A BUBBLING FLUIDIZED BED DISTRIBUTOR PLATE

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JOKIVIRTA, JOUNI:

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ABSTRACT

This thesis deals with a project where Kymen JA Service Oy delivered a bubbling fluidized bed distributor plate to Savon Voima Oyj´s Pieksämäki power plant. The purpose of this thesis was to deliver the grate assembly to Pieksämäki according to the contract.

The project as a whole is examined chronologically, from signing the contract to performance experiences after delivery. Various details related to weaknesses of the fire grate and the benefits of the bubbling fluidized bed distribution plate motivated Savon Voima Oyj to initiate the retrofitting project.

Delivering a fluidized bed grate assembly requires competence on multiple areas, the design being the most important because it determines the grate´s functionality. The contractor must be aware of the associated design options and risks, which are examined in this thesis. The project was successfully delivered to Pieksämäki.

Keywords: distributor plate, bubbling fluidized bed, fire grate

Lahden ammattikorkeakoulu
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TIIVISTELMÄ

Tämä opinnäytetyö kasittelee projektia, jossa Kymen JA Service Oy toimittaa leijupetiarinan Savon Voima Oyj:n Pieksamäen voimalaitokselle. Työn tarkoitus on muuntaa 20 MWt lämpökattilan rakoarina leijupetiarinaksi.

Työssä projekti, joka sisältää useita eri vaiheita, kuvaillaan ajallisesti tarjouspyynnöstä luovutuksen jälkeisiin käyttökokemuksiin. Useat eri seikat liittyen rakoarinan heikkouksiin ja leijupedin hyötyihin vaikuttivat Savon Voima Oyj:n motivaatioon muunnatuttaa arinaratkaisu.

Leijupetiarinan urakoiminen on monialainen tehtävä, jossa vaaditaan usean alan ammattitaitoa, jossa suunnittelun osuus on kuitenkin ratkaiseva arinan toimivuuden kannalta. Urakoivan osapuolen tulee olla tietoinen kaikista suunnittelunäkökohdista ja -ongelmista, joita tässä työssä käydään läpi. Projekti toimitettiin onnistuneesti, sopimuksen mukaan.

Avainsanat: leijupeti, leijupetiarina, rakoarina

CONTENTS

TERMINOLOGY

Bubbling Fluidized Bed (BFB) Method: a method in which the solid fuel is fluidized for combustion

Clinker: slag on a grate

Cogeneration or **Combined Heat and Power (CHP)**: Production of electricity while utilizing the otherwise lost heat

Distributor Plate or **BFB Grate Assembly**: a level which distributes air to create a bubbling fluidized bed

District Heating: a method of providing heat power to customers, typically domestic use

Fire Grate: a type of grate used in grate firing

Grate: a level where solid fuel is placed for combustion

Grate Firing: a traditional combustion method

MWt: megawatt thermal, **MWe**: megawatt electrical

Plugging: Obstruction of nozzle bores in the grate assembly

Slag: Ash attached to boiler parts

Wind Chest, Wind Box or **Air Chamber**: A boiler part situated below a distributor plate

1 INTRODUCTION

The bubbling fluidized bed combustion method is replacing conventional grate firing in small and medium-size power plant boilers since the 70´s. Fundamental similarities of these two combustion methods enable low cost retrofitting. Modernization is continuous through boiler revisions.

The bubbling fluidized bed method is essentially superior to conventional grate firing in several aspects: Allowing a wider range of solid fuels of different qualities, providing a more secure and controllable process as the combustion is stable and uniform. Furthermore, mainly due to the mentioned facts, bubbling fluidized bed combustion also lowers emissions.

Savon Voima Oyj´s experiences with their main boiler combustion method – bubbling fluidized bed – in Pieksämäki power station raised the desire to modernize the stations secondary boiler utilizing the same method. Kymen JA Service Oy, a company specialized in projects such as delivering bubbling fluidized bed distributor plates, received a request for quotation in late 2009.

In this thesis I describe the project of modulating an original grate construction to a bubbling fluidized bed distributor plate in Pieksämäki. I explain the process within the margins the project is carried out – as described in the contract. My personal participation in the project further narrows the perspective, excluding all financial aspects, as well as technical details which are the expertise of other project parties. In addition, the project has a beginning and ending, setting the chronological boundaries.

In the practical part I explore two main areas: design and fitting. Knowledge on the principles of thermal power station working is expected of the reader since the project, as well as this thesis is focused on a single part (the distributor plate) and how it is delivered. The structure of the thesis is mainly chronological. However, the theoretical and practical parts are arranged to suit the chronological setup.

2 PROJECT PARTIES AND BACKGROUND

2.1 Combined Heat and Power in Finland

The European scheme of energy production differs from its Nordic part for its great lack of cogeneration (Combined Heat and Power, abbreviated CHP) solutions: simultaneous production of heat and electricity. For understandable reasons, there has been no notable demand for CHP, in average, because central and southern Europe does not struggle with severe winters as the northern countries do. In the south, the infrastructure of natural gas has been implemented before the innovations in district heating. Furthermore, Finland and its nearby areas lack natural coal resources, which has traditionally prevented from creating “cheap solutions”.

In the European Union as a whole, only 11% of energy is produced by CHP (cogeneurope.eu 2010). In comparison, the same percentage in Finland is 34 in year 2004 (Huhtinen 2008, 11). Combining the production of heat and electricity is beneficial for multiple reasons. CHP raises efficiency significantly since traditional thermal power stations creating exclusively electricity reach a maximum efficiency of 44%, whereas similar thermal stations with cogeneration solutions can exceed 90% efficiency (Huhtinen 1994, 11).

District heating is normally applied when cogeneration serves domestic heating purposes. This is the case of almost 80% of cogenerated production in Finland (Huhtinen 2008, 315), adding up to a number of 1.3 million households being connected to district heating services (hs.fi 2010). Heat energy is transferred to households (and industry) in the form of heated water (or steam in some cases) denoting the consumer must be physically near. Heat distribution over great distances result unwanted energy losses in the form of heat and pressure. These are countered with stabilization. Furthermore, transfer network leakages induce impurities to the system. Thus certain limitations are set to cogeneration, although transferring electricity also has parallel losses.

Finnish cities are relatively small: an average sized city carries a population of only a few tens of thousands. Combined with the fact that population centers are scattered throughout the country, the Finnish energy scheme has developed to be extremely CHP oriented, being one of the economies to utilize cogeneration most intensely. In other words, the Finnish energy industry is not centered, but rather localized and serves consumers nearby.

There are additional features in the Finnish environment that favor cogeneration. Finland has had a relatively big sector of – now declining – paper industry, where steam usage is a necessary part of paper production processes. Different types of wood are used in paper industry, obviously. Still, a tree can only be partially used in the process, and traditionally paper industry has utilized the rest by burning. Through decades, the Finnish energy industry has gathered knowledge on combustion methods, and has been a major developer and manufacturer of thermal power boilers.

2.2 Project Parties

In this part the companies associated with the thesis are presented only to clarify the project surroundings. Two companies, the orderer and the contractor, are discussed in greater detail. The power station work site has been taken into closer examination. However, a number of companies play a part in the project but in the form of services and other functions´ and therefore the company itself is not represented. Company functions are discussed throughout the thesis, especially in ‘Prefabrication of the Bubbling Fluidized Bed Distributor Plate’. Design, prefabrication, finances, installation and managing – all need their experts. In this project, the organization was formed by companies with different know-how cooperating.

A few of the companies involved were previously unknown to Kymen JA Service Oy and their competence had to be evaluated on thin background information. However, this is normal when expertise is bought from a distant field of operation. Also, stating the potentially problematic project organization does not mean that there were problems. Companies performed within the expected limits.

2.2.1 The Contractor: Kymen JA Service Oy

Kymen JA Service Oy was founded in 2008 to serve the needs of energy industry, metal workshops and saw mills. The company handles projects by permanently employing only one person – this is the company´s mode of operation. The nature of services is based on consultation. Kymen JA Service Oy does not possess manufacturing tools or materials, but rather outsources services to companies specialized in their own field of operation. The company is situated in the city of Kouvola in South-Eastern Finland. The services provided by Kymen JA Service Oy range from simple services to project handling. The variety is based on knowledge about metal works and fitting, as calculations on related costs. The concept allows providing services such as:

- Offering calculations for steel structures and pressure applications.
- Project management.
- Project foreman services.
- Welding procedure specifications for MIG, TIG and Shielded Metal Arc Welding (SMAW) methods.
- Heat exchangers and boiler renewals.
- Membrane panel renewal.
- Bubbling fluidized bed distributor plates.

