................................................................................................... 10
  4.5 Pneumatic boiler feed system test .......................................................................... 11
    4.5.1 Experimental setup .......................................................................................... 11
    4.5.2 Test setup ......................................................................................................... 12
    4.5.3 Measuring of dependent variables .................................................................... 13
  4.6 Bed material change test .......................................................................................... 14
    4.6.1 Test setup ......................................................................................................... 15
    4.6.2 Measuring of dependent variable ...................................................................... 15
  4.7 Excess O2 effect on efficiency ................................................................................. 16

5 Results & Discussion ..................................................................................................... 16
  5.1 Boiler statistical data ................................................................................................. 16
    5.1.1 Load variations ................................................................................................. 16
5.2 Airflow mapping ........................................................................................................... 17
  5.2.1 Primary air system ........................................................................................................ 17
  5.2.2 Secondary air system ..................................................................................................... 19
  5.2.3 Tertiary air system ........................................................................................................ 20

5.3 Pneumatic boiler feed system ......................................................................................... 21
  5.3.1 Numerical results .......................................................................................................... 21
  5.3.2 Visual results ............................................................................................................... 24

5.4 Bed material change test ................................................................................................. 28

5.5 Excess O2 effect on efficiency ....................................................................................... 30

6 Conclusions ....................................................................................................................... 31

7 Suggested future work ........................................................................................................ 32

8 References .......................................................................................................................... 33

9 Appendix ............................................................................................................................ 36
  9.1 Appendix A ..................................................................................................................... 36
  9.2 Appendix B ..................................................................................................................... 38
2 Introduction

2.1 Background

Fluidized beds have become increasingly popular due to a wide range in moisture of fuel that can be combusted compared to traditional or grate furnaces. The choice of biomass is a lot wider as generally the higher the moisture content the cheaper the biomass. Another major advantage of a BFB boiler is that combustion takes place at generally low temperatures, this is of importance as CO and NOx emissions increase as temperature increases. Around 20% of carbon monoxide emissions in Sweden are caused by incomplete combustion in utility boilers as well as in the industry (Naturvårdsverket, 2005). It is of interest to convert fuels to energy in a way that high efficiency as well as low emissions are achieved for both economic, environmental as well as safety aspects.

Skellefteå Kraft is the leading and main energy supplier in Västerbotten county in Sweden and the 5th largest energy supplier in all of Sweden. The company has a wide energy diversity such as wind power, hydropower, solar power, biomass combustion as well as other renewable energy technologies (100% förnybar kraft, n.d.). This project will focus on high CO emission problems that Skellefteå Kraft has with a biomass BFB boiler in Malå. High CO emissions are often affiliated with high NOx emissions, however the boiler in Malå has no issues with high NOx emissions, as the NOx emissions rarely exceed 100 ppm. The boiler in Malå was put in to use in 1991 to produce 120 °C district heating for citizens of Malå as well as Setra sawmill. The boiler has a maximum capacity of 16 MW, and the steam produced is also used in a 3 MW turbine which produces electricity for Skellefteå Kraft’s central grid. The boiler used is a Bubbling Fluidized Bed (BFB) boiler made by Foster Wheeler. Biomass fuel is used to operate the boiler, the biomass consists of a mixture of bark, ground wood chips and saw dust. Due to a strategic partnership between Skellefteå Kraft and Setra sawmill, a large majority of the biomass fuel is obtained directly from Setra sawmill just across the road from Skellefteå Kraft’s BFB boiler.

Even since the boiler launch in 1991, exceptionally large amounts of CO have been emitted throughout each season. CO emissions data from 2013 to 2019 can be seen in Figure 1. Data is only taken from when the boiler is operated at max load which ranges from September to April. The figure clearly shows that emissions range from 600 ppm to 1500 ppm throughout each season. This
trend can be seen more clearly in Figure 2 which shows the average CO emissions for all seasons combined.

Currently there exists no law of taxation on CO emission for biomass combustion plants in Sweden, however based on the political situation in Sweden today there are plans by certain political parties to implement taxation on CO and CO₂ emissions from biomass combustion in the future (Miljö- och energidepartementet 2018:471, 2018) ((EU) 2015/1189, 2015). It is in Skellefteå Kraft’s interest to reduce CO emissions for possible future law changes, reduce incomplete combustion, improve boiler efficiency and reduce environmental impact. The environmental protection agency in Sweden (Naturvårdsverket) has on numerous occasions proposed boundaries on CO emissions for combustion plants. In the past Naturvårdsverket has proposed a CO emissions limit of 440 ppm average per day for existing plants (6 % O₂) and for newer plants an average of no more than 440 ppm per hour and 220 ppm daily (Naturvårdsverket, 2005).

If law restricting boundaries of CO emissions are to be implemented for biomass combustion in the near future it would be very problematic for Skellefteå Kraft’s boiler in Malå that emits more than three times the proposed CO emissions level. Skellefteå Kraft’s boiler emissions permit can be seen in Appendix B.

![Figure 2: Average CO emissions from 2013 to 2019](image)

The BFB boiler has had problems with high CO emissions ever since it was commissioned in 1991. A new fuel dispense system was installed in 2005 to improve the overall spread of biomass in the boiler, to get a more uniform distribution as poor spread of the biomass was assumed to be the problem which caused high emissions. Basic calibration tests of the fuel distributing system were conducted in 2005 which can be seen in Appendix A, however numerous changes have been made to the boiler over the past 15 years. Operation engineer Emil Holmfridsson as well as other plant operators have observed heat flames at the fuel entry points of the boiler, they suspect that this is what is causing large CO fluctuations.
2.2 Project Aim

The aim of this project is to identify and map the cause of the BFB boiler’s high CO yield with the help of theoretical literature as well as conduct practical experiments to reduce CO emissions. Additionally, suggest possible changes that can be implemented to resolve this problem and evaluate whether if it is cost effective to implement the suggested changes.

The following questions were used as guidance and answered throughout this thesis:

- What are common problems with BFB boilers that result in high CO emissions?
- What factors are causing high CO emissions in the Malå boiler?
- What changes can Skellefteå Kraft implement to resolve the problem and reduce CO emissions in Malå?
- Are the suggested changes economically viable?

3 Literature review

3.1 Bubbling fluidized bed (BFB) technology

This technology uses a granular material, usually silica sand, to fluidize and mix biomass fuel in a fluidized state to efficiently gasify the fuel as the biomass is violently moved around. The gasified biomass is then burned slightly above the bed where secondary air is introduced (Orang, Tran, Jones, & McCabe, 2017). To achieve fluidization, compressed air (primary air) is pushed through sand at a flow rate of around 1.2 m/s through the nozzles at the bottom of the boiler until the critical velocity is reached and the bed starts to bubble (Alberto & Pena, 2011). If the pressure is too low, poor fluidization is achieved. If the pressure is too high, the entire sand base will lift which defeats the purpose of BFB combustion technology. The primary air makes up 30% to 40% of the total combustion air (Malmgren & Riley, 2012). Secondary air makes up most of the rest which is injected through small holes in the side walls of the boiler high up which aims to combust gases after gasified in the fuel bed (Malmgren & Riley, 2012). To start up the boiler oil burners are usually used, when the sand reaches a hot enough temperature of around 800 °C the sand is hot enough the self-ignite biomass. Biomass can now be added and the oil burners can be turned off. The boiler can then self-sustain itself with biomass fuel only. A fluidized granular bed material has three different functions: Retain heat of the boiler, mix and spread out the biomass and ignite the added biomass. The advantages of a BFB boiler are low emissions and high fuel flexibility. A BFB boiler can combust biomass with a wide range in moisture content between 30% and 60%. This range is a lot wider when compared to traditional grate furnace technology which has low flexibility in moisture content (Rummel & Paist, 2016). Combustion in a BFB boiler generally occurs at a low temperature range which reduces the overall emissions. BFB boilers are a very efficient combustion technology usually ranging above 90% efficiency (Alberto & Pena, 2011). An overview of a BFB boiler can be seen in Figure 3 below.
3.2 Carbon monoxide (CO)

When complete combustion is achieved, the products that are obtained are carbon dioxide, water and heat as shown in Equation (1) below.

\[ \text{Biomass} + O_2 \rightarrow CO_2 + H_2O + \text{Heat} \]  

Obtaining high CO emissions in a boiler often indicates that incomplete combustion is occurring. Incomplete combustion occurs when there is a lack of oxygen during combustion. Carbon and carbon monoxide are formed as shown in equation (2) (Caillat & Vakkilaninen, 2013).

\[ \text{Biomass} + O_2 \rightarrow CO + CO_2 + H_2O + \text{Less Heat} \]  

When incomplete combustion occurs, the maximum energy conversion potential of the fuel is not achieved. The carbon monoxide gas emitted poses an environmental risk and is not desired as it is a poisonous gas. Carbon or so-called “soot” is also a product of incomplete combustion (Clark, 2017) (Caillat & Vakkilaninen, 2013). High soot formation is not desired in boilers as it increases maintenance of the boiler as well as decreases heat transfer efficiency due to soot layer buildup on heat exchanger pipes (Naturvårdsverket, 2005). High levels of carbon monoxide increase corrosion rates dramatically, the overall lifespan of various internal boiler components is reduced in the presence of high CO levels (Skvaril, Avelin, Sandberg, & Dahlquist, 2014).
3.3 Common performance problems

3.3.1 Moisture content

Variation in moisture content of biomass fuel is often a cause of incomplete combustion which results in high CO emission. Biomass with a very high moisture content can make it difficult to sustain optimal bed temperatures. If the biomass is too wet for the boiler, dry fuel such as sawdust or pellets must be mixed with the fuel to sustain combustion in the boiler (Malmgren & Riley, 2012). On the other hand, if the fuel is too dry, it is difficult to regulate the gasification rate and controlled combustion. A BFB boiler requires wet based biomass to function efficiently otherwise it is very difficult to control the combustion.

