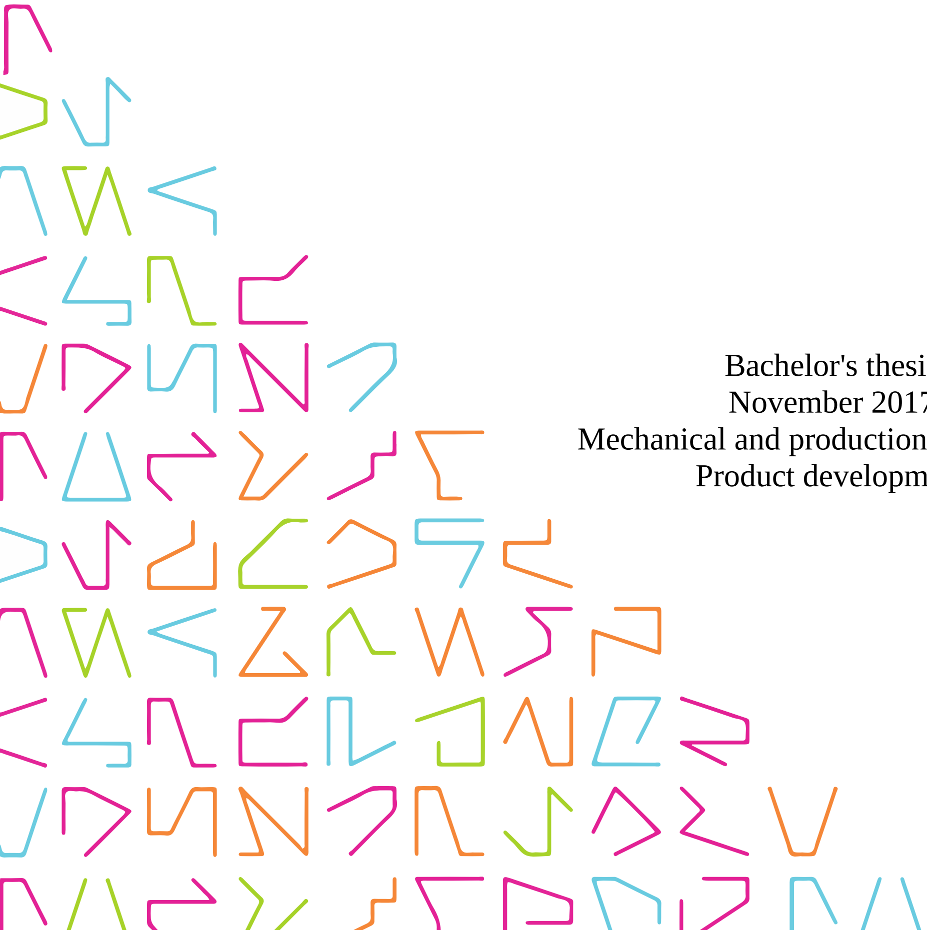
TAMPEREEN
AMMATTIKORKEAKOULU

DEVELOPMENT OF A CONTAINER TRANSPORTABLE BAG HOUSE FILTER

Veli Hakanen



Bachelor's thesis
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ABSTRACT

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Development of a Container Transportable Baghouse filter

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The purpose of this study, as commissioned by the Environmental Systems department of Valmet Technologies, was to create a concept of utilizing freight containers for transportation of baghouse filter subassemblies. The goal was to get an insight of required modifications to the design of the baghouse filter and their effects on fabrication and assembly. An estimation of efforts required for adopting the concept was done by first evaluating the scope of needed modifications to meet the size restrictions set by the dimensions of the containers. Based on the evaluation, modifications were planned to the original design of the baghouse filter and their effects on fabrication were assessed.

The planning resulted in new design solutions for the subassemblies that needed to be modified. For the casing subassembly, a re-division of the original panel design was created to meet the requirements for its size. For the module of the nozzle house, two solutions were evaluated, a panel design and a division of the module into sections, of which the section design was considered more advantageous. Finally, an evaluation of the effects on manufacturing was done, that also included feedback from the fabricating shop.

A conclusion of the process is that the container concept can be utilized within the scope of the thesis. The required modifications may affect the manufacturing costs, but the container concept may result in lower transport costs. Adopting the concept would still require more efforts, that would include further planning, production of drawings and evaluation of the rest of the bag house filter from the viewpoint of the concept. The thesis can be used for further evaluation and estimations regarding the concept.

Keywords: baghouse filter, intermodal container, development, welding

TIIVISTELMÄ

Tampereen ammattikorkeakoulu
Kone-ja tuotantotekniikka
Tuotekehitys

HAKANEN, VELI:
Kontti-kuljetettavan letkusuotimen kehitys

Opinnäytetyö 38 sivua, joista liitteitä 3 sivua
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Valmet Technologies:n ympäristöjärjestelmät-osastolle tehdyssä opinnäytetyössä tarkasteltiin konttien hyödyntämistä letkusuotimen alikokoonpanojen kuljettamisessa työmaalle. Tavoitteena oli muodostaa käsitys tarvittavien alikokoonpanoihin tehtävien muokkausten suuruudesta ja niiden vaikutuksista alikokoonpanojen valmistukseen ja kokoonpanoon. Jotta konttien kokoon perustuvat rajoitukset pystyttiin saavuttamaan, täytyi muokkaukset määrittää. Määrityksen jälkeen alikokoonpanoihin tehtäviä muokkauksia suunniteltiin ja niiden vaikutusta valmistukseen arvioitiin.

Suunnittelun tuloksena alikokoonpanoille, joiden kokoa piti muokata, saatiin uusia suunnitteluratkaisuja. Kammioiden osalta ratkaisu oli paneelirakenteen uudelleenjako ja paneelien korkeuksien muuttaminen. Suutinkammiolle arvioitiin kahta ratkaisua, jakoa paneeleihin tai osastoihin, joista osastoihin jako havaittiin paremmaksi ratkaisuksi. Lopuksi valmistajalta saatujen kommenttien tukemana selvitettiin suunniteltujen muokkausten vaikutusta alikokoonpanojen valmistukseen.