(kymenjaservice.fi 2010)

2.2.2 The Orderer: Savon Voima Oyj

Savon Voima Oyj is the name for a parent company comprising multiple specialized companies. Obviously, the project did not concern the whole corporation, but an individual power station and one of its boilers. However, it is important to know how the company fits on the energy industry scheme. Savon Voima Oyj´s official website states the following main details: Total annual sales of 230 million Euros make it one of Finland´s largest energy service providers, employing more than 200 professionals (savonvoima.fi 2010).

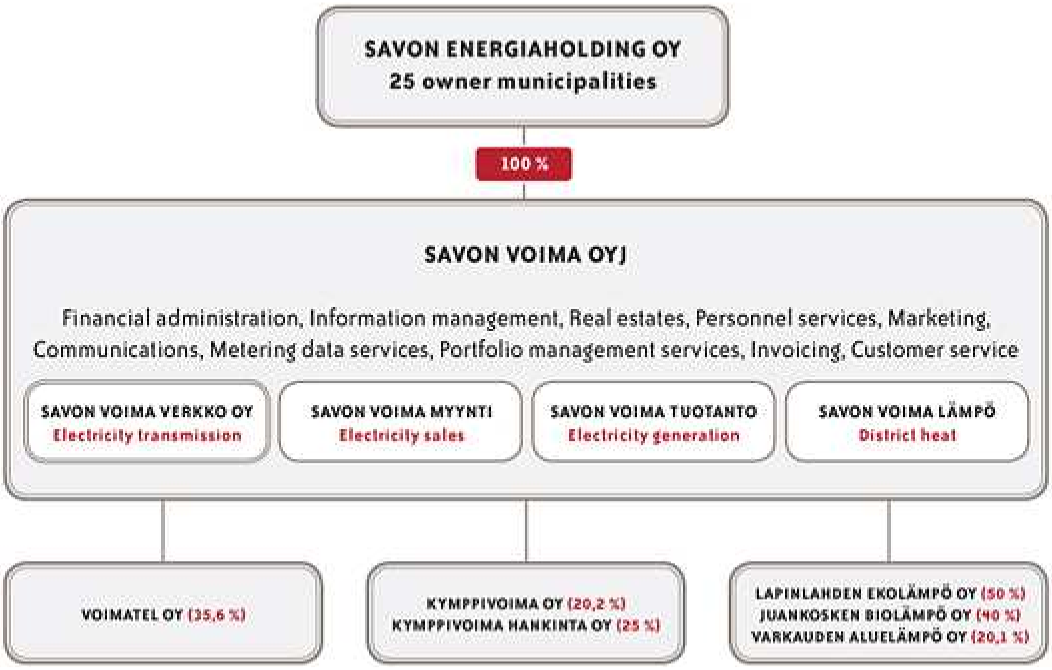


FIGURE 1: Group structure and the most important affiliates (savonvoima.fi 2010)

Explained in Figure 1, the parent company is formed by four companies of their own business areas. These companies include network sales, electricity sales and generation. The company the project has been delivered to is Savon Voima Lämpö Oy which specializes in district heating services. To avoid confusion, however, I refer to the orderer party in this thesis as Savon Voima Oyj.

2.2.3 Savon Voima Oyj´s Pieksämäki Power Plant and the LK 1 KPA Boiler

Savon Voima Oyj´s power plant (in Figure 2), located in the city of Pieksämäki, can be considered as a typical Finnish power station. The city carries a population of over 20 000 inhabitants. However, the population density of roughly 13 per square kilometer indicates how small the main urban area actually is. Therefore, the district heating networks provides energy to approximately a mere 650 connections (the number counts explicitly the connections: apartment blocks and small households are treated alike). Despite the low connection count, the network provides heating for approximately 90% of the city´s heated volume.

FIGURE 2: An aerial view of Savon Voima Oyj´s Pieksämäki power plant. The heat center housing the KPA boiler on the right © Savon Voima Oyj

The Pieksämäki power plant comprises three separate boiler units. The main boiler is a cogeneration unit, producing the base load of both heat and electricity. The unit can produce a maximum output of 10 MWe electrical and 25 MWt district heat power. The second boiler, called LK 1 KPA boiler (abbreviated as KPA boiler), produces exclusively heat for the district heating network and can provide a maximum output of 20 MWt (prior to retrofitting). The third and the smallest unit (comprising two separate boilers) is designated for emergency and peak output. For its functional nature and very low utilization rate, it is operated by heavy fuel oil. The two boilers previously mentioned use shared solid fuels: wood chips and cutter peat in varied ratios depending on annual seasons and availability. A three unit power station offers flexibility, providing electricity but also adjustable heat output. The main boiler cannot provide sufficient regulation of both forms of energy independently, for the fact that electricity capacity is bound to the heat power output.

The KPA boiler is used for load sharing in peak heating periods as well as used alone outside the heating period. Production figures of the boiler in 2009 give an idea of its capacity and utilization (interview Tepponen 2010): Average production of approximately 6 MW with 4000 hours of use (5½ months) denotes an annual production of just below 25 GWh. However, the production figures vary greatly depending on the year.

The KPA boiler is not a typical boiler in many aspects, as its manufacturer Outokumpu Oy has made unconventional decisions on the design. A distinct feature, visible in Figure 10 (on page 33), is the hinged wind chest allowing easy access and, when opened, exposing the grate area conveniently. Commonly such mechanisms are not included in boiler designs and larger openings have to be cut, or otherwise improvised. The wind chest hinge mechanisms might have been originally constructed because of the KPA boilers second distinct design feature – the grate itself. Figure 4 on page 11 illustrates the highly machined stationary fire grate which consists of hundreds of separate bars. This type of construction has proven to be highly problematic in use. An unconventional feature is the convection part (membrane) as it begins from a three meter height above the grate surface

2.2.4 Other Project Parties

The prefabrication of the bubbling fluidized bed distributor plate involved a number of companies. The design has been delivered by two separate firms dividing the design into process and structural design. The structural designer, Kymtec Oy, calculated the integrity of the structure, and simulated the weight carrying capacity of the plate design under different loads, as well as designed the arrangement in which the nozzle tubes were erected. The functionality of the BFB distributor plate was designed by Boilerstart Oy, which calculated the nozzle sizes after accepting the design proposition of Kymtec Oy.

It may be added, that the design phase in the project did involve unofficial consultation of individuals which took concern to some of the design features of being faulty and unnecessary risky. However, these persons did not desire to be officially involved in the project.

A material provider for the project for tubes (pipe material) and nozzle cover plates was Cronimo Oy. Machining the materials was conducted by, another, two separate companies: Suomen Putkilaser Oy and Avemet Oy which provided the base plate. Kemas Oy, located in Kouvola, handled the welding assembly of the BFB distributor plate parts.

An additional party involved in the project fitting was a one-man company Asennus Siitonen Oy which provided skillful fitting services and the equipment. The installation also required a party for insulating the furnace parts. Refrak Oy was selected for this task for their price. Coincidentally, they had previously worked in Pieksämäki and were familiar with the KPA boiler. How these project parties collaborated is discussed further in later chapters.

2.3 Comparison of Grate Firing and Bubbling Fluidized Bed Method

In this part the two combustion methods related to this thesis (the methods used in Pieksämäki power plants district heating boiler) are examined and compared. Revealing these theoretical level details set the basis for understanding the practical reasons for grate retrofitting.

There are numerous methods of delivering fuel to a boiler. Typically the used method is designed according to the intended fuel properties. For example, pulverized fuel, such as fine coal, can be injected into a boiler by a pneumatic method by using burners. Fuel oil is injected similarly, creating a constant flame. In turn, in fire grate combustion where the fuel rests on a level of grate bars, similar flaming of fuel is not possible. Fundamentally, a boiler type is fixed to a certain set of fuels and cannot be converted without considerable costs. There are exceptions though. In the following, I present how replacing conventional grate firing with bubbling fluidized bed combustion is possible and desired.