Wood-based biomass can vary a lot in overall moisture content. Common wood-based biomass combusted in furnaces are often byproducts from the wood industry. Byproducts include e.g. bark, sawdust and woodchips. Moisture content depends on various factors such as age of the forest biomass, weather, seasons as well as tree species. Young trees tend to have a higher moisture content compared to older trees (Wagner, 1967) (Vadla & Dibdiakova, 2012). Moisture content values depend on the season that the trees are harvested. During autumn, the moisture content in sawmill byproducts are generally higher when compared to winter and summer. However certain periods of winter moisture content can increase during temperature shifts from minus to plus when snow starts to melt (Hart, 2009).

If there are large variations in moisture content, the regulators in the boiler have a hard time keeping up. This leads to an overall poor efficiency, increased operational costs, high emissions and high levels of incomplete combustion, as optimal conditions are never reached (Malmgren & Riley, 2012).

3.3.2 Biomass size

Uniform biomass size is important in BFB boilers, as the parameters set are to supply an overall turnover rate in biomass combusted. If the biomass particles are too large the overall exposed surface area to hot granular material will be reduced, this reduces the rate of gasification since it will take a lot longer for the biomass to completely gasify (Malmgren & Riley, 2012). Very large biomass particles will also cause poor fluidization and eventually cause the fluidized bed to collapse. However, if the biomass particles are too small the particles will not be gasified in the fuel bed but simply rise and burn in the air due to turbulence in the boiler. This will result in combustion occurring generally high up in the furnace which results in increase risk of slagging, high emissions and low thermal heat transfer efficiency. The recommended biomass particle size for BFB boilers are between 5 mm and 50 mm (Malmgren & Riley, 2012). Both too large and too small particles lead to a decrease in boiler efficiency and an increase in emissions.

3.3.3 Biomass fuel distribution

To obtain efficient combustion, fuel distribution is an important factor to obtain a high efficiency and low emissions. Uneven fuel distribution is a common problem in BFB boilers. Extensive studies have been made into the effects of fluidization velocity, distribution of bed material and particle size on boiler efficiency and performance at Chalmers University of Technology. It has been found that the distribution of bed material has a large effect on energy efficiency that is transferred to the boiler walls (Ekvall & Magnusson, 2011). Poor and uneven heat transfer to water tubes in the walls of the boiler ultimately leads to low efficiency. Uneven fuel distribution also increases incomplete combustion as areas with an excess of biomass will not have sufficient air to fully combust (Ekvall &
Magnusson, 2011). An increase in incomplete combustion leads to high emissions and poor efficiency as not all thermal energy is utilized. For instance, if biomass is added on only the left side of the boiler, the temperature on the left side of the boiler will be lower than on the right side due to cooling effect of wet biomass. Too little air will be present on the left side of the boiler compared to the right due to excess biomass in the left portion of the boiler. Hence, leading to uneven combustion, poor efficiency and high emissions. It is important to spread the biomass evenly throughout the entire furnace to utilize all areas of the furnace, as well as have enough air for all areas of the boiler, to achieve complete combustion (Kristinsson & Lang, 2010).

3.3.4 Airflow symmetry
Air distribution in a BFB boiler consists of primary, secondary and tertiary air. It is important for these systems to be regulated properly and controlled for a boiler to work efficiently. For example, if the right side of a furnace receives more air than the left, incomplete combustion will occur which leads to high CO and NOx emissions, poor efficiency and many other negative issues (Kristinsson & Lang, 2010). Uneven air distribution will cause an excess of air in certain areas of the furnace and a depletion in other parts of the furnace. It is important to achieve symmetrical and even air distribution within the boiler to achieve even and uniform combustion. Both emissions and efficiency of the boiler are severely reduced if uneven air distribution is present (Schuster, 2002) (Kristinsson & Lang, 2010).

3.3.5 Load variations
For optimal operating conditions a boiler with an even load is preferred. If the load of a boiler is generally even it is very easy for the regulators to steer the boiler, as only minor changes are to be made to sustain efficient operation. It becomes a lot more complicated in the presence of major load shifts as it takes time for the boiler to adjust to new load parameters. Major load changes contribute to incomplete combustion, increase in maintenance, decrease in boiler efficiency and an increase in emissions (Huttunen, o.a., 2017). This stress occurs as the boiler drastically must increase or decrease parameters quickly to fulfill the new load demand. During this transition period high emissions are produced as the boiler is not performing with optimal conditions until the new load is reached (Huttunen, o.a., 2017).

3.3.6 Bed agglomeration
A granular bed material in a fluidized bed boiler is a major component needed for a BFB boiler to function. The most common material that is used to achieve this is natural sand. Although there are many other materials that can be used, silica rich natural sand is usually preferred due to availability and low cost (Knutsson, Schwebel, Steenari, & Leion, 2014).

A granular material has three different functions in a fluidized bed boiler:

- Act as a heat retainer
- Fuel mixing
- Gasifies and ignites fuel

Although sand is cheap and widely available, there are some problems associated with the use of sand in a biomass-fueled boiler. The ashes that remain after the wood-based biomass is combusted contain high levels of group 1 and 2 metals of the periodic table (Nordin, Skrifvars, Backman, Hupa, & Öhman, 2000). The most common compounds present in wood-based biomass mixes are potassium,
phosphorus and calcium. When combined with high temperatures of around 800 °C to 900 °C, which is the usual state in a fluidized bed boiler, it has been proven that agglomeration occurs (Folkeson, 2014) (Scala & Chirone, 2008). Ash in combination with heat forms a layer around the silica sand bed particles, over time the high temperature causes the particles to become increasingly sticky. The affected particles then start to stick to each other forming larger and larger lumps. This process is called agglomeration of bed material. If this process is left to continue in a BFB boiler it will result in complete de-fluidization (Skrifvars, Zevenhoven, Backman, Öhman, & Nordin, 2000).

The problem that is associated with agglomeration formations is that it can result in the shutdown of the boiler to free up blockages that have been formed. Studies have shown that channeling and de-fluidization sometimes occurs in fluidized bed boilers at the temperature range between 800 °C and 900 °C. It is at just this temperature most BFB boilers operate (Skrifvars, Zevenhoven, Backman, Öhman, & Nordin, 2000) (Miller, 2017). Agglomeration formations make the boiler bed material more uneven both affecting biomass distribution efficiency and thermal distribution of the bed (Dunajski, Nowak, & Kurk, 2013). To get an even spread of biomass and an even thermal spread in the boiler the bed material must be uniform in size. An uneven fluidization or uneven bed temperature both effect the overall efficiency of the boiler. The bed will no longer have ideal combustion parameters which ultimately leads to high temperatures, incomplete combustion, uncontrolled stops and high emissions (Dunajski, Nowak, & Kurk, 2013).

There are ways to reduce agglomeration problems in a fluidized bed boiler. A common method that is widely used is simply to regenerate parts of bed material whilst the boiler is in operation. Most BFB boilers have drain ports at the bottom of the fuel bed. The sand can easily be drained as the boiler is in operation. New sand can then be added from the top until the desired bed pressure is obtained again. As sand is relatively cheap this is an effective way of reducing agglomeration in fluidized boilers. Regulating a low bed temperature is an effective way to reduce agglomeration. The goal is to try to keep the ash from exceeding its softening temperature to reduce agglomeration. As temperature increases so does the frequency and occurrence of agglomerates (Miller, 2017) (Skrifvars, Zevenhoven, Backman, Öhman, & Nordin, 2000). Other methods involve addition of fuel additives to change the ash composition in order to reduce the formation of low temperature melting compounds. Common additives compounds that are used for this application are calcium or clay-based minerals (Steenari, Åmand, & Bohwalli, 2016).