Konseptin hyödyntäminen on mahdollista opinnäytetyöhön sisältyvän laajuuden osalta. Konseptin myötä valmistuskustannukset voivat nousta, mutta kuljetuskustannukset voivat laskea. Konseptin käyttöönotto vaatii vielä lisää työtä, kuten suunnittelua, piirustusten valmistamista ja letkusuotimen muiden alikokoonpanojen läpi käymistä konseptin näkökulmasta. Opinnäytetyön tuloksia voidaan jatkossa käyttää konseptin jatkokehityksessä.

Avainsanat: letkusuodin, kontti, kehitys, hitsaus

SISÄLLYS

1 INTRODUCTION

A bag house filter is a device for removal of particles in flue gas originating from combustion of various fuels in a boiler. Bag house filter is used in a flue gas system of a power plant and is situated between a boiler and a stack. Due to its size, the bag house filter and its subassemblies require a considerable amount of space during transportation. Thus, a concept of utilizing freight containers for transportation of the bag house filter's subassemblies is assessed. This thesis is of a research and development process for Valmet Environmental Systems department regarding possibilities of the container concept and the efforts needed for the concept to be utilized.

As an outcome of the thesis project, an insight on how the container concept for the bag house filter could be implemented is provided. The goal is to have an assessment of required modifications to the design of the bag house filter and their effects on fabrication and assembly. Eventually, Valmet will have an idea of how the bag house filter's subassemblies and parts would be transported inside containers and what are the needed efforts compared to the original concept. Work is done by evaluating subassemblies individually and defining the scope of required modifications to match the restrictions set by the freight containers' dimensions. In practical part, modifications and design solutions are planned and the results are fitted inside containers.

The evaluation and modifications are limited to a bag house filter, that consists of four compartments. In addition, only plate structures of the bag house filter are concerned, as they take up more space during transportation and reducing their size would enable using containers for the transportation of the bag house filter. However, some plate structures are excluded from the thesis.

2 BACKGROUND

2.1 Valmet Corporation

Valmet is a global company, that develops and supplies technology, automation and services for pulp, paper and energy industries. Valmet has a strong market position in all its businesses, and has achieved a leading position in all its key market segments. Valmet has around 12 000 employees in 30 countries, and delivers thousands of automation systems and technology solutions and serves over 3000 customer plants and mills around the world. In 2016, Valmet's total net sales were approximately EUR 2,9 billion, and comparable EBITA margin was 6,7%. Head office is located in Espoo and Valmet's shares are listed on the Nasdaq Helsinki. Valmet's offering includes pulp mills and tissue, board and paper production lines, bioenergy producing power plants and automation and service solutions for processes. (Valmet 2017a, 6-9.)

Valmet has industrial history of over 200 years, but the Valmet of today was reborn in a demerger of Metso Corporation in 2013. Metso was demerged into two companies, Valmet and Metso, and the new company Valmet Corporation acquired Metso's Pulp, Paper and Power business. Additionally, Valmet and Metso agreed on a sale of Metso's Process Automation Systems business to Valmet in 2015, thus forming the Valmet into the company it is now. (Valmet 2017d.)

Valmet consists of four business lines: Automation, Pulp and energy, Paper and Services. Additionally, Valmet is organized into five geographical areas, that provide services, sales and project deliveries in the areas they are responsible of. These areas are EMEA (Europe, Middle-East and Africa), North America, South America, Asia Pacific and China. The business lines each provide services and products of their field:

Automation business line offers its customers automation, quality control, measurement and analyzer solutions. These can range from single measurements to mill wide process automation systems. The main customers are pulp and paper, energy production and other process industries, as well as marine and oil & gas industries.

Pulp and energy business line provides customers with entire pulp production lines, heat and power generation solutions and biomass based energy boilers. Also, biomass conversion and environmental protection systems are offered.

Paper business line offers technology for board, tissue and paper production. Valmet offers complete production lines and machine rebuilds, as well as individual machine sections and key components.

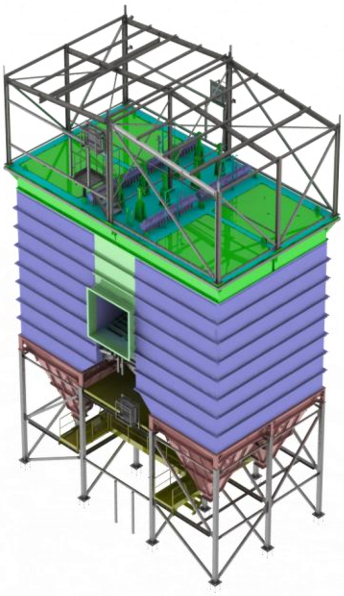
Services business line provides customers with maintenance and shut-down management, spare parts, process support and upgrades, life-cycle services and fabrics. Services are offered globally for pulp and paper mills and energy and some other process industries. (Valmet 2017a, 8; Valmet 2017b.)

2.2 GASCON™ Bag house filter

Bag house filter (BHF) offered by Valmet Technologies and designed by Environmental Systems department is a device for removal of particles in flue gas originating from combustion of various fuels. (Valmet 2017c.) Bag house filter is a solution for dry flue gas cleaning and is used as a part of a flue gas system. In a power plant, the flue gas system transfers the flue gas originating from the boiler to the stack and cleans the pollutants and particles from it. Bag house filter’s main purpose is to separate fly ash and particles from the flue gas in the flue gas system, and additionally reduce the amount of acid gas components, heavy metals, dioxins and furans in the flue gas. (Valmet 2012.)

BHF (picture 1) consists of multiple compartments, that are filled with filter bags and that can be separated and sealed from each other with inlet and outlet dampers. The filter bags are filter elements, through which the flue gas is drawn by an induced draft fan located on the clean gas side of the flue gas system, downstream of the bag house filter. The fan generates a suction pressure and gas flows through the filter bags. The untreated flue gas inside the compartments on the untreated flue gas side of the BHF flows through the bags leaving fly ash, dust and the additives on the surfaces of the filter bags. The cleaned flue gas is then led through the clean flue gas side of the BHF to the outlet and forwards through the flue gas system. The filter bags are cleaned periodically with pulses of compressed air, releasing the accumulated fly ash, dust and additives on the surfaces of the filter bags and dropping them into hoppers on the bottom of each compartment. (Valmet 2012.)