As illustrated in Figure 3, both methods are set to the same premises. Primary air is delivered from below, through a level (fire bar or distributor plate). Fuel is delivered by a simple method of placing it onto a level. Ash disposal is based likewise on gravity (a stationary grate has no parts maneuvering the fuel). With these similarities in the combustion methods, it is possible to convert one type to another with relatively low cost. This is possible by retrofitting a distributor plate, replacing the fire bar.

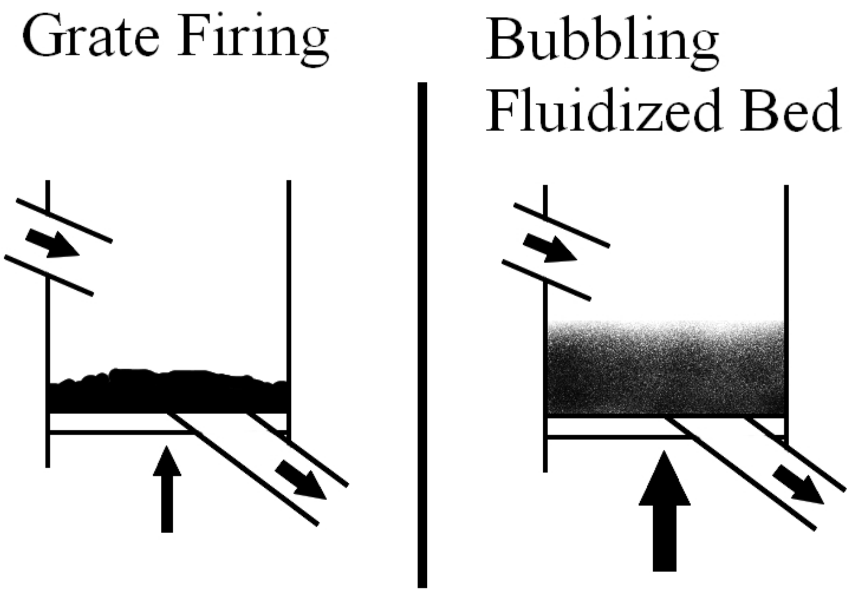


FIGURE 3: Fixed bed grate firing and bubbling fluidized bed (in the thesis scenario) illustrating fuel delivery and ash disposal, as well as primary air similarities

2.3.1 Grate Firing

Grate firing is probably the first combustion system for solid fuels because of its simple structure. It is intended for all traditional solid fuels. In the process fuel is placed onto a grate and (primary) air is provided from underneath. The fire grate used in Pieksämäki power plant´s KPA boiler is an advanced construction of the conventional grate firing method. The fundamentals are illustrated in Figure 3.

The output with the grate firing method ranges from small scale domestic use starting of approximately 15 kW to medium scale industrial boilers of 80 MW output. However, grate firing is typically used in under 5 MW boilers. In more powerful boilers other combustion methods – mainly fluidized bed types – have replaced grate firing. (Maskuniitty 1995, 393)

The fire grate used in Pieksämäki consists of bars, or rather, small openings between bars in order to provide primary airflow, illustrated in Figure 4. Each opening is originally designed to be 0.8 millimeter wide, thus being extremely prone to plug in heavy fuel oil start-ups (Tepponen 2010). Furthermore, thermal expansion in a fire grate assembly with small openings is a huge design problem, which is created by direct contact between the grate and the fuel. This unavoidable feature can only be dealt with expensive solutions, such as using alloys unapt to thermal expansion. Complex structural design is one solution, but results in costly manufacturing, fitting and maintenance. Both solutions were used in the KPA boiler.

FIGURE 4: Closer examination of the stationary fire grate bars of the KPA boiler prior to retrofitting

Inducing fuel and disposing ash are based on gravity as explained in Figure 3. The disposal is placed not in the middle, but on the perimeter area. Such implementation leads gradually to unsymmetrical combustion for the fact that fuel accumulates unevenly when induced (and removed). Primary air travels through the fuel in areas with least resistance and therefore the air can "escape" in the areas with less density, and vice versa.

Even though a variety of solid fuels can be utilized in grate firing – from large pieces of wood to fine cutter peat – a limitation is set by moisture even in developed grate constructions. Moisture content exceeding 60% requires use of supplementary fuels. Furthermore, some emissions, as carbon monoxide and hydrocarbons are directly caused by imperfect combustion typical to grate firing. (Maskuniitty 1995, 396 & 407)

2.3.2 Bubbling Fluidized Bed Combustion

Bubbling Fluidized Bed (BFB) is a subgroup of Fluidized Bed Combustion (FBC) methods. In both methods the fundamental principle is to turn solid fuel material into fluid-like form. A bed of fluidized material is generated with (primary) air jetted through nozzles in a distributor plate into a sand-fuel mix. Different types of fluid forms can be created depending on the primary air velocity, and the type and particle size of the fuel mix. In the BFB method, the bed is relatively stable (not too turbulent and the fuel does not circulate in the boiler). The BFB process can be described as resembling a pot of boiling water, as illustrated in Figure 3.

A characteristic of a fluidized bed is the expansion of the bed when primary air velocity is increased. In solid (and static) sand, empty space acquires approximate 0.4 of the volume. While reaching the so called "minimum fluidized velocity" of primary air, empty volume is still unchanged. Beyond this critical velocity the bed begins to bubble and expand. Bubbling is not analogous to primary air velocity but stays stable while velocity is increased until a point is reached where sand starts to escape with flue gas. (Huhtinen 2000, 155)

Fluidized bed combustion applications have entered commercial usage in the 70´s. Fluidized bed as a combustion method is suitable for wide range of fuels, even those considered low quality. Abrupt changes in fuel quality can be dealt with ease. The operating temperature in BFB varies between 750°C and 950°C which is relatively low compared to other combustion methods. (Hyppänen & Raiko 1995, 417)

BFB offers advantages compared to traditional combustion. Fluidized beds create a uniform composition of fuel thus creating uniform burning. Therefore, the process temperature also remains uniform and can be controlled more accurately. In contrast, as discussed earlier, conventional grate firing is practically incapable of creating such conditions. Furthermore, preprocessing of moist fuels becomes less necessary or needless because of the considerable heat capacity of fluidized beds.

Bubbling beds have also their disadvantages. The process creates conditions for violent erosion. High velocity particles subject internal parts (mainly the grate and interior walls) to erosion. A protective coating or masonry must be applied for two reasons: erosion and preventing heat spots from emerging near the walls. In addition, nozzle erosion must be considered because small changes of size and shape affect fluidization and therefore affect the whole process. Furthermore, the BFB method requires vertical surface area which is comparative to the output. Thus, without alterations to the fuel, increasing the output of a once build BFB boiler costly structural changes are required.

Compared to conventional grate firing, the BFB method bears a further defect: Whereas the minimum output can be very low with grate firing, the lowest output of the BFB method is limited by minimum fluidization velocity and bed temperature. On the other hand, the maximum output is restricted by the fuel material's terminal velocity. In a situation where primary air velocity exceeds the terminal velocity, fuel material escapes the bed. Moreover, excessive temperatures restrict the output: Process temperature must be approximately 100 degrees Celsius below ash melting point, which practically denotes a temperature of 900 degrees Celsius, depending on the fuel. Otherwise, the sand mix may sinter and cause expensive maintenance. Nevertheless, the BFB output span starts from 30%. (Huhtinen 2000, 158 & 159)

2.3.3 Bubbling Fluidized Bed Emissions

In this part, I discuss emission formations unique to the BFB process. It should be noted that the laws and regulations concerning emissions in Finland do not apply to this particular boiler, therefore emissions were never a design aspect. However, emission formation related to the combustion method is related, because laws and regulations can be changed in the future.

On the contrary to an intuitive belief, higher combustion temperatures do not produce lower emissions. BFB offers relatively low burning temperatures and an easily controllable environment. For example, bed uniformity creates higher confidence on heat sensor readings; therefore the process can be more easily adjusted.

Nitrogen oxides form in two different reaction types, thermal and fuel bound. The toxic NOx thermal emissions are formed well above the operational temperatures of BFB, and compared to other combustion methods, are not a notable emission source. Fuel based NOx emissions do form, however, if the source of oxygen is not limited. This reaction type can be controlled with phasing primary and secondary air, the latter being directed into the freeboard above the bed, typically by a half and half division (Hyppänen & Raiko 1995, 417).