4 Method & Performance

The results from the literature review showed that bed agglomeration, airflow symmetry, biomass moisture content, biomass particle size and uneven fuel distribution (inconsistent biomass fuel bed) are often possible causes for incomplete combustion, poor efficiency and high CO emissions in fluidized bed technology. A visit to the plant in Malå was made to gain better understanding of the boiler plant setup and to get a better idea of what problems were suspected for causing high CO fluctuations in the BFB boiler. Bases on the literature review results as stated above, statistical data from 2013 – 2019 and employee operator experience, different methods and practical tests were carried out to troubleshoot and reduce CO emissions in the BFB boiler in Malå. The conducted methods include the following; Boiler background analysis; Boiler statistical data analysis; Airflow mapping; and Excess O2 effect on efficiency, which are described below.
Based on the methods and findings as shown above the following experimental tests were derived to further investigate and troubleshoot the problem. The fuel delivery port was researched and analyzed as operation engineer Emil Holmfridsson suggested that this was where the problem starts. The BFB boiler has various variables that can be changed. The goal of the practical experiments was to keep certain variables constant whilst changing another variable to see if it had a reducing effect on the CO emissions. These tests were performed during March when the boiler operated at maximum capacity load of 16 MW. The practical tests were independent of each other and were conducted to see if CO emissions in the BFB boiler could be reduced. These practical experiments include the following; Pneumatic boiler feed system test (biomass bed distribution); and a Bed material change test which are described below.

4.1 Restrictions
4.1.1 Biomass particle size
The biomass practical size was very consistent during all conducted experiments as nearly all the biomass was obtained from the same supplier (Setra sawmill). No particle exceeded 100 mm in length. An assumption is made that this variable is constant.

4.1.2 Biomass humidity
The biomass moisture content of the used fuels ranged between 50 % and 56 % during all conducted experiments, i.e. within a very narrow interval. If the biomass material had a high moisture content, briquettes were mixed with the fuel to reduce moisture content. An assumption was made that this variable is constant.

4.2 Boiler background
Wood-based biomass was combusted in the boiler in Malå. The wood mix always consisted of a mixture of bark, ground wood chips and saw dust. The wood mix compositions varies depending on size and type of lumber that is processed at Setra sawmill; However, the mix generally mainly consists of 2/5 wood chips, 2/5 bark and 1/5 saw dust. The fuel mix can be seen in Figure 4, Figure 5 and Figure 6 and. Pellets were added occasionally if the biomass mix moisture content was too high.

The boiler in Malå received its fuel from Setra sawmill right across the road from Skellefteå Kraft’s plant. The timber byproducts that are produced by Setra were chipped and mixed at the sawmill facility. The biomass was very uniform and well mixed as it left Setra sawmill and was moved by conveyer belt across the road to a large storage hall. The fuel was then distributed by a large claw
that positions the fuel in different sections. The fuel was stored in such a way to give it time to sit to get an even moisture content as the dry biomass in the mix pulled moisture from the wet biomass. Moisture was also reduced through natural evaporation. The principle of first in first out was applied to obtain even fuel humidity. The biomass sits in storage for around 24 hours before it was picked up by the claw again and fed through a series of feeding screws and conveyors to further dry, mix and break down the biomass particles. The biomass was then injected with the use of a pneumatic feed system into the boiler. The boiler has two pneumatic feed systems situated next to each other on the third level of the building. The pneumatic fuel system can be seen in Figure 7. A general overview drawing of the entire plant can be seen in Figure 3.

The boiler in Malå has a unique system for sustaining constant fuel moisture content. If the biomass from Setra sawmill has a high moisture content, the BFB bed temperature will decrease as the fuel is too wet to sustain the boiler. When the temperature sinks below a set value of 800 °C, briquettes are automatically mixed into the fuel until the desired bed temperature range of 800 °C to 830 °C is reached again. When the biomass fuel mix has a high moisture content, wood briquettes are mixed in to obtain a uniform fuel moisture content. The briquettes even out the moisture content so that the boiler always receives a steady fuel moisture content range between 50 % and 56 %. This system was also activated if there was a sudden load variation by the network and the boiler bed temperature sinks. If the briquettes are not enough to raise the bed temperature and the temperature drops below 785 °C, pellets were automatically dosed into the fuel mix. If this was still not enough to sustain the boiler and the temperature dropped below 750 °C, two oil burners were activated as a third and final contingency to increase bed temperature.

The BFB boiler also had a system in place if the bed temperature was too high. It is undesired to have a very high bed temperature since emissions increase with a rise in temperature, the risk of bed agglomeration increases as well. If the bed temperature increased above 830 °C, exhaust gases were recycled back through the boiler bed until the temperature was decreased below 830 °C again. The exhaust gas recycling input could be regulated from 0 % to 100 % flow depending on the temperature increase over the set limit of 830 °C.

The air that was needed to run the boiler was powered by two different fans. Fan 1 supplied air to the primary and pneumatic fuel injection system, whereas fan 2 supplied air to the boilers secondary and tertiary air holes. Both fan 1 and fan 2 supplied air at a temperature of 40 °C.
4.3 Boiler statistical data analysis

All boiler variables and setting parameters were logged in a database on Skellefteå Kraft’s server over the past years. This data was examined to evaluate possible causes of high CO emissions. Historical data since 2013 was available. The data includes temperature sensors, boiler load (Sawmill load / Resistance load), fuel bed pressure, emissions and various other data.

4.4 Airflow mapping

As the theory shows above, primary, secondary and tertiary airflow symmetry is of importance. All airflows were measured and compared to deduce whether even air distribution from left to right side of the boiler was achieved. A flowmeter (pitot tube) was used to measure and map all airflows. Calibration or adjustments of flows were made if flows deviated between both sides of the furnace.

A flowmeter (pitot tube) works by establishing the static and dynamic pressure. It is derived from Bernoulli’s flow equation. Dynamic pressure is the difference between the static pressure and the overall total pressure, this can be seen in equation (3).

\[ P_{\text{tot}} = P_{\text{static}} + P_{\text{dynamic}} \]  

(3)

The total pressure is measured through the nose of the pitot pipe as shown in Figure 8. Static pressure is defined when the air is at rest or the measurement of flow whilst traveling along the stream. Forces are being exerted on the air particles from all directions. This is measured through the opening parallel to the flow which can be seen in Figure 8. With the use of equation (4) and (5) an expression for airflow rate is obtained (Instruments, n.d.) (Understanding the Distinction Between Total, Static and Dynamic Pressure, 2017).

\[ P_{\text{dynamic}} = \rho \frac{v^2}{2g} \]  

(4)

\[ v = s \times \sqrt{\frac{2(P_{\text{tot}}-P_{\text{stat}})}{\rho}} \]  

(5)

\[ v = \text{Velocity (m/s)} \quad s = \text{Pitot factor} \quad \rho = \text{Air density (kg/m}^3) \]

This measuring method is very sensitive to temperature changes as well as turbulence. If such technology is used, special attention to calibration to the temperature of the measured air must be taken since air density is dependent on temperature (Understanding the Distinction Between Total, Static and Dynamic Pressure, 2017).
4.5 Pneumatic boiler feed system test

A pneumatic boiler feed system by Foster Wheeler was introduced in 2005 to the boiler in Malå to try to achieve a more even biomass fuel spread in the boiler bed. The calibration report and tests conducted by Foster Wheeler can be seen in Appendix A. It was aimed to achieve a more even fuel spread and increase the efficiency of the BFB boiler as well as lower emissions due to a more stable and complete combustion. A slightly lower CO emission value was achieved however there was still a lot of room for improvement. Before this system was introduced the biomass was simply dumped in with the help of a feed screw as well as gravity. This caused all the biomass to be concentrated close to the feed ports, it was not evenly spread throughout the boiler.

The pneumatic boiler feed system has never been recalibrated since installation in 2005 although various changes have been made to the boiler since installation. Over the years heat flames have been observed by plant employees at the inlet of the boiler feed port, this is assumed to be one of the possible causes of high CO emissions values. The following experimental test aimed to gain a better understanding of how the pneumatic boiler feed system works by mapping all the airflows. A series of tests were conducted to determine if a certain test combination could improve the boiler’s efficiency and reduce CO emissions.

This boiler feed system can be seen in Figure 7. It consists of six different airflows. Pipes 1, 3 and 4 are transport air, this airflow pushes the biomass forward from when the biomass enters the port. The biomass fuel port leads directly into the boiler which has a temperature of around 800 °C when in operation. To stop the port from becoming warm and to stop the fuel from already combusting in the fuel port a cooling pipe cools the port. This is seen as pipe 2 in Figure 7. Pipe 5 is the spreading air which aims to spread out the fuel when it reaches the end of the port. The final pipe is the casting air which is seen as pipe 6 in the diagram, it aims to cast out the biomass fuel into the boiler. The boiler has 2 identical pneumatic boiler feed systems next to each other.