The amount of acid gas components, heavy metals, dioxins and furans in the flue gas is reduced with additives injected to the flue gas duct upstream of the bag house filter. Hydrated lime or sodium bicarbonate are added to capture sulfur oxide, hydrogen chloride and hydrogen fluoride, which are the acid gas components in flue gas. In addition, activated carbon is injected to the flue gas to reduce the amount of heavy metals and dioxin emitted in the flue gas. Pollutants and the additives react inside the flue gas ducts and continue the process on the surface of the filter bags. (Valmet 2012.)



PICTURE 1. Bag house filter is used for dry flue gas cleaning.

2.3 Container concept

During the development of the GASCON BHF a possibility of a container-transportable solution was considered, but was not developed further. The purpose of this thesis is to assess the option of using containers for transportation of the BHF and define the efforts needed for the concept to be utilized.

Regarding the practical part and evaluation done as part of the thesis, only a four-compartment bag house filter will be examined. Multiple four-compartment bag house filters have been built by Valmet and due to BHF’s modular structure the same design solutions may practically be adapted directly to six and eight compartment filters as well.

The BHF is made of multiple subassemblies, that are steel beam and plate structures. Parts of the subassemblies are fabricated in a machine shop before transportation to the site where the bag house filter will be built. The main subassemblies are assembled on the pre-assembly area near the site the BHF will be erected on. Bag house filter is a rather big construction, over 20 meters high and 13 meters wide, and its subassemblies, and their parts as well, also take up quite a lot of space. Regarding the transportation of the bag house filter from the fabrication facilities to the construction site, the most space is required by the parts of the plate structure subassemblies, for example the casing of the compartments and the nozzle house. Reducing the sizes of the parts would enable transporting them in freight containers. As the plate structures of the BHF require a lot more transportation space than the beam structures, this thesis will only cover the plate structures of the BHF.

2.3.1 Containers and break bulk

By far, the subassemblies of the BHF have been transported to the construction site as break bulk cargo. Break bulk cargo is defined as conventional, uncontainerized cargo shipped in packages or units such as pallets, or in units of one (Hinkelman 2009, 26). Break bulk is often transported on a skid or a pallet and is generally used as a shipping method for cargo that is oversized or too heavy for containers, e.g. oversized vehicles, manufacturing materials and construction equipment (Crowley 2017). With the concept, containers would be used instead of break bulk and for this purpose, the globally used ISO-standardized containers are a valid option. Using containers for transportation has multiple benefits, that could be utilized regarding the transportation of the BHF as well.

Intermodal ISO-containers’ advantage is that they can be manipulated anywhere in the world with multiple modes of transport, practically covering the whole transport chain. Having the deliverables loaded into one transport unit for their whole journey, without needing to handle, unload and reload them between modes of transport, saves time and reduces risk of damaging the cargo. The intermodal containers enable combining of transportation modes and finding less costly alternatives than unimodal transportation solutions. (Rodrigue 2017)

Compared to container transport, the break bulk is more labor-intensive, and loading and unloading of the cargo between transport modes is time-consuming. (Searates 2017) The increased handling also increases costs. In addition, break bulk requires additional equipment and shipping times are longer. Break bulk shipments also have higher risk of damage, spoilage and risk of theft. (Precision Project Cargo Shipping Inc. 2016)

Freight containers are practically independent warehouses, that can help preserve the condition of the deliverables. Containers are resistant to shocks and weather conditions, and therefore provide good shelter for the parts during transportation and until they are unloaded for assembly at the pre-assembly site. (Rodrigue 2017; IMO, ILO, UNECE 2014, 1) Use of standardized ISO-containers allows for more precise planning and common ground for all the parties to work on. For example, the dimensions of the containers are predefined which makes it possible to take them into consideration in the practical design work regarding this thesis.

2.3.2 Goals

The goal of the thesis project is to provide an insight on how the container concept for the BHF could be implemented and what are the required modifications and actions to be done. Restrictions and modifications to the design of the bag house filter are to be evaluated, and changes to the fabrication and assembly work are assessed. As a result, Valmet should have an idea of how the parts of the BHF could be transported inside containers and an estimation of the work to be done at the fabrication facilities and at the pre-assembly area, compared to the original concept.

3 THEORY

3.1 Intermodal containers

Freight containers (picture 2) are large articles of transport equipment, into which cargo is packed for transportation and which are of permanent character and suitable for repeatable use (SFS-ISO 668 1980). Freight containers, that comply with the container standards established by the International Organization for Standardization (ISO) are referred to as ISO containers. On this thesis, only ISO containers are observed and evaluated.

The ISO-standardized freight containers originate back to the 1961, when a technical committee on Freight Container Dimensions (ISO TC 104) was installed by International Organization for Standardization, initiated by the US. The committee created a draft which determined the dimensions and weights for four types of containers, that were eventually presented in the standard ISO 668 in the 1970s. (Ham, Rijsenbrij 2012, 42, 46)

PICTURE 2. A 40’ standard freight container (MSC 2017a)

3.1.1 Specifications

Size and design of containers has been standardized to a far extent. ISO standards regarding containers define dimensions and design for various types of containers, of which dry cargo containers, also referred to as standard containers, are the most common. 20 foot (6,09m) and 40 foot (12,18m) long and 8 ft 6 in high containers are the most important and the most used container sizes. Cargo volume and vessel capacity is commonly measured in Twenty-foot Equivalent Units (TEU), but since the 40-foot long containers form the majority of the global container fleet today, Forty-foot Equivalent Unit (FEU) is also used. (World Shipping Council 2017)

A 40-foot container, “High cube”, which is one foot taller than the standard 40-foot container has steadily increased its proportion of the world container fleet after it was introduced in the 80s. Approximately 85 percent of the world container fleet is formed by these three container types. (CSI 2014)

According to Ham and Rijsenbrij (2012, 46), the most important ISO standards for freight containers are:

- ISO 668 Series 1 Freight Containers - Classification, Dimensions and Ratings;
- ISO 830 Freight Containers-Terminology;
- ISO 1161 Series 1 Freight Containers - Corner fittings, Specifications;
- ISO 1496 Series 1 Freight Containers - Specification and Testing;
- ISO 3874 Series 1 Freight Containers - Handling and Securing;
- ISO 6346 Freight Containers - Coding Identification and Marking;
- ISO 9711 Freight Containers - Information related to containers on board vessels;
- ISO 9897 Freight Containers - Container Equipment Data Interchange;
- ISO 10374 Freight Containers - Automatic Identification,

of which ISO 668 and ISO 1496 contain required specifications for the container concept.