Emissions are formed of the substances induced to the process, thus some emissions can be avoided by using certain type of fuels. Wood based materials, such as wood chips and bark, lack sulfur, therefore, no sulfur monoxide emissions can be produced by utilizing these fuels. However, heavy fuel oil used in boiler start-ups and cutter peat do contain sulfur, but the quantities used are insignificant in the emissions. A method unique to fluidized bed combustion is to lower the emissions by adding limestone with the fuel to precipitate sulfate.

3 PROJECT INITIATION AND DISTRIBUTOR PLATE DESIGN

The original request for quotation reached Kymen JA Service Oy already in December 2008. Based on the information provided by Savon Voima Oyj, a quote could be given. The bidding process continued. An agreement was reached and the contract was signed in March 2009. Project definition included delivering the distributor plate, ash disposal (excluding valves and auxiliary instruments) and coating the distributor plate (excluding the furnace shaft masonry). The used contract was made on a standardized form, “agreement on small building works” (RT 80265). The particular form is favored because it states the responsibilities of each party, and conveniently fits such projects.

3.1 Demand for Retrofitting

The KPA boiler has a history of poor functioning with its original fire grate construction. Although the main features of the grate are not conceptual, the highly detailed – and thus expensive – grate structure has proven itself to be prone to malfunctions. Throughout the KPA boilers history, its poor operation has been disregarded because of the low utilization rate of two to four months average in a year. Furthermore, in the early millennium, the fire grate went through a revision. The original fire grate was replaced with an identical one, as a spare piece was delivered with the boiler, and stored for later use. The experienced problems, however, continued.

Retrofitting a BFB type distributor plate is considered low cost – if compared to the original construction costs of a fire grate. The structure of a BFB distributor plate is significantly simpler. However, the design can be comparatively complex even though addressing a different set of problems.

In an interview, the Superintendent of Pieksämäki`s power plant gave four reasons directly related to the used fire grates properties, of why the retrofitting was initially desired (Tepponen 2010). In order of importance:

- The main reason why the modification was desired for the KPA boiler is the structural weakness of the original fire grate: the grate could not handle thermal expansion even when replaced.
- The fire bar openings were prone to plug in heavy fuel oil start-ups.
- Another grave fault in the original construction was the ash disposal placed on the perimeter of the grate area, which caused poor ash removal.
- Yet another detail is the heat sensor positioning, which was not originally vertical but tilting, and therefore affected the process (created an air cavity).

The Superintendent continues on the additional reasons not related to poor performance of the fire grate (Tepponen 2010):

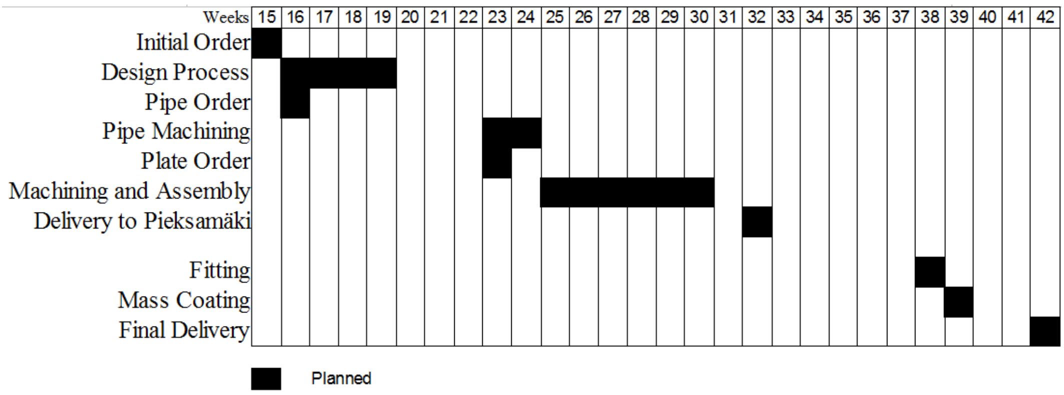
- The main boiler unit has been retrofitted to utilize the BFB method in the 90´s. The performance history encouraged to uniform their combustion methods.
- BFB method offers a more controllable combustion (because of the reasons mentioned earlier).

It should be noted, that the retrofitting did not include a desire to increase the boiler maximum output, but rather changing the combustion method to BFB type for its operational benefits. With the original grate a maximum output of 20 MWt could be reached. The BFB distributor plate could not actually deliver the same output. A power of estimated 16 to 20 MWt used was guaranteed for the BFB distributor plate.

3.2 Planned Project Schedule

The intention was to set the boiler fully operational before cold winter weathers. In practice, this gave seven months to complete the project within the agreed end margin. Risk of financial damage is limited to the winter season – when outside temperatures stay above the level that requires more than 25 MWt – the amount the main boiler provides for the district heating network. Of course, this is a mere assumption for the fact that power plant operators have their methods of compensating energy losses.

TABLE 1: Original project schedule April 7th 2009 (translated by author)



Boldly estimated, the project could have been completed in two or three months, even within the same resources – assuming that the materials would have been instantly available and no notable obstacles would have been encountered. Of course, this is merely a thought to demonstrate the actual extent of the project.

Excessive time gave the opportunity to create a bumper zoned schedule. The project consists of three main phases: design, prefabrication and fitting. Planning and scheduling extra time after each step provided caution, in case complications occured. The bumper zones can be seen as gaps in Table 1 (the schedule is an appendix of the contract of the project). The time period free of scheduling between the designing and prefabrication phases was, in fact, unavoidable, because of material delivery times. Material selections were made in the bidding process, in the earliest possible stage to secure that the needed materials were in stock and could be delivered.

The fitting phase was initially intended to last one week. Further and more detailed planning of the fitting included an additional two days, extending the original schedule. A week after the fitting was reserved for the masonry team.

Probably the most critical bumper time is the last gap, the time between the fitting and the – very last planned event – final delivery. The functionality of the BFB distributor plate was planned to be tested while the boiler is running cold. For this, a reasonable time of two weeks was considered for Savon Voima Oyj to examine the distributor grate's performance.

3.3 Bubbling Fluidized Bed Distributor Plate Design Process

As stated earlier, the design process of the BFB distributor plate was acquired in large parts from companies specialized in distributor plate designing. Nevertheless, the contractor, Kymen JA Service Oy, must be aware of all the associated risks. Hyppänen and Raiko (1995, 425 & 426) state a number of conditions the distributor plate has to meet by design:

- A distributor plate must spray an even, or a desired airflow, depending on the design.
- The design must be able to contain the fuel in the combustion chamber and not let backflow occur.
- The nozzles are not desired to wear-out, clinker or plug.
- The design must deal with erosion.
- The design must withstand corrosion.
- A distributor plate must tolerate heat.
- A plate must also handle the weight of the bed material.

However, there were design aspects that were not followed to my knowledge. For example, corrosion was considered being such a minor factor that it was not mentioned.

The design is based on what is considered traditional of a bubbling fluidized bed grate assembly: a base plate carrying spray tubes.

3.3.1 Bearer Structure

The fire grate installed in the original structure was extremely heavy – approximately 4.5 tons is assumed according to calculations. The bearers underneath the grate were designed to withstand thermal movements and carry the fire grate. These bearers being a part of the original grate, in Figure 5, were considered useful and capable in supporting the distributor plate and the bed material. The distributor plate weighed a mere 1.5 tons.

Inspection showed no substantial signs of wearing. The bearers are constantly cooled by the primary air, and overall, are not subject to wearing forces unlike other boiler parts. The solution of using already existing bearers gave the basis for the distributor plate design, for the reason that bearers and nozzle tubes require being intermeshed. The weight carrying capacity of the structure was simulated by Kymtec Oy. Results assured that the structure can handle the distributor plate and its functions.