4.5.1 Experimental setup

4.5.1.1 Equipment

A flowmeter with a sensor diameter smaller than 10 mm was used to measure all the pipe flows. The small sensor could easily be inserted in to small holes in the pipes to obtain a reading.

For the camera setup both cameras were connected to a computer by two ethernet cables, a computer was used to record and save all the video footage. Compressed air and cooling water were also used to cool the cameras and blow away ash formation on the camera lens.

The constant, independent and controlled variables for the pneumatic boiler feed system test can be seen in Table 1 below.
Table 1: Variables for the pneumatic boiler feed system test

<table>
<thead>
<tr>
<th>Constant parameters</th>
<th>Independent</th>
<th>Dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Load (15 MW)</td>
<td>- Transport air</td>
<td>- Emissions (CO, NOx)</td>
</tr>
<tr>
<td>- Biomass fuel humidity (53%)</td>
<td>- Spreading air</td>
<td>- Boiler bed temperature</td>
</tr>
<tr>
<td>- Total airflow (6 Nm^3/s)</td>
<td>- Casting air</td>
<td>- Temperature before super heater 2 lower</td>
</tr>
<tr>
<td>- Feed bed pressure (11.5 kPa)</td>
<td></td>
<td>- Temperature before super heater 2 upper</td>
</tr>
<tr>
<td>- Biomass particle size (5 mm - 50 mm)</td>
<td></td>
<td>- Temperature before super heater 1</td>
</tr>
<tr>
<td>- Cooling air (73 m/s)</td>
<td></td>
<td>- Exhaust gas temperature</td>
</tr>
</tbody>
</table>

In the following experiment the cooling air was set as a constant variable as it was assumed that it would not affect the results. This variable was not changed to avoid possible overheating and damage to the port. Transport air 1, 2 and 3 were treated as one variable in the experiment as no change was observed when the variables were changed individually. The tests were carried out during winter time; therefore, the load was set as a constant as the boiler always operates at maximum capacity of round 15 MW. The biomass moisture content was set as a constant as the biomass fuel only ranged between 50 % to 56 %. All biomass was obtained from the same supplier (Setra sawmill) which results in a very uniform and even biomass supply both in humidity as well as consistency. The airflow for the primary, secondary and tertiary systems are all dependent on the biomass moisture content as well as the load of the boiler. However, as the load and biomass humidity are presumed to be constant, all airflows as well as the feed bed pressure were presumed constant as well. To ensure that an even biomass moisture content was obtained the moisture content was tested in the morning (09:00) and in the afternoon (15:00).

4.5.2 Test setup
A test series of variables A, B and C were conducted. The three variables are the following; A - Transport air (Transport air 1, Transport air 2, Transport air 3); B - Spreading air; and C - Casting air. The three variables that can change are shown in Table 2.

An airflow meter was used to find the maximum and minimum values of the pneumatic boiler feed system at which the boiler could still function. This was performed by slowly changing the valve inlet flows one at a time and measuring the different airflows with the use of an air flowmeter. To obtain the minimum flow rate the pipe valves were slowly changed in small increments until the minimum threshold for every pipe was found. When finding the minimum, the same adjustments on both ports were made simultaneously to find the minimum value needed to sustain boiler operation. This process was conducted for both pneumatic boiler feed systems (12 pipes total). After the base values maximum (+) and minimum (-) were obtained the medium (0) base value was calculated. After all airflow values were obtained, the average of both port 1 and 2 was used as base values for the three parameters A, B and C as shown in Table 2.
Table 2: Base variables for Transport air, Spreading air and Casting air

<table>
<thead>
<tr>
<th>Variable</th>
<th>+</th>
<th>-</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – Transport air</td>
<td>+</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>B – Spreading air</td>
<td>+</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>C – Casting air</td>
<td>+</td>
<td>-</td>
<td>0</td>
</tr>
</tbody>
</table>

After the Min, Max and zero values were obtained a test series of 11 tests were conducted to see if any of the following combinations resulted in a CO emissions decrease, the test combinations can be seen in Table 3. Three of the 11 tests were controlled tests. This aimed to increases the reliability of the data if similar results were obtained between the three series.

Table 3: Test combinations for the pneumatic boiler feed system

<table>
<thead>
<tr>
<th>Test</th>
<th>A - Transport air</th>
<th>B - Spreading air</th>
<th>C - Casting air</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>6</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>8</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The independent variables for each test were changed 15 minutes before the official test start. This precaution was conducted to give the boiler time to adjust and stabilize to the new parameter settings. This step lead to more accurate and reliable results as it was sure that the obtained data was from that specific test and did not include the adjustment period.

The test series were conducted in winter time of March of 2019. During the winter months the boiler is always operating at maximum capacity. Since the tests were performed during winter time the assumption that the load was constant was made. Each test was conducted for a total period of 30 minutes (15 min stabilization period before each test).

4.5.3 Measuring of dependent variables
To increase the reliability and accuracy of the results, both visual results and numerical results were recorded.

4.5.3.1 Numerical results
The main focus for the different test were the CO emissions of the BFB boiler. However, to see if other data affected the experiment, the following data was collected:

- Emissions rate (CO, NOx)
- Bed temperatures
- Temperature before super heater 2 lower
• Temperature before super heater 2 upper
• Temperature before super heater 1
• Exhaust gas temperature
• Boiler bed pressure

4.5.3.2 Visual results
To gain a better understanding of how the independent variables affected the fuel feeding port, images of the biomass input port were taken during the experiment. With visual data from the entry port as well as the entire fuel bed the boiler could carefully be studied. A clear visual image was given as how the change in different airflows affected the spread of biomass and combustion within the boiler. The cameras used during this experiment were supplied by Visionsteknik AB. These cameras can tolerate very high temperatures and use air as well as water for cooling. The cameras produce high detailed and high-quality images and video of the inside of the boiler. The cameras that were used can be seen in Figure 9, Figure 10 and Figure 11.

One camera was placed at a view point at the top of the boiler on level 5, the camera was positioned in such a way as to give an overview of the entire fuel bed from above. Another camera was angled towards the inlet of biomass port 1 on level 3. This angle was chosen to see the change of the fuel spread on the port as different parameters were changed. The entire test duration was filmed and later analyzed to determine if any visible changes could be seen within the boiler. A sequence of images were taken out of the video for each test for further image analysis in the program ImageJ.

4.6 Bed material change test
The results from the literature review showed the performance/quality of the bed material can have a large effect on the boiler’s overall performance as well as efficiency. With theory in hindsight a test was conducted to increase the frequency of bed material regeneration. Current procedure at the plant was to change a portion of bed sand every other day excluding weekends. This implies that a small portion of the sand was changed on Monday, Wednesday as well as Friday every week. The total changed portion for each bed material change is round half a cubic meter. One bed material change amounts to around a 3 % sand replacement when compared to the entire material bed mass. As the quality of the bed material decreases overtime, the risk of agglomeration formation as well as
large particles (agglomeration clumps) increase. It was of interest to investigate whether this was occurring in the boiler in Malå as it might be a factor as to why the boiler experienced high CO emission. The aim of this experiment was to see if the frequency of bed material changes in the BFB boiler had an effect on the boiler’s efficiency and emissions.

The tests were carried out during winter time; therefore, the load was set as a constant as the boiler always operates at maximum capacity of round 15 MW. The biomass moisture content was set as a constant as the biomass fuel only ranged between 50 % to 56 %. All biomass was obtained from the same supplier (Setra sawmill) which results in a very uniform and even biomass supply both in humidity as well as consistency. The airflow for the primary, secondary and tertiary systems were all dependent on the biomass moisture content as well as the load of the boiler. As the load and biomass humidity are presumed to be constant, all airflows, feed bed pressure as well as biomass partial size were presumed constant as well. To ensure that an even biomass moisture content was obtained the moisture content was measured two times for each test.

Table 4: Variables for the sand change test

<table>
<thead>
<tr>
<th>Constant parameters</th>
<th>Independent</th>
<th>Dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Load (15 MW)</td>
<td>- Sand change frequency</td>
<td>- Emissions CO, NOx</td>
</tr>
<tr>
<td>- Biomass fuel humidity (53 %)</td>
<td>One change (3 % of total bed material regeneration)</td>
<td>- Boiler bed temperature</td>
</tr>
<tr>
<td>- Total airflow (6 Nm^3/s)</td>
<td></td>
<td>- Temperature before super heater 2 lower</td>
</tr>
<tr>
<td>- Pneumatic boiler feed system (10.5 m/s)</td>
<td>Three changes (9 % of total bed material regeneration)</td>
<td>- Temperature before super heater 2 upper</td>
</tr>
<tr>
<td>- Feed bed pressure (11.5 kPa)</td>
<td></td>
<td>- Temperature before super heater 1</td>
</tr>
<tr>
<td>- Biomass particle size (5 mm - 50 mm)</td>
<td></td>
<td>- Exhaust temperature</td>
</tr>
</tbody>
</table>

4.6.1 Test setup
A portion of three times more sand was changed to see if it influenced boiler emissions. Each test was conducted for a total of 10 hours to see if there was any correlation between the frequency of sand change and emissions. The independent, dependent and constant variables can be seen in Table 4. The extracted sand out of the boiler was time based. For each sand change the drain port was opened for three seconds. After a portion of sand had been removed new sand was added from a pipe on the 4th floor, around 40 seconds compensated for 3 seconds of drained sand due to difference in pipe diameter. New sand was added until the bed pressure of 11.5 kPa was reached again. The first change was made at 07:00, second change at 11:00 and the third change at 15:00. All three portions could not be changed at the same time since bed temperature would drop dramatically and cause a shutdown of the boiler.