ISO 668 standard classifies series 1 containers based on external dimensions and standardizes their weight and size specifications. Rating, i.e. gross mass of a container, for each type of container is also specified in the standard. (SFS-ISO 668 1980)
ISO 1496 standard includes basic specifications and testing requirements for series 1 general purpose containers and certain special purpose types. (SFS-ISO 1496/1 1989)

3.2 Container sizes and restrictions

Based on the sizes of the original parts and subassemblies of the bag house filter, a 40-foot ISO container is going to be evaluated for the container concept as a default. The 20-foot long ISO container is not long enough for the longest parts to fit in, thus making the use of the longer container a better basis for the development of the concept, since less modification of the existing parts would be needed. According to ISO 668, the designations for the ISO 40-foot 8’ 6’’and 40-foot “High cube” containers are 1AA and 1AAA, where 1AA is the designation for a 2438 mm (8 ft 6 in) high and 1AAA for a 2591 mm (9 ft 6 in) high container.

3.2.1 Dimensions

The external dimensions and the tolerances of the ISO containers have been standardized and are specified in standard ISO 668, and the classification on the standard provides provisions on which the internal dimensions of the containers are based on. ISO 1496 is the authoritative standard for the internal dimensions of the ISO containers. ISO 1496 states that internal dimensions of the containers shall be as large as possible, but must comply with the minimum requirements set for the length, width and height set by the standard (SFS-ISO 1496/1 1989). These dimensions are given on a table for each container designation (table 1).

TABLE 1. Internal dimensions of the series 1 containers based ISO 1496. (SFS-ISO 1496/1 1989, edited)

Freight container designation	Minimum height	Minimum width	Minimum length
		mm	mm
1 AA	Nominal container external height minus 241 mm	2330	11998
1 AAA		2330	11998

As is seen on table 1, the minimum internal dimensions of container designations 1AA and 1AAA, i.e. 40’ and 40’ HC containers, are 11998 mm for internal length and 2330 for internal width. Minimum internal height is based on nominal external heights of the containers, which are found on standard ISO 668. On table 2 are defined the designation specific external dimensions for 40-foot long containers, as per the ISO 668. Consequently, based on tables 1 and 2 the minimum internal dimensions for 1AA and 1AAA are 11998 mm for length, 2330 mm for width and 2591 mm - 241 mm=2350 mm for height of 1AA and 2896 mm – 241 mm=2655 mm for 1AAA.

TABLE 2. Table for external dimensions and ratings for series 1 container Designations 1AA and 1AAA as per ISO 668. (SFS-ISO 668 1980, edited)

Freight container designation	Length, *L*		Width, *W*		Height, *H*		Rating, *R* (gross mass)
	mm	tol.	mm	tol.	mm	tol.	kg
1AA	12192	0 -10	2438	0 -5	2591	0 -5	30480
1AAA	12192	0 -10	2438	0 -5	2896	0 -5	30480

The internal dimensions of the containers used for the transportation of the bag house filter basically define the restrictions of the space available, but from the aspect of practical use of the container, fluent loading and unloading of the parts should also be considered. Regarding the loading procedure, the door opening of the container may restrict the utilization of the whole transverse cross-section of the container if the door opening is smaller than the internal cross-section. ISO 1496 also specifies the dimensions for the door opening of containers. The standard states that door opening shall be as large as possible, and preferably equal in size with the cross-section of the container, yet not less than 2286 mm wide and 2261 mm high for 1AA and 2566 mm for 1AAA. (SFS-ISO 1496/1 1989) However, browsing on door opening dimensions for containers of some major shipping service providers reveals that the actual dimensions on available standard dry freight containers tend to be closer to the internal height and width of the containers rather than the minimum sizes set by the standard. For example:

- **A.P. Moller–Maersk Group**: Height 2274 mm, Hi Cube height 2577 mm and width 2340 mm (Maersk Line 2017)
- **Mediterranean Shipping Company S.A. (MSC)**: Height 2280 mm, Hi Cube height 2585 mm and width 2340 mm (MSC 2017b)
- **CMA CGN Group**: Height 2280 mm, Hi Cube height 2585 mm and width 2340 mm (CMA-CGM 2017)
- **COSCO**: Height 2280 mm, Hi Cube height 2585 mm and width 2340 mm (COSCO Shipping 2017)

With the dimensions given on the table 1 and the minimum door opening dimensions, cross-sectional space available for the parts of the bag house filter can be estimated. The vertical and horizontal space taken up by the rack the parts of the bag house filter will be transported on should be subtracted from the available cross-sectional space. In addition, vertical space needed for the lifting of the rack during loading of the container should be estimated and subtracted from the estimation for available horizontal space, as well as some clearance as room for maneuver.

The vertical and horizontal space required by the rack depends on its final design, materials and dimensions, but an estimation can be made to be used as a basis. A space of 100 mm on each side could be reserved for a beam structure the rack will consist of. Subtracting the estimations for vertical and horizontal space reserved for the rack structure from the minimum door opening dimensions and leaving some clearance for lifting, a free cross-sectional area of about 2 m by 2 m would be a rather safe estimation for a 1AA container. As with a 1AAA container there is about 300 mm more horizontal space, approximately a 2 m wide and 2,3 m high space is free for the parts to be placed in.

Lengths of individual parts of the bag house filter don’t set any restrictions, since 40-foot-long container’s internal length is about 12 meters and the longest parts in a four-compartment filter are about 7 meters long. However, loading of containers may be concerned beforehand to ease usage of all the available transport space and to minimize the number of containers needed.