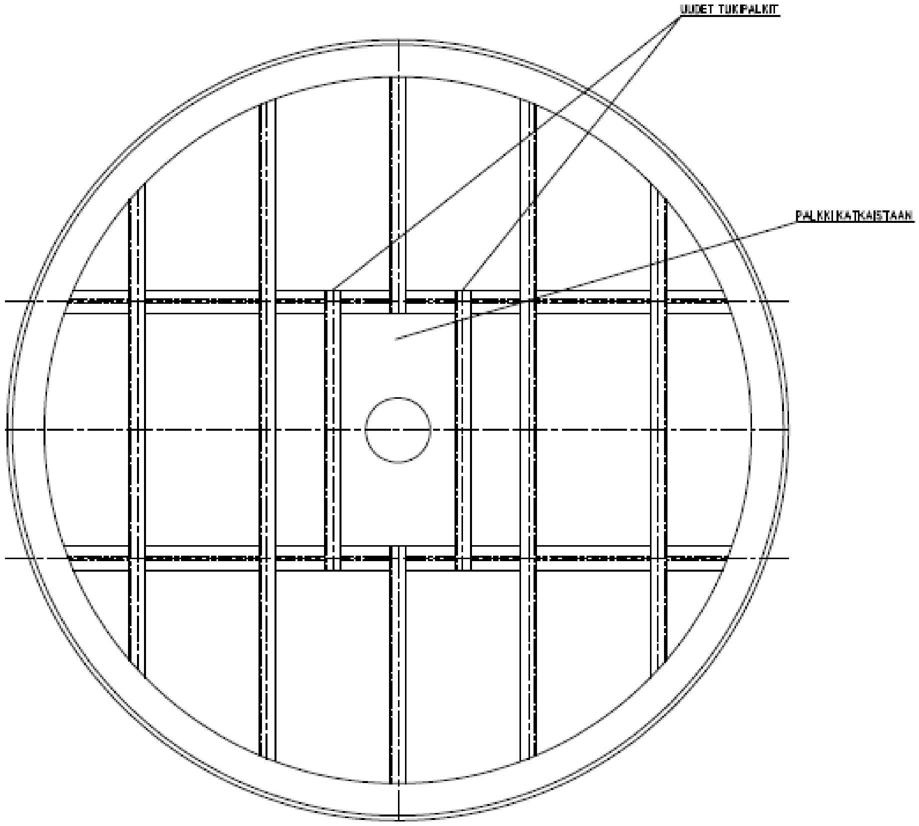


FIGURE 5: Grate bearers. Two additional beams added to compensate the lost carrying capacity

It was necessary to modify a part of the bearer structure, because the ash disposal in the fire bar was placed in between the bearer structure, avoiding contact to any beams. The BFB design placed the removal precisely in the center of the grate area for creating an even ash disposal. In order to do this, the center bearer part was to be cut away in the fitting phase. Two additional bearers were to be installed to compensate the loss in carrying capacity of the removed bearer part.

The bearer arrangement is important in two accumulative aspects. First, for some reason it was taken self-evident, in our party, that the bearer arrangement would cement the nozzle tube positions. The bearers and the nozzle tubes were not to overlap in any parts. However, the designer, Kymtec Oy, saw it easier to first calculate the nozzle tube arrangement. This solution required bearers being repositioned according to the nozzle tube arrangement. Miscommunication on this matter caused difficulties in the fitting phase.

3.3.2 Airflow Distribution and Nozzle Design

In converting a relatively small grate fired boiler into a BFB type, as in this project, building a scale model or simulating the grate assembly is not sensible because of their extremely high price. However, poor nozzle design may result to a catastrophic scenario. For example, if the nozzle size is designed by mistake too narrow, the fluidization does not function properly. In this scenario the fault would be noticed in test runs after fitting – at the earliest. Also the distributor plate would then be already sealed into position (because of the combustion chamber shaft coating). Repair machining of the approximately 2400 nozzle bores would thus be challenging.

The nozzles were designed by Boilerstart Oy. Years of expertise in addition to academic education is required to acquire the competence to define spray nozzle size and pattern. Defining nozzle sizes with mathematical formulas, the designer must be aware of all the related components and features and use consideration in evaluating the used variables.

A number of design solutions were left for Kymen JA Service Oy to resolve for the reason that different sources recommended different options. An example being a major design feature: sloping nozzle geometry versus horizontal nozzle plane. Cone shaped sloping nozzle plane would in theory guide the fuel toward the outtake tube but would also deliver unnecessary complexity to calculations due to pressure loss, and thus compromise proper fluidization. Consultation revealed that in such small furnaces, as in the KPA boiler, the advantages of a slope are insignificant and thus the alternative was chosen.

3.3.3 Backflow and Plugging Prevention

If fine material, as sand, is poured in large enough quantities to form a pile, the angle of incline in which the mass accumulates is approximately 45 degrees. The same principle is considered in order to prevent backflow. Each nozzle tube embodies a cover extending enough to hide in 45 degrees all nozzles. The covers, illustrated in Figure 6, are furthermore intended to protect the nozzles from clinking resulting from heavy oil start-ups.

Reaching the mentioned design solution required excessive consultation. An early design proposition included nozzles wider in diameter than depth. This would lead to a situation where fuel is able to pour through freely (at least in theory). The distributor plate is ultimately designed to prevent backflow by two structural solutions: nozzle depth surpassing the diameter, and covers extended to protect the nozzles. This represents a low cost solution. However, pressure differences in process shutdowns force the bed material into the wind chest, even in more complex constructions.

Flue gas can be taken into circulation for preheating and for nitrogen oxide emission prevention. This feature causes the nozzles to plug because of the circulating alkali vapors, and can eventually disturb the process. However, the formation is slow and highly dependable on how the boiler is operated. For these reasons, nozzle plugging because of alkali vapors was not a design aspect. Furthermore, the feature can be considered more or less unavoidable.

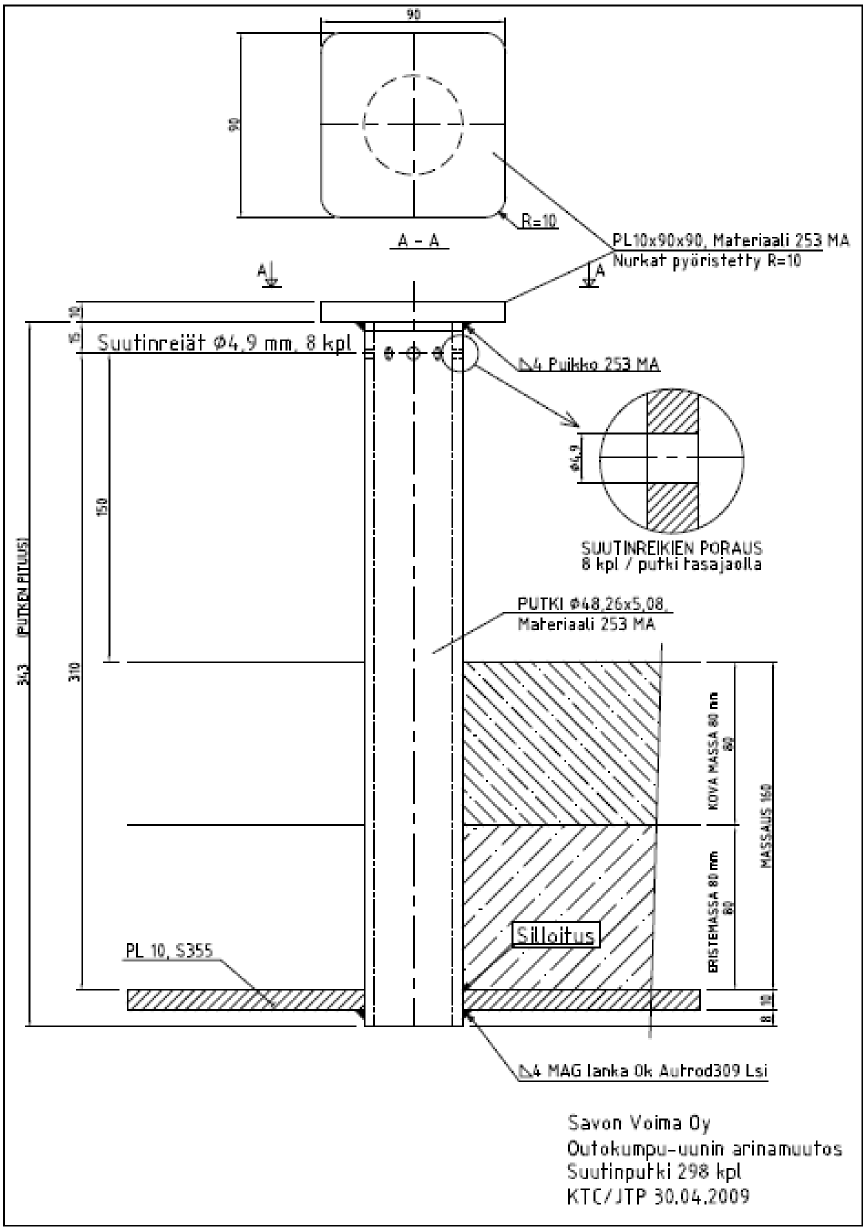


FIGURE 6: Nozzle tube assembly

3.3.4 Erosion Prevention

Erosion is an important design factor in the BFB combustion method. In the BFB process the combustion chamber is subject to violent erosion. There are some rather crude ways of managing it. Heavy masonry is applied to the affected furnace shaft wall. In the KPA boiler, masonry is included in the boiler`s original design. Primary air jetting through the nozzles forms highly erosive pockets from which the masonry needs to be protected. However, protecting the masonry with a coating is not within the margins of the contractor`s responsibilities, and therefore not further discussed.