4.6.2 Measuring of dependent variable
The emissions data was logged over the test period from the start of the experiment. The time frame when the sand was exchanged was filtered out and ignored as the moment when the sand was exchanged fluctuated bed temperatures which ultimately influenced emissions as it took time for the sand to warm up to the desired operational temperature of 800 °C to 830 °C.
4.7 Excess O₂ effect on efficiency

The biggest efficiency losses in a BFB boiler are usually through the exhaust gases. Since Skellefteå Kraft’s boiler in Malå was operated on a 6 % O₂ excess (original conditions), it was of interest to investigate whether it could benefit Skellefteå Kraft economically by operating the boiler at a lower O₂ excess. High CO emissions were a restriction as to why the boiler was not operated at a lower O₂ excess. Based on TS % composition of forest residue biomass, the specific heat capacity of different gasses produced during combustion, the temperature of the exhaust gases and the overall biomass moisture content, the heat losses for the boiler exhaust gasses were calculated. A typical elemental composition of forest residue with the following data was used; C (50.84 %), H (5.72 %), O (41.4 %), N (0.66 %) and ash (1.07 %) (Nurek, Gendek, & Roman, 2019).

5 Results & Discussion

5.1 Boiler statistical data

5.1.1 Load variations

The boiler in Malå supplies both Setra sawmill as well as the town itself with hot water. This makes up the overall load that the boiler regulates after. Figure 12 shows how the load is divided between the town of Malå as well as Setra sawmill. The graph shows that the town load for district heating is very uniform. However, this cannot be said for Setra sawmill which is the major consumer of heat. The load varies a lot over a period of 24 hours as illustrated in the graph, sometimes load changes of 4 MW occur in just a few minutes. This is mainly due to the start and stop of different wood drying programs at Setra sawmill which consumes large amounts of heat.

Setra consumes 60 % and the town only 40 % of the total load. Ultimately it is Setra that is responsible for load variations which can clearly be seen in Figure 12. The total load curve as shown in green closely follows the sawmill load curve shown in blue. Skellefteå Kraft does not have a buffer or storage tank, the load is inflicted directly on the boiler with drastic sudden changes.

![Figure 12: The hot water load variations for town district heating, Setra saw mill and total boiler load](image-url)
Figure 13: Load variations effect on boiler CO emissions

Drastic load changes are a contributing factor to high emissions as the theoretical analysis has shown. Load fluctuations from Setra sawmill were graphed against CO emissions for the boiler in Malå to see if sudden changes in load influences emission’s as theory suggests. It can clearly be seen in Figure 13 that peaks or sudden decreases in load from Setra sawmill influences CO emissions. A clear peak in CO can be seen right after a change and over time the CO stabilizes again. During sudden regulator changes it takes time for the boiler to compensate and reach the new parameters, hence the poor performance until the new parameters are reached and the boiler is stabilized again.

For optimal boiler running conditions the load should be constant, however this is not the case with the boiler in Malå, the load constantly fluctuates with frequent intervals. To attend this problem, it is suggested that a buffer tank should be installed to take up the sudden load fluctuations by Setra sawmill. Instead of adding unnecessary stress on the boiler and regulators the fluctuations could be taken up by a buffer tank instead. The implementation of a buffer tank in the system would produce a more constant load which would result in an emissions reduction and performance improvement.

5.2 Airflow mapping
Before the practical experiments on the BFB boiler were conducted all airflows of the primary, secondary and tertiary air were mapped to see if there were any inconsistencies in the flow symmetry. It is very important for the air distribution to be symmetrical in each section. For instance, if more air would be added in on the right side instead of the left side at the bottom of the bed an uneven fluidization would occur. The biomass would be mixed more on the right side than on the left as well as the right side having more air to combust than on the left. The goal to achieve good combustion is having a uniform bed, hence air distribution is an important factor. Both primary, secondary and tertiary airflows symmetry are important to obtain clean combustion, low emissions and high boiler efficiency (Schuster, 2002) (Kristinsson & Lang, 2010).

5.2.1 Primary air system
The flow rates of different sections of the primary airflow system were measured to see if the primary air distribution is symmetrical. The flow distribution for the primary air system can be seen in Figure 14.
A display in the control room shows the air pressure of both the right side of the boiler and the left side. The left side had a pressure of 11.3 kPa and the right side 10.7 kPa. It could clearly be seen that there was a pressure difference between the two sides by 0.6 kPa. To confirm this data a test hole was drilled in the left and right primary air inlet pipes to measure the flow as can be seen above. The flow meter also showed a difference in reading between the left and the right which can be seen in Table 5.

**Table 5: Primary air flows to bed nozzles, before and after adjustment**

<table>
<thead>
<tr>
<th></th>
<th>Before adjustment</th>
<th></th>
<th></th>
<th>After adjustment</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
<td></td>
<td>Left</td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>Primary air to bed nozzles</td>
<td>m/s</td>
<td>m/s</td>
<td></td>
<td>m/s</td>
<td>m/s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>7.8</td>
<td></td>
<td>10</td>
<td>9.7</td>
<td></td>
</tr>
</tbody>
</table>
The discrepancy in air flow was due to an outdated motorized duct damper that was no longer in operation and was stuck in a 50\% open position, hence reducing the airflow. The right damper was adjusted to a 100\% open position, increasing the flow rate. After this change the pressure on the left and right were even, both reading 11.1 kPa in the control room as well as having even flows when measured with the flowmeter, this can be seen in Figure 16 and Table 5.

The primary air directed to the bed nozzles was reduced from a 5\% discrepancy to 0.7\% between left and right. This change has resulted in even airflow between the left and right side of the boiler bed and a more uniform fluidization is achieved. Figure 16 shows the effect of the primary air adjustment on CO emissions. It can clearly be seen how left and right pressure signals are spaced apart and how after the calibration they merge together into one. This change slightly reduce CO emissions by 14\% which can be observed in Figure 16. This finding supports theoretical findings of the importance of even airflow distribution in boilers. Before the change the left side was receiving more air than the right side, meaning that more fluidization and combustion air was entering the left side when compared to the right side. Uneven combustion often results in poor efficiency and an increase in emission hence the slight emissions drop when the problem was attended to.

Figure 15: Primary air pressure to bed nozzles after adjustment

Figure 16: Primary air pressure (Left and Right) sensor against CO emissions

5.2.2 Secondary air system
The secondary airflow system consists of two ducts on each side of the boiler. Each side of the boiler has an “upper” and a “lower” secondary airflow. When the left and the right side of the lower secondary airflow system were measured and compared, both values were generally even. However, upon measuring the airflow of the upper secondary vents a major difference in air distribution was found. The left side of the boiler had a reading twice as large as the right side of the boiler as can be
seen in Table 6. This discrepancy could have had an impact on the overall combustion symmetry of the boiler. The right side of the upper secondary airflow system was adjusted to around 18 m/s so both the right and left side receive the same airflow. Upon conducting this change a slight increase in CO emissions was noticed. This was strange as even airflow between left and right is optimal for good combustion. This suggests that there was an underlying problem of a possible leakage in the pipes, that the air was simply not reaching the boiler.

### Table 6: Secondary air flows, before and after adjustment

<table>
<thead>
<tr>
<th></th>
<th>Before adjustment</th>
<th>After adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Secondary air</td>
<td>m/s</td>
<td>m/s</td>
</tr>
<tr>
<td>Upper</td>
<td>17.5</td>
<td>9.1</td>
</tr>
<tr>
<td>Lower</td>
<td>8</td>
<td>8.3</td>
</tr>
</tbody>
</table>

#### 5.2.3 Tertiary air system

A slight change in tertiary air distribution between left and right was found as can be seen in Table 7 below. Once again, the right side of the boiler received more air than the left side of the boiler. This slight difference was corrected as can be seen in the table to the right. Upon changing the flow, no noticeable change in the boiler’s temperature or emissions data was seen. The difference between the flow values was quite small and might be an explanation as to why no change could be observed.