3.2.2 Loads

Ratings for the ISO containers are given in the standard ISO 668. Rating is the gross mass and the maximum mass for operation of a container. Rating of each container type in part determines the maximum payload one can load into a container. Maximum payload is often indicated on containers, but it can be calculated by subtracting the tare of a container from its rating (GDV 2017). Tare is the mass of an empty container, and for a 40’ container it can be from 2800 kg to 4000 kg and for a High cube 3900-4200 kg (Universal Cargo 2016).

Regarding the container concept, the potential maximum payload is of interest since it should be evaluated whether or not it is setting restrictions on fitting the subassemblies inside the containers. Ratings for container designations 1AA and 1AAA are found on table 2. The rating for 1AA and 1AAA containers is 30480 kg, and with a tare of about 4000 kg one gets a maximum payload of about 26500 kg for a 1AA and about 26200 kg for a 1AAA container. These estimations of maximum payload can be used for reference when observing if the combined mass of the subassemblies loaded inside the containers is close to the maximum allowed mass.

3.3 Stowage of the bag house filter

A number of guides and codes of practice exist for stowage of cargo, that describe the secure loading of cargo inside containers and requirements for stowage of goods (FTA 2017). This thesis will not go into detail regarding the subject, but they can be regarded as guidance when observing the loading of the containers. IMO/ILO/UNECE Code of Practice for Packing of Cargo Transport Units (CTU) gives advice on safe packing of cargo transport units, including containers. On Annex 7 of the publication, Packing and securing cargo into CTUs, are several guidelines that should be taken into consideration, especially following:

- The mass of the loaded cargo must not exceed the payload limit of the container
- Maximum payload of the container is to be distributed homogenously on the entire loading floor
- Centre of gravity should be close to half the width of the container in transverse direction and below half of the height vertically.

(IMO&ILO&UNECE 2014, Annex 7)

Stowage of the bag house filter’s subassemblies and parts they consist of will be done by loading the entities on a rack specifically designed for this purpose. The rack should be designed to restrain movement of the loaded parts during transportation, distribute the weight of the cargo evenly on the container floor and allow simple loading and unloading of the cargo. The payload ought to be distributed over the container floor via transverse and longitudinal beams of the rack, that would also be supporting the parts from beneath while loading the rack into a container. By placing plate assemblies, like panels, as flat as possible on the rack, it will be easier to ensure the centre of gravity of the load is as low as possible, and the weight will be more evenly distributed.

By using racks for stowing the parts of the BHF, the cargo can be restrained on the rack prior to loading, thus making it easier to ensure proper fastening and making it possible to avoid manipulation of bulky parts inside the container with little excess space. Standard containers have door openings in one end of the container, through which the rack is to be loaded. Regarding the loading procedure in practice, one solution of loading could include equipping the rack with wheels in one end and lifting from the other, while pushing the rack inside into a container. However, detailed design of the rack and planning of the stowing procedure are not included in this thesis.

3.4 Welding

Welding is a fundamental method of joining parts, and is also used in assembly and fabrication of the bag house filter. The subassemblies are assembled by welding and the subassemblies are welded together to construct and erect the bag house filter. Along with the modifications to the design of the BHF, also their impact on welding and welding costs will be assessed.

3.4.1 Welding costs

Welding process is usually chosen based on cost and technical terms. Technical limitations of particular welding methods can be e.g. the type of material, material’s thickness and welding position. In addition, some limitations may be set by, for example, work environment, production resources and special quality requirements. Consequently, the general factor of choosing a welding process is its cost. Traditionally four things are regarded when estimating the cost of a welding procedure. These are consumables, labour, equipment and energy. (Weman 2003, 184)

For welding cost estimation, multiple concepts are used, including deposition rate, deposition efficiency, job time, etc. Welding costs include welding consumable cost, machine cost, energy cost and labour cost. On this thesis, the focus is on things that can be manipulated via design choices, as multiple factors are decided and evaluated by the fabricating party, that is also affected by many of the restrictions. Thus, the labour cost will be observed further. (Weman 2003, 184-187)

Labour cost is a product of operation time and hourly cost. The first one can be influenced, the latter is made up of direct wages and other costs to the welder’s employer. Operation time is part of job time, which is time taken by an execution of a particular welding job. Job time consists of setting-up time and operation time. As its name suggests, setting-up time is the time used for setting up the welding work and starting the work. Operation time is the time taken by welding, including:

- **Arc time**, during which the arc is struck
- **Additional time**, time directly related to welding, including replacement of filler wire/ electrode, gas nozzle cleaning and slag chipping
- **Handling time**, which includes weld preparation, tack welds and handling workpieces
- **Contingency allowance**, time not directly linked to welding.
  (Weman 2003, 185-186)

As the operation time is made up of the time taken up by completion of different parts of the work described above, reducing some or any of them would eventually decrease the labour cost.

Klas Weman (Weman 2003, 188-189) introduces methods of reducing welding costs in his book Welding Processes Handbook. According to him, costs are influenced right from the design stage to the production by multiple factors. Labour cost is the biggest cost in manual welding, and can be reduced by affecting the total job time. The methods to reduce the job time valid for the scope of this thesis include various things. Only about 30% of the work time is productive arc time, so proper planning of the work may save time. Equipment to manipulate and hold the welded pieces can be used to achieve better welding positions. Replacing welded structures with bended parts can reduce the amount of welding.

3.4.2 MIG/MAG and MMA welding

Regarding the fabrication and assembly of a BHF, two welding methods are covered briefly: MIG/MAG (Metal Inert/Active Gas) and MMA (Manual Metal Arc) welding or

Shield Metal Arc Welding (SMAW), or simply stick electrode welding. Some of their characteristics are introduced for the purpose of providing background for the thesis.