Erosion must be considered in the nozzle design. This could be done by designing the nozzle parts replaceable. It was proposed that separate nozzle pieces would be used. This would allow low cost maintenance in the future – once the nozzles have worn out. As mentioned earlier, the utilization rate varying from two to four months annually, and the wearing being directly related to the boiler operation time led to the decision of not applying costly design solutions. Furthermore, a low cost solution was desired by Savon Voima Oyj.

3.3.5 Temperature Tolerance

In operation the BFB distributor plate does not have to endure critical temperatures because of the primary airflow`s cooling effect. Taken from inside the boiler building, the primary air provides room temperature air to the boiler (unless flue gas is re-circulated). As discussed also earlier, a BFB boiler operates in furnace temperatures ranging from 750 to 950 degrees Celsius.

A situation may occur when the nozzle tubes reach extremely high temperatures, up to 700°C. A disturbance in primary airflow may drop the hot fluidized bed flat onto the distributor plate. In this scenario, with no or little cooling air, the nozzle tube temperature rises. High thermal force combined with the fuel`s weight may cause damage to the grate if improper materials are applied. Consultation suggested three different materials suitable for the nozzle tubes. Stainless steel, acid-resisting steel and heat-resisting steel were the options and all of these alloys are suitable under normal operation. Fire-resisting 253 MA Sandvik steel was chosen to handle all possible malfunctions. The chosen steel is also temperature resistant enough (scaling temperature is 1150°C in air) to prevent nozzles from deforming.

The base plate requires protection from the violent forces effecting in the combustion chamber. Initially, a low cost solution was considered of placing the nozzle plane high enough, for the sand-fuel mix to sediment onto the base plate. For reliability it was decided to leave the nozzle plane in its original height (310mm), however, adding two layers of insulation, illustrated in Figure 6.

3.3.6 Design Outcome

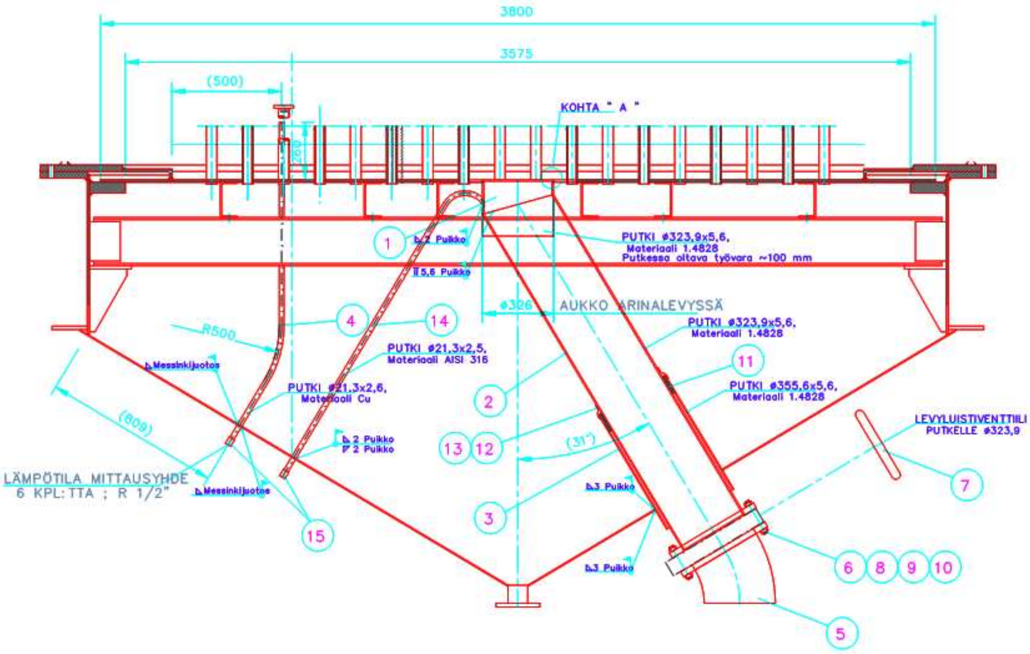


FIGURE 7: The bubbling fluidized bed grate assembly cross-section, including ash disposal duct and auxiliary instruments

Unlike the fire grate, the BFB distributor plate was designed to be sealed into position. In other words, the mass coating seals the furnace, and opening the wind chest would destroy the coating. The grate assembly, illustrated in Figure 7, is expected to outlive the boiler service life without substantial maintenance, although the protective coating might wear out. The most crucial features, such as the nozzles, are not expected to wear out because of low utilization rate. The ash disposal`s thermal movement mechanism was based on simplicity and was similar to the previous design.

The design included the idea to divide the base plate into two symmetrical halves. There were other options also – obviously – to divide it into multiple segments. Two was considered to be maneuverable enough.

The ash disposal design followed a simple rule that the duct diameter must exceed the largest particle diameter the bed creates. The wood chips used in the boiler have a particle size of 60mm. Nevertheless, the fuel might agglomerate and create much larger particles. On the other hand, a too large ash disposal would disturb the airflow uniformity in this type of arrangement.

Bubbling fluidized bed grate assembly in numbers:

- Base plate diameter: 3800 mm
- Grate area diameter: 3150 mm
- Grate area: 7.79 m^2
- Nozzle tubes: 298 pieces
- Nozzles per tube: 8
- Nozzle size: 4.90 mm
- Nozzle plane height: 150 mm
- Nozzle tubes per square meter: 38.25 pieces
- Maximum output: 16MW… 20 MW
- Maximum fuel power per square meter: 2.05 MW/m^2 ...2.57 MW/m^2
- Minimum output: 4.8 MW … 6 MW (30% rule)
- Minimum fuel power per square meter: 0.62 MW/m^2 …0.77 MW/m^2 (30% rule)

3.4 Prefabrication of the Bubbling Fluidized Bed Distributor Plate

The main components used for the BFB grate assembly are base plates, nozzle tubes and their covers (so called “hats”, welded on top of each nozzle tube). Figure 8, in addition to the whole prefabrication process, illustrates the companies providing the materials. Cronimo Oy delivered the tube material (pipes) for Suomen Putkilaser Oy for machining while Avemet Oy could provide both the materials and machining for base plate and the nozzle tube covers. Different companies were chosen for the distinctly dissimilar machining properties of pipe and plate material.

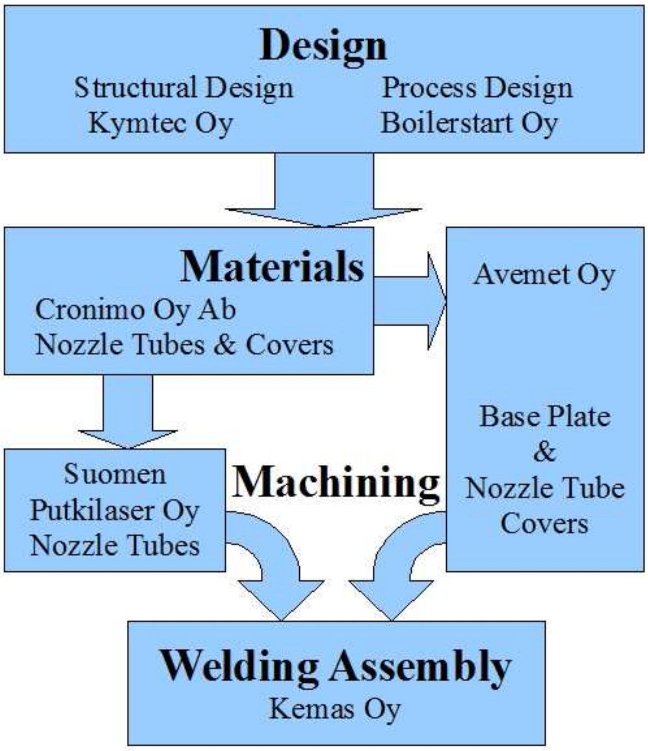


FIGURE 8: The distributor plate prefabrication process

The nozzles were machined into pipes by using laser – a bold decision considering the margins laser cutting equipment is capable of, and the very precise nozzle shape required for the BFB grate assembly to function. Avemet Oy laser cut the shape and holes for the base plate and filleted the nozzle tube covers.