### Table 7: Tertiary air flows, before and after adjustment

<table>
<thead>
<tr>
<th></th>
<th>Before adjustment</th>
<th>After adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Tertiary air</td>
<td>m/s</td>
<td>m/s</td>
</tr>
<tr>
<td></td>
<td>3.3</td>
<td>2.6</td>
</tr>
</tbody>
</table>

In the control room settings, it was noticed that the feed rate of the left and right feeding screw were set to different feeding intervals. This might have been changed by the operator in the past to compensate for the difference in airflow distribution from left to right, as the left side received more primary, upper secondary and tertiary air compared to the right side. It seems logical that in the presence of more air, the left side would gasify and combust at a slightly higher rate compared to the right, hence the higher fuel feed rate to the left side to compensate for this.

Based on theoretical knowledge even airflow distribution has a large impact on a boiler’s overall efficiency and function. As outlined above all the different airflows in the primary, secondary and tertiary were measured and calibrated. The feed rate of the biomass feeding screws were also set to equal between the two sides. The only positive noticeable change on CO emissions from all three airflows was when the primary airflow to the bed was equalized. The equalization of the secondary airflow increased CO emissions suggesting that there are possible leakage issues in the secondary air system. A lower flow to the right side of the boiler might have been set by the operator to try to compensate for the difference in bed temperature from left to right.
5.3 Pneumatic boiler feed system

5.3.1 Numerical results

The different maximum flows in the pneumatic boiler feed system were measured. The results can be seen in Table 8 below.

Table 8: Maximum airflow rate in both left and right pneumatic feed systems

<table>
<thead>
<tr>
<th>Pipe</th>
<th>Flow (m/s)</th>
<th>Pressure (Pa)</th>
<th>Pipe</th>
<th>Flow (m/s)</th>
<th>Pressure (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>153</td>
<td>1</td>
<td>19.9</td>
<td>238</td>
</tr>
<tr>
<td>2</td>
<td>72.6</td>
<td>-</td>
<td>2</td>
<td>73.2</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>23.3</td>
<td>328</td>
<td>3</td>
<td>17.5</td>
<td>185</td>
</tr>
<tr>
<td>4</td>
<td>11.4</td>
<td>78</td>
<td>4</td>
<td>20.4</td>
<td>251</td>
</tr>
<tr>
<td>5</td>
<td>11.6</td>
<td>81</td>
<td>5</td>
<td>11.8</td>
<td>84</td>
</tr>
<tr>
<td>6</td>
<td>47.2</td>
<td>1338</td>
<td>6</td>
<td>48.8</td>
<td>1432</td>
</tr>
</tbody>
</table>

A surprising observation was made that all the fuel transport air pipes had been switched off since the installation of the system in 2005 as can be seen in the primary airflow overview in Figure 14. For port 1 and port 2 pipes 1, 3 and 4 have been completely closed. It was every difficult to obtain a maximum reading from the pipes that were initially closed due to 14 years of sediment, biomass and dust buildup that had blocked the pipes even when the valve was fully open. However, with the use of a hammer and several minutes of banging on the pipes, airflow was restored to all of the transport pipes. Although all the transport pipes have the same diameter, different flows were obtained. This is suspected to be due to sediment and biomass that is still lodged in the pipes. The maximum, medium and minimum base values were obtained based on the maximum flow data measured for the pneumatic feed system as can be seen in Table 9.

Table 9: Base values for pneumatic boiler feed system

<table>
<thead>
<tr>
<th>Variable</th>
<th>+</th>
<th>-</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Transport air (m/s)</td>
<td>12</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>B - Spreading air (m/s)</td>
<td>12</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>C - Casting air (m/s)</td>
<td>47</td>
<td>15</td>
<td>23</td>
</tr>
</tbody>
</table>

A minimum value of zero could not be selected for the spreading air and the casting air as these two variables were critical to the biomass entering the boiler. Hence a value of 15 m/s was chosen for the casting air and a flow of 3 m/s for the spreading air. The cooling air in the pneumatic boiler feed system was ignored as a variable during these tests as it was essential that it was not changed from its maximum value as it might otherwise cause overheating.
Table 10: Numerical test results for boiler pneumatic feed system

<table>
<thead>
<tr>
<th>Test</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>CO (ppm)</th>
<th>NOx (ppm)</th>
<th>Bed Temperature (°C)</th>
<th>Before superheater 2 lower (°C)</th>
<th>Before superheater 2 upper (°C)</th>
<th>Before superheater 1 (°C)</th>
<th>Total air flow (Nm³/s)</th>
<th>O2%</th>
</tr>
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Table 10 outlines the numerical results obtained from the boiler pneumatic feed system test. Test 1 and 2 had to be aborted due to a sudden decline in boiler temperature. The loss in temperature increased the fuel screw speed however the minimum value of casting air and spreading air was not enough to move and spread enough fuel in to the boiler. Both tests had to be aborted before causing a complete boiler shutdown. Test 7 shows the initial conditions that the boiler pneumatic feed system has been set to for the past generation. The conditions of no transport air, high spreading air and high casting air produce high amounts of CO of around 1000 ppm. The test series that produced the least amount of CO was test 8. A combination of high transport air, high spreading air and high casting air levels give the lowest CO emissions by far out of all test combinations. When all the tests are compared it can be made clear that the increase of transport air dramatically reduces CO emissions. It is quite ironic that this variable has been completely switched off for the past 14 years as it seems to have a large impact on combustion efficiency and emissions.
Tests 9 through 11 aim to show the reliability of the data. All three of these tests generally give even numerical values, the CO emissions ranges by 55 ppm between the three tests and the temperature by 7 °C. This clearly shows that the data is very consistent and accurate. The uncertainly values for all the tests are generally very low, it is noticeable when a higher CO value is obtained the uncertainty range increases as CO levels tend to vary more. Although there is a general average standard deviation of 140 ppm for all measured CO emissions values, the data shows a clear trend that the increase of transport air decreases CO emissions levels dramatically. The biomass moisture content during the test was in the range of 52 % to 54 %. A further variable that was constant was the boiler load with around 14,8 MW. These two variables being fairly constant further increases the reliability and accuracy of the obtained data.

The temperature data of the three different sensors in the boiler show a very interesting trend. To get a better illustration of the temperature sensor positioning in the boiler refer to Figure 17. As test 8 is carried out a higher temperature is obtained in the lower part of the boiler, a lower temperature is obtained in the middle of the boiler and a lower temperature is obtained at the top of the boiler. There is an increase in temperature by 45 °C when original conditions (Test 7) are compared to test 8. These temperature changes suggest that combustion is occurring a lot lower and closer to the fuel bed than before. This gives the fuel more time to combust and combusts a lot cleaner which is reflected on the low emissions that test 8 produced. The increase of airflow and spread of the biomass in the fuel bed moves combusting down closer to the boiler bed when compared to the original settings as shown in test 7. This can clearly be seen in Figure 18 which shows the temperatures at the top, middle and bottom of the boiler as test 7 conditions transition to test 8 conditions. The figure clearly shows that as the test change occurs, the bottom temperature increases whilst the top and middle temperatures decrease. The blue vertical line in Figure 18 shows when the transition between the two different tests occurs.
Figure 18: Temperature transition from Test 7 (Original conditions) to Test 8 (Optimal conditions) in different parts of the boiler

Data from Table 10 and Figure 18 both suggest that there is not enough air is present in the lower secondary zone for original operating conditions (Test 7) of the boiler which leads to incomplete combustion which leads to high CO levels. Both port 1 and 2 outlets are in height with the lower secondary zone. The increase in overall airflow as achieved in test 8 increase the spread of the biomass more evenly as well as supplies more air to the lower secondary zone which results in low levels of CO. With the use of test 8 settings, the emissions of the boiler in Malå are significantly reduced.

5.3.2 Visual results

Throughout the pneumatic boiler feed system test video data was collected, however only very small changes were observed visually between most of the tests. To highlight the major change only visual data from original settings (test 7) and optimal settings (test 8) are presented and discussed.

Figure 19 shows the pneumatic fuel port inlet into the boiler for original conditions (test 7) for camera 2. Original conditions are high spreading air, high casting air and no transport air. The red arrows in the figure illustrate the flow of biomass material. It was observed that smaller biomass particles were simply driven upwards by draft from the fuel bed and that larger particles would simply fall downwards as the bottom red arrow illustrates. With test 7 conditions poor fuel distribution is achieved as the image clearly shows. Although the spreading air and the casting air operate with maximum capacity, it is simply not enough to efficiently distribute the biomass material. The poor biomass distribution explains visual observations made by plant employees of heat flames that have been occurring surrounding the ports as the biomass material is only spread close to the ports and not throughout the entire boiler. This is a major factor contributing to high emissions as it is important to obtain even fuel distribution as the theoretical research shows in order to receive high boiler efficiency and low emissions. This is clearly not the case as illustrated in Figure 19 below.
A significant visual change was observed for test 8 conditions as can be seen in Figure 20 for camera 2. All three variables are opened to maximum capacity for test 8, the change in biomass spread is clearly illustrated by the red arrow. The increase in airflow caused improved spread of the biomass. The biomass is thrown and spread out further and more evenly in the boiler hence lower emissions and improved boiler efficiency.