MIG/MAG is the most used welding method in developed industrial countries. MIG/MAG welding includes an arc between a workpiece and the wire electrode, that is fed continually through a hose and a gun and melted. The arc and the weld pool are shielded by a shielding gas also supplied through the gun. Due to the need of shielding gas the method is not very suitable for outdoor use due to the wind. (Weman 2003, 41)

Equipment for stick electrode welding is simple, and the method is straightforward. Welding process includes striking an arc between the workpiece and the electrode, that melts the electrode which is also a filler material and a protective slag is formed from the coating of the electrode. The method doesn’t require shielding gas, and thus is not affected by wind. Consequently, stick electrode welding can be performed outdoors and is good for erection of structures. However, changing of the consumed electrodes and removal of slag decrease the arc time. (Weman 2003, 63)

4 PRACTICAL PART

4.1 Evaluation of original subassemblies

To utilize containers in transporting the bag house filter parts, it should be made possible to fit the filter inside containers. As the restrictions set by the dimensions of the containers have been defined, evaluation can be done to see how the original parts and subassemblies fit inside these boundaries and what is the scale of required modifications.

Evaluation was started by creating a table, on which the dimensions and weights of all the plate structure subassemblies and parts of a four-compartment bag house filter were added. Table was formed by importing Bill of Materials of the subassemblies from CAD-models to an Excel sheet, and adding columns for the widths, heights and lengths measured by hand from the CAD-models of each individual subassembly and part. The measured dimensions were compared to the boundary values defined earlier based on the internal dimensions of the standard ISO-containers. Thus, an insight was perceived on how many subassemblies or parts would not fit inside the required dimensions set by the container. The table for the subassemblies, their parts and their sizes can be seen on appendix 1.

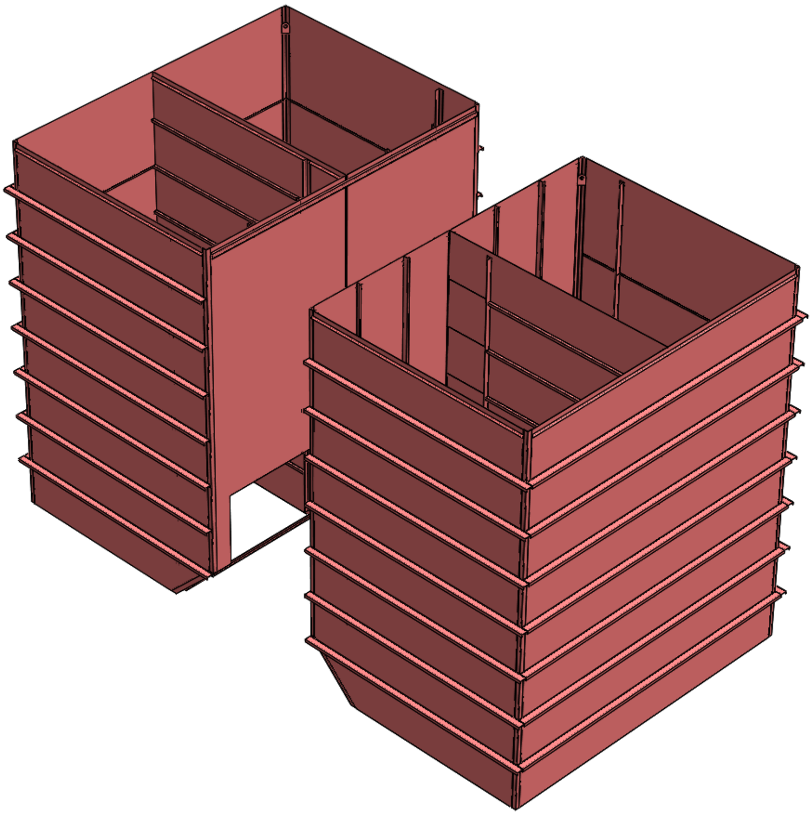
The largest plate structures of the BHF are the casing of the compartments and the nozzle house. Casing is welded together of panels, which are several meters in height and length. Nozzle house consists of four nozzle house modules, one for each compartment, and additional accessories. According to the table that includes the sizes of the subassemblies (appendix 1), the most modifications would be needed for the casing, nozzle house and the outlet duct subassemblies. Casing counted for 13 panels that exceeded the predefined limits for their size. Nozzle house’s modules are also going to have to be divided into smaller subassemblies. Duct consists of multiple panels, that are too big to fit inside a standard container, and thus need to be resized.

4.2 Modification of the bag house filter

Based on the information gathered on evaluation of the dimensions of the subassemblies, the entities to be modified could be pointed out and the actual modification could be started. The main subassemblies to be modified, casing, outlet duct and nozzle house, could be edited individually as their interfaces with the other subassemblies should remain unchanged.