FIGURE 9: Welding assembly of grate parts at Kemas Oy workshop. A jig used is seen in the foreground

The welding assembly was conducted by Kemas Oy. The grate being assembled is illustrated in Figure 9. The nozzle covers were welded onto the tubes. Subsequently, with a jig specially made for this task, the nozzle tubes were positioned following the designed arrangement. First tacking from above for positioning, and thereafter, a complete seam welded from the underside. Finished parts were delivered to Pieksämäki.

4 FITTING

In this part I explain the fitting process which could be considered in three levels: Above all, fitting requires planning of the surroundings and being realistic (especially financially) about resources: Available tools and equipment, personnel and features of the work site. Furthermore, the details in the contract, such as laws and regulations, have to be considered. Determining these enable to envision a more detailed process of how the fitting is actually executed.

4.1 Preliminary Planning and Safety

Visiting the Pieksämäki power station approximately five months before the scheduled fitting date it became apparent that the actual fitting would not be an overwhelming task. The work site offers ease of access as heavy vehicles can enter the boiler building. The KPA boiler's wind chest could be opened which avoided using improvisation on that matter. The area provides enough space to put final touches to the distributor plate. It was also checked whether compressed air and three-phase current connections are present in the vicinity of the boiler. The tools determined necessary for the fitting (welding machines, pneumatic torque wrench and portable plasma cutter) require these connections.

It was determined in the bidding process that the fitting is a task for two persons: The mere safety aspects require more than one person. However, three is excessive for such a small work site. Having only two persons involved in the fitting requires good pairing. The second person assigned for the fitting was an experienced fitter also providing the tools and equipment, based on a list devised by Kymen JA Service Oy. Some tools and personal protection were provided by Kymen JA Service Oy.

Pieksämäki is situated roughly 200 kilometers north from both of the person's residences assigned to carry out the fitting commission. As an option to everyday-traveling an accommodation was acquired at Pieksämäki.

Safety was naturally taken into consideration. Working inside a power plant boiler involves a basic set of safety equipment, dealing with the possible hazards. Heat-proof clothing, safety shoes, helmet and heavy duty gloves are part of normal equipment, as are ear, eye and breathing protection. A boiler houses fine ash, and therefore respirators are absolutely necessary.

Insurance companies in Finland require an occupational safety card from a commission worker. This is considered standard. As importantly, every person who wields a spark or a flame in a temporary work site requires by law a valid hot work card. How hot works are conducted is stated in several separate laws and regulations, but the principle is found in the Rescue Act (Rescue Act 468/2003, chapter 6, section 23) stating that special caution must be taken when there is a risk of fire. Based on the requirements of the law, the work site was equipped with two 12 kilogram fire extinguishers.

4.2 Planning of the Retrofitting

Initial planning gave five weekdays to finish the fitting. An additional two days in the following week were planned in as a caution. A one week schedule with two persons working 48 hours counts as 96 man hours calculated to carry out the fitting. However, the span of nine days offers a conceivable scenario where two persons doing twelve hours per day for the nine consecutive days results to a theoretical maximum of 216 man hours. Therefore, in case of complications it was considered that doubling the working hours within the same scheduled time span is possible. No other personnel of any organization were to work at the same site during the fitting. Nor was there any agreed obligation to be present on the site in any particular time. In other words, the option to work at evenings and weekends was available – in case of emergencies.

The actual fitting was planned to be straightforward. Before dismantling the fire grate, the air chamber needed to be opened. The hinge mechanism was expected to function normally. The pneumatic torque wrench was designated for this purpose for the tens of bolts holding the air chest in position. A plasma cutter was acquired for its convenience in dismantling the fire grate. The bolts holding the grate structure were expected to be in a bad condition. Therefore, simply cutting them with plasma was thought best instead of unscrewing.

The distributor plate weighs approximately 1.5 tons. Lifting the grate assembly in two separate parts into position requires a sensible method of lifting. First, a crane truck was considered as one option of hoisting the grate halves. However, the decision was left for the fitting because maneuvering the BFB grate parts with ratchet lever hoists was a low-cost option. The structure surrounding the hanging KPA boiler is ideal for attaching hoists.

The ash disposal duct and other auxiliary fittings were to be placed after the air chamber is again in position with the distributor plate. For unknown reasons, the disposal duct was designed to exit the air chamber rather low, as seen in Figure 7. The exact angle was left for the Superintendent to decide on the work site. Of course installing a new ash disposal also meant that the previous one needed to be blocked.

4.2.1 Execution: Removing the Fire Grate

After arriving and setting up the equipment and applying for temporary hot work permit, performing the actual retrofitting could begin. The wind chest was attached with bolts and screws. Two hinges on the right side from the primary air duct, seen in Figure 10, and a 10 ton chain block and tackle on the left made the opening effortless, as originally planned.

The wind chest was opened successfully. However, it required removing parts from the chambers way and placing the approximately 600 millimeter diameter primary air duct on an additional hanging support. Being detached from the wind chest, the air duct is supported only by a hold designed to handle small scale movement a hanging type boiler encounters.

The following step was to remove the grate. Figure 4 illustrates the fire bars with very few spots for attaching a ratchet lever hoist. The grate was extremely heavy and this phase of the fitting is the most physical part. Fortunately, the fire grate could be removed in small segments. Scrap metal, which the formerly expensive grate ended up to be, was handed over to Savon Voima Oyj´s own recycling.

The opened boiler gave very little visibility of the upper parts of the furnace, even with high power spotlights. In fact, the spotlights prevented eyes from adjusting to darker objects. After few hours of grate dismantling – successfully removing about a half of the grate – the surrounding furnace shaft masonry was discovered to be worrying. Two slabs of the highest tile row, approximately five meters above the grate level, were slightly tipped inwards. The slabs weighed about 200 kilograms each.

The problematic and potentially fatal situation led to consultation with Savon Voima Oyj´s Superintendent. Initially, no one had the competence to evaluate the real risk of collapse, for it was unclear where the centers of mass were. Furthermore, the risk of collapse was noticed before by Savon Voima Oyj´s personnel, who informed the masonry company responsible. A person from the company in question actually inspected the shaft, in spring 2009, stating there being no danger of collapse.

A closer inspection from our party using a ladder gave reason to presume that the heavy tiles were actually loose: fine dust could be seen blowing out of a slab`s cracks when pushed. Continuing the fitting was determined too risky. In order to stay in schedule, the Superintendent arranged a so called “emergency crew” to dismantle the higher parts of the furnace shaft masonry. The project was interrupted, and because the masonry crew could not provide an exact point of time of completing the masonry dismantling, our fitting team left Pieksämäki.

4.2.2 Execution: Fitting the Distributor Plate and Finishing

After over a day the hazardous tiles were removed and allowed the project to continue. Remains of the grate were removed with no trouble, by detaching the grate parts with the plasma cutter and hoisting the segments down one by one. The next phase was to fit the BFB grate assembly.

As a complete surprise, measuring indicated that the nozzle tube arrangement and supporting bearers overlapped, which was not the intention. Repositioning the bearers was not considered at all in the fitting planning. Further investigation revealed that all associated drawings were in fact dimensionally correct. However, the drawings lacked to literally state that the bearers require alterations.

FIGURE 10: Wind chest mechanism opened and grate bearers detached. Primary air duct and fire grate ash disposal visible

Supporting bearers consist of two main beams and six upper bearers perpendicular to the main ones. Altogether, alignment and shape of two higher bearers required alteration. Because of the wind chests round shape all four ends were reshaped. Figure 10 illustrates the upper bearers detached for improvised reshaping. The bearers were to be lengthened and suitable beam to lengthen the bearers with would have been impossible to find in the ever tightening schedule. Fortunately a redundant part of bearer (the part to be removed for the centered ash disposal) could be used in this purpose. Nevertheless, the incident caused exactly 30 man hours of additional work.