The comparison between Figure 19 and Figure 20 clearly shows the visual internal change of events in the boiler as the transport air is increased from zero to maximum flow. A much clearer and less turbulent image is obtained as the biomass is ejected at such a high speed that the camera does not pick it up. Both images complement the numerical findings and clearly display the visual effect of biomass spread with change of airflow in the pneumatic feed system. The increase of transport air significantly improves biomass spread which reduces CO emissions and improves boiler efficiency.
Camera 1 is situated at the top of the boiler which aims to give a bird’s eye view of the boiler fuel bed. Figure 21 illustrates conditions with test 7 parameters and Figure 22 illustrates conditions with test 8 parameters. The images from test 7 and 8 clearly show how combustion is occurring a lot lower in the boiler in test 8. In Figure 21 the blue line shows the height of the upper secondary air holes, with test 7 conditions these are completely covered by flames and cannot be seen in the image. As conditions are changed to test 8 as shown in Figure 22 the upper secondary air holes can be seen clearly which implies that the increase of transport air has shifted the zone of combustion lower and closer to the bed of the boiler. This finding further supports and strengthens the obtained numerical data of temperature values that have been discussed earlier.

The images also show that uneven combustion is occurring in the boiler, more violent and turbulent combustion is occurring on the right side of the boiler as illustrated by the arrows in Figure 21. This is a separate problem independent of the pneumatic boiler feed system test as this problem is seen both in images from test 7 as well as test 8. This is an interesting find as airflow distribution is even in the boiler with both the left and right side receiving around 8 m/s for lower secondary and 17 m/s for upper secondary as can be seen in Table 6. However, this explains how emissions are increased as the flow rate between left and right are equalized as discussed earlier. This further supports the hunch that there is a major leakage in pipes on the left side of the boiler as the flow is the same for left and right however images show that the right side is receiving more air than the left side. The earlier calibration caused an even larger difference which resulted in the increase of CO emissions. Figure 23 shows 5 different screenshots taken at different times from different tests to illustrate where combustion is occurring in the boiler bed. Images from all pneumatic boiler feed system tests showed the same conclusion. It can clearly be seen that combustion is occurring more to the right for
all conducted tests. The left image in Figure 25 shows an image overlay of where combustion is occurring in the boiler. It can clearly be seen that combustion is occurring more on the right side of the boiler, this is thought to be a contributing cause to high emissions as not enough air is received in the left secondary zone of the boiler. The left image in Figure 25 clearly confirms suspicions as previously stated during the secondary airflow calibration stage.

**Figure 23:** Images of the boiler fuel bed taken from above (original state). The first row shows the fuel bed without a filter. The second row shows the fuel bed with a filter to highlight parts where combustion is occurring the most. These images are taken from different tests from the pneumatic boiler feed system test. They highlight a separate problem independent of what test is conducted. Right side: Upper secondary (17.5 m/s), Lower secondary (8.3 m/s); Left side: Upper secondary (17.3 m/s), Lower secondary (8 m/s).

**Figure 24:** Images of the boiler fuel bed taken from above (after secondary airflow leak adjustment). The first row shows the fuel bed without a filter. The second row shows the fuel bed with a filter to highlight parts where combustion is occurring the most. Images are taken from after secondary airflow leak adjustment. Right side: Upper secondary (5 m/s), Lower secondary (5 m/s); Left side: Upper secondary (8 m/s), Lower secondary (12 m/s).
Before the airflows were adjusted to try to obtain a more even fuel bed the following flows were measured in the upper and lower secondary zone; Right side: Upper secondary (17.5 m/s), Lower secondary (8.3 m/s); Left side: Upper secondary (17.3 m/s), Lower secondary (8 m/s). In order to obtain even combustion in the boiler bed, the numerical flow values from the air flow mapping stage were simply ignored. With only the use of camera video feed from the boiler, the left and right sides were adjusted until the boiler bed burned evenly from left to right. The right side secondary airflow was dramatically reduced to 5 m/s for lower secondary and 5 m/s for upper secondary. The left side was increased to maximum flow for both upper and lower secondary airflows, 8 m/s and 12 m/s. The increase on the left and decrease of the right side compensated for all the lost air on the left side, this resulted in even airflow distribution and even fuel bed combustion. The visual representation of this change can be seen in Figure 24. It can clearly be seen that the adjustment of airflow has resulted in a more even fuel bed.

![Figure 25: Image overlay of 5 separate images of the fuel bed. The left image shows the original state. The right image shows the fuel bed after the secondary air adjustment](image)

When the left image and the right image in Figure 25 are compared the significant change can be seen very clearly. A more even combustion is obtained when the secondary airflow is adjusted to produce an even fuel bed. Lower and more constant CO emissions were obtained after the boiler had an even fuel bed just as theory shows. During the next summer stop a deeper investigation should be conducted to find out what is happening with all the air on the left side of the boiler, to locate possible left secondary air pipe leaks in the insulation layer of the boiler.

### 5.4 Bed material change test

The bed material change test was conducted over a period of 10 hours. Sand was changed in the morning at 07:00, 11:00 and 15:00. The sand was extracted at the base of the boiler for three
seconds, new sand was then added until the desired bed pressure of 11.5 kPa was reached. During the sand test large agglomerations lumps were observed in the waste sand as can be seen in Figure 26. The figure also shows how the material is changed over time from fresh sand to large agglomeration. These lumps are clear evidence that agglomeration occurs which might contribute to high emissions as the sand is not changed frequently enough. Figure 27 shows the comparison between one and three sand changes and how this affects the emissions values. It can clearly be seen that a more frequent sand change gives lower emissions. Original operating conditions are that the sand is changed one time every other day which amounts to a 3 % bed material regeneration per change. The comparison between one change (3 % regeneration) and three sand changes (9 % regeneration) has resulted in a CO emissions decrease by 20 %. However, since this test was conducted over a period of 10 hours the general decrease in bed temperature might have affected the overall results. Although the sections of when the sand was changed were filtered out, it could still have affected the results. Both readings have an uncertainty of around 100 ppm, the frequency of 1 to 3 changes collide within the mentioned uncertainty range. To obtain more accurate data to make a more definite conclusion the test should be carried out for a longer period. However, this data is still evidence of a change that can be made by Skellefteå Kraft to obtain lower emissions. A proposed change of a portion of bed material daily is suggested to reduce emissions.

![Figure 26: Bed agglomerations of various sizes found in waste sand after the sand change.](image)

![Figure 27: Quantity of Bed material changes impact on CO emissions (1 change is 3% of total bed material mass), (3 changes is 9% of total bed material mass)](image)

All changes and improvements have resulted in a CO emissions reduction of 68 %. The change that has affected emissions the most was the increase of airflow in the lower secondary zone of the boiler. With current settings the secondary airflow is not operating at full capacity to compensate for
leakage on the left side of the boiler in order to obtain an even fuel bed as Figure 25 shows. It is with high certainty that when the leak is attended to during the annual operational stop that even lower emissions values can be achieved and that the boiler can be further fine-tuned.

5.5 Excess O2 effect on efficiency

Table 11 shows the effect of O2 excess on the exhaust gas losses based on 53 % biomass moisture content, 17.5 m3/h biomass feed rate, 7.5 MJ/kg biomass energy content and 145 °C exhaust gas temperature. The stated parameters are the average operational parameters from Skellefteå Kraft’s plant in Malå. The economical calculations are based on market price average of around 0.6 kr/kg of wet biomass material (53 % moisture).

Table 11: Excess O2 % effect on boiler efficiency

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<td>Savings per year (tkr)</td>
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</table>

Skellefteå kraft operates their boiler at 6 % excess air which is the maximum amount allowed by Naturvårdsverket in Sweden (Naturvårdsverket, 2005). At 6 % O2 excess calculations show that there will occur a 11 % energy loss to exhaust gases as shown in Table 11. However, at 3 % excess O2 there is only a 9 % loss of energy to the exhaust gasses. Exhaust gases in a BFB boiler account for the biggest overall efficiency loss (Malmgren & Riley, 2012). It is economically beneficial for Skellefteå kraft to reduce their emissions in order to operate the boiler at a lower excess air percentage resulting in lower exhaust energy losses. Currently Skellefteå Kraft cannot operate the boiler at 3 % or 4 % excess oxygen since CO emissions will be in the 3000+ ppm range. In the course of this thesis, emissions have been reduced, this opens an opportunity to operate the boiler at 3 % or 4 % O2 which could save Skellefteå kraft 180 kkr to 255 kkr annually as shown in Table 11.
6 Conclusions

The aim of this project was to identify and map the cause of the BFB boiler’s high CO yield with the help of theoretical literature studies, evaluation of previous boiler operation data as well as practical experiments to reduce CO; furthermore, suggest possible changes that can be implemented to resolve this problem. A literature study was conducted to gain a better understanding of possible causes of high CO in fluidized bed combustion of biomass technology. The literature study showed that bed agglomeration, airflow symmetry, biomass moisture content, biomass partial size and biomass bed distribution all are common problems that can cause high CO emissions.