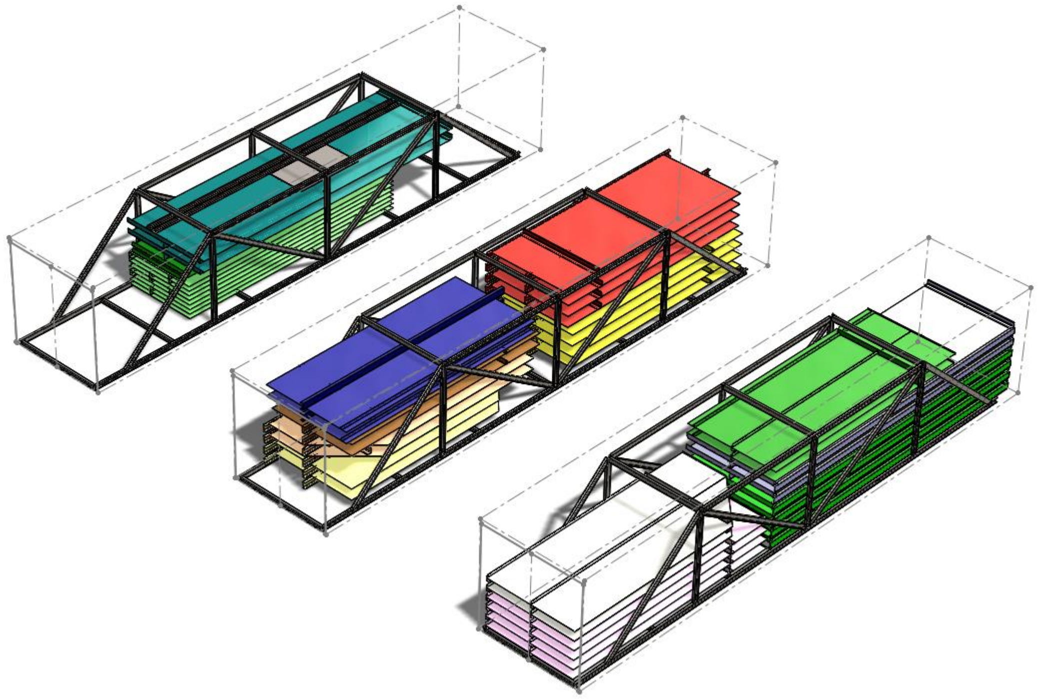
4.2.1 Casing

The casing of the BHF is made of multiple panels, welded together to form the four compartments. Each panel has an appointed position in the assembly and is designed to fit in its place among the other panels. The panels are steel plates with U-beam stiffeners welded on them to support the structure and resist the suction pressure inside the compartments. The four-compartment-casing is composed of two two-compartment halves, that are practically the same, but are facing each other as mirrored reflections. For a BHF with four eight-meter-high compartments the panels basically form three rows of panels on top of each other, forming a box that is the casing (picture 3). The top row of panels, forming the top of the casing, is about 2 meters high, a size that should still fit inside a container. The two lower rows, forming the middle and the bottom of the casing, include panels that are about three meters high, a height too big for containers. Additionally, four long panels facing the duct that is located between the two halves of the casing, in the middle of the BHF, are too wide for containers. These panels can be seen highlighted under Casing 4C-8L on the table in appendix 1.



PICTURE 3. Casing of a four-compartment BHF.

Having the predefined size limits of 2 m by 2 m for the modified subassemblies, the three-meter-high panels were chosen to be modified into panels that are only two meters high. To replace the 2 meters of plate gone due to the reduction of the height, the middle row of plates could be replicated and added to the middle to form a fourth row of panels, having the combined height of the panels still total to eight meters. In practice, the plates that together with the stiffeners form the panels, were simply made about 1 meter narrower, depending on the panel. Along with the plates, the stiffeners were also modified so that the interfaces between panels remained the same regardless of the modifications. The four panels facing the middle of the BHF can be changed to be made of two separate panels each, welded together at the pre-assembly area. An illustration of the panels before and after the modification can be seen on appendix 2. In picture 4 is a visualization of the modified panels inside 40-foot-containers.



PICTURE 4. Representation of panels of a four-compartment BHF casing loaded inside 40’ containers.

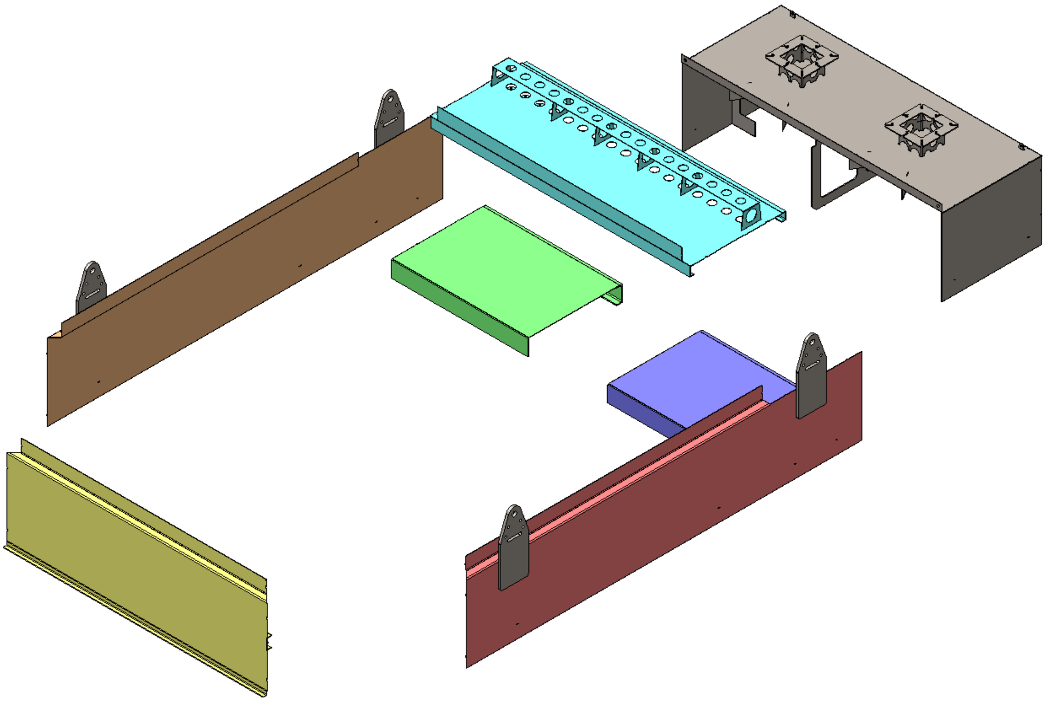
4.2.2 Nozzle house

At first, regarding the size restrictions set by the containers, the nozzle house proved to be a rather problematic subassembly for modifications. It seemed that external dimensions of the modules of the nozzle house and the base design effectively prevent putting the whole space of the container to use unless major modifications are planned. As the width of a module is more than 3 meters and the height more than a meter, dividing the modules into pieces that could be stacked on top of each other or next to each other inside the container could be challenging.

The module consists of a damper module including outlet dampers for the compartment, piping for the filter bags cleaning, an opening for a top hatch and support for the filter bags. Each module has a hatch on top of it, that grants entry inside the nozzle house module and enables maintenance work. These hatches are over three meters wide and long, and reducing their size to be container-compatible is not a simple task, since they include insulation and seals to close off the compartments. The hatches are not included within the scope of the thesis. The outlet damper section, which in the original design is fabricated separately and attached to the module, will still be transported independently and welded to the module at the pre-assembly area.