Finally, all four bearers' ends were repositioned and reshaped. The awaited moment of lifting the BFB grate parts into position could begin. A gasket tape was attached on the wind chest before hoisting the distributor halves on. Three ratchet lever hoists were placed to carry out the task in simple lift and drag manner. Figure 11 captures a rewarding moment of reaching one of the projects objectives.

FIGURE 11: The second grate half nearly in position. A gasket tape circling the wind chest is partly visible

The final phase consists of closing the wind chest and sealing it. The hinges provide a mere mechanism for moving the chest. Aligning it into final position requires multiple rounds of bolt tightening in star pattern. Fitting the ash disposal duct was fast and effortless. However, the Superintendent had us only partially install the duct, because the decision on the type of valves to be used had not been done. Refitting the parts removed from the chests path in the beginning was one of the last tasks. Additional work involved fitting heat sensor tubes.

4.3 Fitting Summary

Bearer alteration and masonry dismantling were complete surprises. Scheduling two extra days, however, made the difference. The fitting was finished just in time before the masonry company, Refrak Oy, appeared. Originally their schedule was agreed negotiable. Their crew consisted of several workers and a material lorry and it became apparent that changing their schedule is practically out of question.

Nevertheless, the problems encountered were not because of anything our party did. On the contrary, the fitting – without all the extra hours – was conducted ahead schedule, and being an example of how to deal with surprising situations and improvising successfully. The situations also led to consultations between parties. Good planning became important, since nearly all the tools mentioned in the list were in use and there was no mentionable need to resupply, but also, the tool list was not excessive.

5 CONCLUSION

5.1 Final Delivery

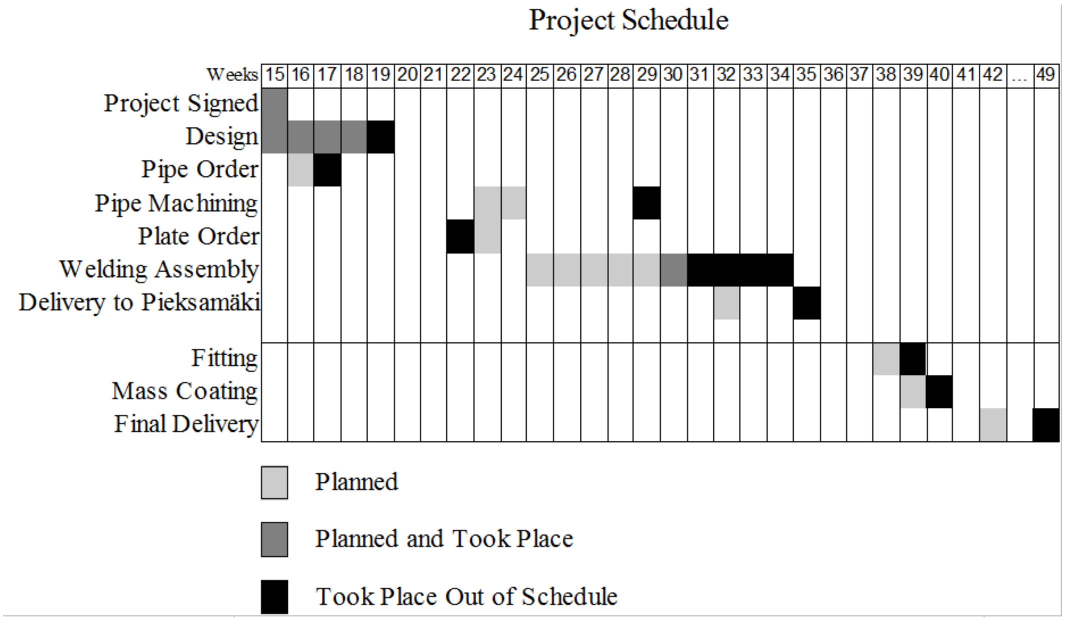
Savon Voima Oyj needed to test and approve the functionality of the distributor plate before accepting the project as delivered. Also, Savon Voima Oyj had their further modifications made (valves, heat sensors and auxiliary instruments) before first cold test runs. The bubbling abilities were tested with dry sand. The grate assembly passed this test. Usually this type of testing is sufficient to ascertain the fluidization properties of a grate, although hot bed and fuel with large particle size heavily affect the performance. The final meeting was scheduled for any time after successful testing.

Savon Voima Oyj had another appliance installed in the same revision period: a new burner system for fuel oils. The boiler needs to be heated in start-ups to 450-500°C. However, the new burner system in tests failed to do this! For this fact it was initially unclear if the installed distributor plate is performing poorly.

5.2 Schedule Comparison

The project was not conducted in a tight schedule. In fact, the project was carried without any haste. Summarizing the project by adding events to the original schedule (Table 2) illustrates the progress rather well. Obviously, schedule being an appendix of the contract, it should be expected that the schedule is also followed.

TABLE 2: Schedule comparison



As explained in earlier chapters, the designing phase turned out to be more challenging than expected. Early design propositions had to be discarded because the grate area diameter revealed to be slightly smaller than marked into original drawings. A furnace shaft masonry update had narrowed the bed diameter from 3600 millimeter to 3150 millimeter. Such change in diameter had drastic effects on the design. Redesigning caused minor delays to the schedule.

Once the design process was far enough to decide the tube material, eighteen pieces of pipe was ordered. However, only 14 pieces arrived on time. The total length was not sufficient enough to manufacture the grate. The four pieces were promised to arrive briefly. Nevertheless, none of the missing pipes were heard of, not before contacting the provider again. Eventually the parts were delivered in late July. Grate welding assembly could only be finished when all pieces arrived. This misfortune postponed the distributor plate delivery for three weeks, at least in theory.

The planned bumper before scheduled fitting came valuable for of the delays in the earlier phases. Fitting started one week behind schedule on Savon Voima

Oyj´s request. Apparently the boiler needed run for the last time with the conventional combustion method.

5.3 Performance Experiences

In an interview the Pieksämäki power plant Superintendent (Tepponen 2010) revealed how the retrofitted distribution plate had performed in the winter period after project delivery: Centering the ash disposal has made removing impurities significantly easier. The process currently uses more sand (quartz sand) then before the retrofitting, therefore controlling the combustion is more stable. Also, heavy fuel oil does not clinker the nozzles, like in the fire grate assembly. Furthermore, 30% of the maximum output is considered being the lowest output limit, at least a sensible one. The delivered distributor plate functions in 25%, thus surpassing the estimated low output.

Savon Voima Oyj is satisfied with the performance the grate assembly can deliver. The severe winter of 2010 pushed the utilization rate high. Deep evaluation about the performance cannot be made because of the lack of sufficient historical data. However, I presume it is safe to state that the basic features perform properly.

5.4 Self Assessment

The purpose of this thesis was to deliver and install a bubbling fluidized bed distributor plate to Pieksämäki power plant according to the contract. I was personally involved from signing of the contract to ending the project, which denotes a time period of eight months. Adding the effort writing this thesis took, it has been a long but interesting learning process. The project comprised of several phases and different fields of specialties which offered an interesting subject for the thesis.

Savon Voima Oyj received a well performing distributor plate as mentioned earlier. However, the process of reaching the project end in a personal level is more interesting. I have advanced on four areas while writing and working on the thesis. First and main development is on the area of the energy industry: Even though working in the energy industry earlier, writing this thesis has deepened my understanding of the energy scheme in Finland. Furthermore, power plant functions constitute a complex mixture of different branches of science. Understanding BFB combustion process requires skills on physics, mechanics and automation. Furthermore, the combustion itself is a chemical process, and, at least basic understanding of stoichiometric calculations is required.

Second field of personal development consists of understanding project management. Consultation has been crucial to the project, as discussed earlier; difficult decisions were made because of the contradictory design proposals. As a learning process, understanding project management has been successful. As a result of this thesis, I have gained comprehension of how business to business operations are practiced.

Work site management is the third area of personal development. Although the fitting phase did not involve a large organization, the same fundamentals of work site management do apply independently to organization sizes. These basics include hierarchical system of interactions and being aware of responsibilities.

By writing this thesis in English I pursue my persistent aim of mastering technical English. The task has proven to be more challenging than expected. Main difficulties in writing in English derive from the fact that Finland is one of the leading countries in BFB combustion implementations and has developed its own Finnish lexicon. While the source material was in Finnish, many of the concepts are different in English and confirming them has been time consuming. Nevertheless, developments in language skills have definitely been one of the main personal achievements during the writing of this thesis.

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