The results from evaluation of the boiler operational data showed that load variations have a minor effect on CO emissions. It is clear that sudden load variations slightly increase CO emissions however, it is not the major contributing factor for high emissions in Skellefteå Kraft’s boiler.

The following conclusions were made after conducting changes and experiments regarding certain relevant variables in Malå’s BFB boiler.

- An increase in transport air for the pneumatic boiler feed system resulted in a dramatic CO emission decrease by 63 %. The overall average temperature before super heater 2 was increased by 45 °C. This shows that the implemented changes have moved combustion closer to the fuel bed. This change occurred due to an overall increase of air in the lower secondary zone as well as an increase in the spread of biomass material in the boiler bed. Combustion occurring lower in the boiler produces cleaner combustion and decreases maintenance and wear on later parts of the boiler. Emissions have been reduced from an average of 1230 ppm to 400 ppm at 6 % O₂ excess. The CO emission levels are now below the 440 ppm recommended by Naturvårdsverket.

- Primary airflow calibration between left and right side of the boiler resulted in a change from 410 ppm to 350 ppm, i.e. a CO emissions reduction of approximately 14%.

- An increase in the frequency of sand changed in the BFB boiler showed that CO emissions could be reduced. A change from one (3 % bed mass replacement) to three sand changes (9 % bed mass replacement) resulted in a decrease in CO emissions from 350 ppm to 280 ppm. The CO emissions were reduced by 20 % with the increase of small portion sand changes. However, the experiment was only conducted under 10 hours. A longer study should be conducted to draw more certain conclusions and increase reliability and accuracy of the bed material test data.

- With the use of special cameras, it was found that there is uneven combustion in the boiler. A higher combustions intensity was found on the right side of the boiler than on the left side. This is due to insufficient air presence in the left secondary zone. The cause of the pressure drop is suspected to be a large leakage in the left secondary upper and lower pipes inside the boiler insulation. A more even combustion intensity in the furnace was achieved by increasing secondary airflow on the left and reducing secondary airflow on the right to compensate for the leakage. The shift to an even boiler bed further reduced CO emissions.

In conclusion, by the suggested adjustments proposed in this thesis a 68 % CO emissions decrease for Skellefteå Kraft’s BFB boiler in Malå was achieved compared to original boiler settings. The suggested changes will most likely also result in increased boiler efficiency and reduced maintenance to super
heater 1, super heater 2 as well as the economizer. The recommended changes imply a very small cost for Skellefteå Kraft hence no deep economic analysis was produced. The significant CO decrease in Skellefteå Kraft’s boiler has opened opportunity to operate the boiler with lower excess air which ultimately decreases exhaust heat losses. If Skellefteå Kraft were to succeed in operating the boiler at 3 % O\textsubscript{2} excess, a sum of 255 kkr could be saved annually. The following recommendations should be implemented by Skellefteå Kraft in the boiler in Malå to sustain low CO emissions levels as well as achieve even lower emissions in the coming season:

- Increase the bed material change frequency.
- Clean pneumatic airflow system during summer stop annually.
- Ensure airflow symmetry within the boiler is achieved annually.
- Increase airflow to lower secondary zone.
- Use recommended airflows for pneumatic boiler feed system.
- Invest in a buffer tank to reduce load variation by Setra Sawmill.
- Reduce secondary air nozzle size to increase combustion air in the middle of the boiler.
- Increase the feed port ramp angle to increase biomass casting length in the boiler.
- Investigate left side secondary air flow (possible leakage suggested)

7 Suggested future work
This project has established that not enough air is present in the lower secondary zone. Continued work is suggested to establish if even lower CO values can be achieved if a separate fan would be installed and only be used for the pneumatic boiler biomass feed system. This project was limited since the pneumatic feed system currently receives air from the primary air system, it would be of interest to test even high airflows to the lower secondary zone.
8 References


100% förnybar kraft. (n.d.). Retrieved from Skellefteå Kraft: www.skekraft.se


Wagner, C. (1967). Seasonal variation in moisture content of eastern canadian tree foliage and the possible effect on crown fires. OTTAWA: Minister of Forestry and Rural Development.
# Appendix

## Appendix A

Tests from 2005

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<td>Right side spoon increase</td>
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<td>Different biomass, new fuel</td>
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<td>9</td>
<td>Increase left side spoon</td>
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<td>Change prim sec factor to 43%</td>
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<td>Decrease boiler to minimum load</td>
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9.2 Appendix B
Environmental emissions license for Skellefteå Kraft

Tillstånd enligt miljöbalken för kraftvärmeverk på fastigheten Rubanken 3, Malå kommun.

(1 bilaga)

BESLUT

Länsstyrelsen lämnar, med stöd av 9 kap. 6 och 8 §§ miljöbalken (1998:808) Skellefteå Kraft AB (bolaget) tillstånd att inom fastigheten Rubanken 3 driva befintligt kraftvärmeverk och komplettera detta med ytterligare utrustning.

Sammanlagt installeras tillförd effekt vid anläggningen för förbränningskraft

Detta beslut får tas i anspråk när det vunnit laga kraft.

Länsstyrelsen återhåller beslut daterade 1990-08-31, dnr. 2450-33229/90, och 1998-09-29, dnr. 245-652498, om tillstånd enligt miljöskyddslagen för verksamheten. Återkallandet sker med stöd av 24 kap. 3 § 6 § miljöbalken och gäller från den tidpunkt när detta tillståndbeslut har vunnit laga kraft.

För tillståndet gäller följande villkor.

1. Om inte annat följer av övriga villkor ska verksamheten bedrivas i huvudsakligt överensstämmelse med vad bolaget uppgivit i ansökningshandlingarna. Ändringar i anläggningens utformning eller i verksamheten får inte göras utan ett tillsynsmyndigheten i god tid underrättas. Tillsynsmyndigheten prövar om ändringarna kräver anmälan eller om tillstånd måste sökas.

2. Verksamheten får endast avse värme- och produktion av elektricitet. Trådförbrinlser och oljevärnletna ska överensstämma med vad som angivits i anmälan.

Villkor för fastbränslecellnings

3. Utställ av stoft i rökgaser från fastbränslepomma får som riktvärde inte överstiga 50 mg/Nm³ torr gas vid 15 % CO₂.

4. Utställ av kväveoxide, benämnda som NO₂ från fastbränslepomma får som riktvärde och årsmedelvärde inte överstiga 100 mg/MJ tillfört bränsle.
Utsläppen av svavel minskar med närmare två tredjedelar vid en utbyggnad enligt planerna jämfört med nollalternativet, medan utsläppen av kväveoxidier blir i stort sett oförändrade jämfört med nollalternativet. De totala utsläppen av svavel motsvarar ca 2,5% av den mängd som deponeras i Malå kommun, medan utsläppen av kväveoxidier motsvarar drygt 10% av kväveinsläppet i kommunen.

Tungmetallinnehållet i bränslet är ca 3,15 kg Cd och 0,5 kg Hg i år i nollalternativet och ca 4,1 kg Cd och 0,65 kg Hg i nyanläggningsalternativet. Innehållet av metaller m.m. i de bränslen som ensätts med en utbyggnad av fjärrvärmeägaren och elproduktionen har inte beräknats.

Koldioxidutsläppen från anläggningen beräknas minska med närmare 8000 ton per år vid utbyggnad jämfört med nollalternativet.

<table>
<thead>
<tr>
<th></th>
<th>CO₂ (ton/GWh) Totalt</th>
<th>NOx (kg/GWh) Totalt</th>
<th>S (kg/GWh) Totalt</th>
<th>Stoft (ton/GWh) Totalt</th>
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<tbody>
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<td>2002</td>
<td>31,3</td>
<td>397</td>
<td>49,4</td>
<td>51,0*</td>
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<td>0-alt 2005</td>
<td>78,6</td>
<td>396</td>
<td>89,6</td>
<td>41,4*</td>
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<td>396</td>
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<td>144,3**</td>
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</table>

Specifika utsläpp till luft, * Stoft räknat på 35 mg/Nm³ vid 13 % CO₂. ** Stoft beräknat på 100 mg/Nm³ vid 13 % CO₂.

Inga dammsningsproblem har rapporterats från kraftvärmeverket sedan tidigt 1990-tal.

Utsläpp till vatten
Utsläpp till vatten består av spännvatten, dagvatten och kondensat.

Spillvatten från personalutrymmen samt vatten som används för att spola inne i pannhuset leds via spillvattenledning till Malå reningverk. Dessa vattendrag är avsedda som undvikelse för oljetillgångar som inte ska utgå från en utbyggnad av anläggningen.