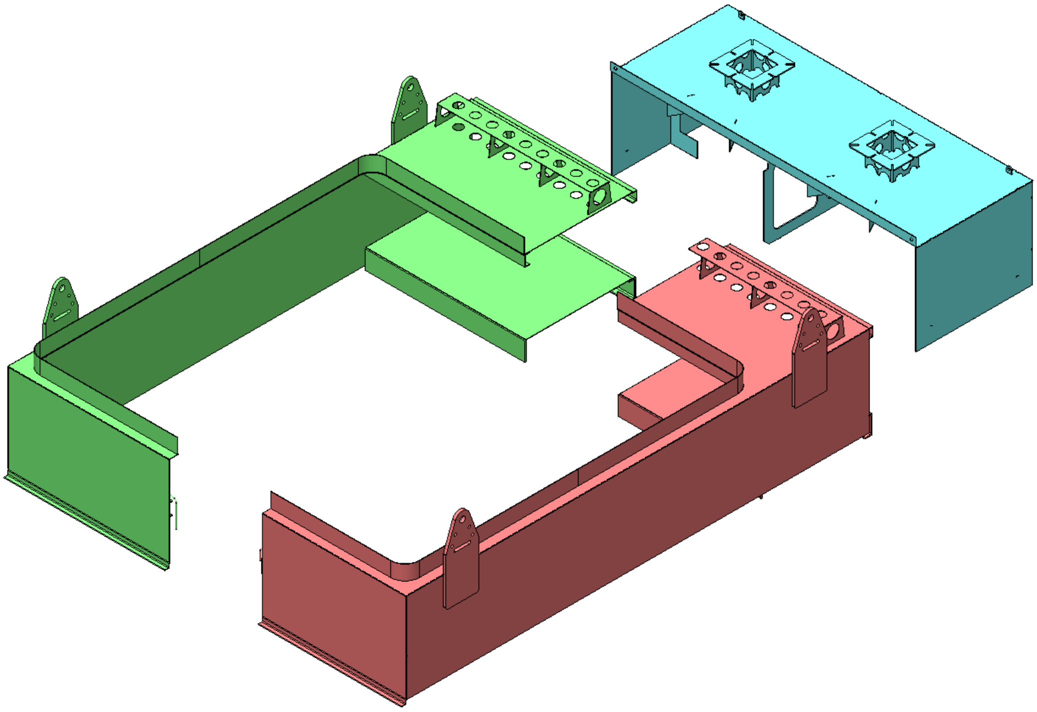
Two options for the nozzle house module to be fitted in a container were come up with: dividing the module into three container compatible sections (one of which is the damper module) or breaking the module down into panels that will be assembled at the pre-assembly area to form the module.

The panel design of the module would still have the damper module attached to it, but the remainder would be broken down into panels, that would fit inside a container. The panels would take up less space during transportation, but still include everything that is needed for the module when the module is assembled. Base design for the panels of the module can be seen in picture 5. Breaking the module down into panels is based on the original design of the module. The original module is basically a box, having its sides, top and its end made of straight plates.



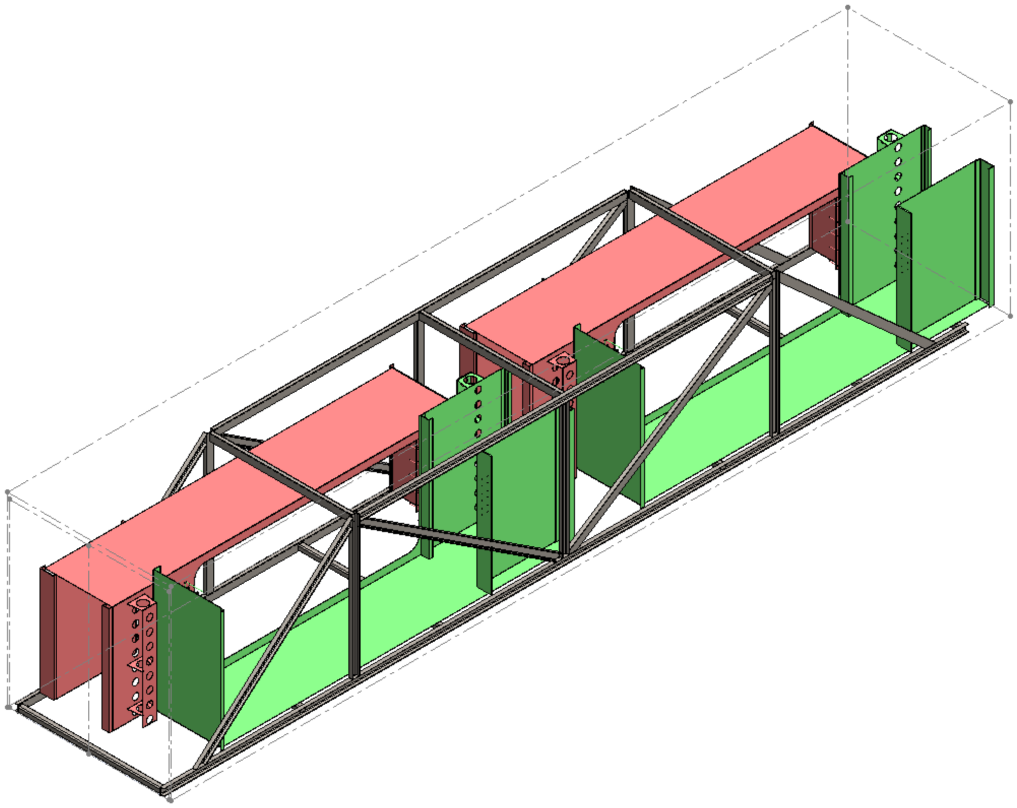
PICTURE 5. Nozzle house module was broken down into panels, that would be joined together at the pre-assembly area. Filter bags support and the pipes for bag cleaning are not visible, hatch edge details are not included.

The three-section-module would have the damper module at the end of it, and the rest of the module would be divided into two sections lengthwise. Dividing the remainder means that some original parts are “cut-in-half”, forming two individual halves of the module that would be transported separately and attached together in pre-assembly phase. The modifications regarding the forming of two halves are directed towards the top parts of the module, the edge of the hatch, the supports for the piping, and the filter bags support. The two halves would need to be modified to be easily connected at the pre-assembly area. The principle can be seen in picture 6, which however lacks the details and the modifications for better connectivity.



PICTURE 6. Nozzle house module was divided into three sections, that would be joined together at the pre-assembly area. Filter bags support, hatch edge details and the pipes for bag cleaning are not visible.

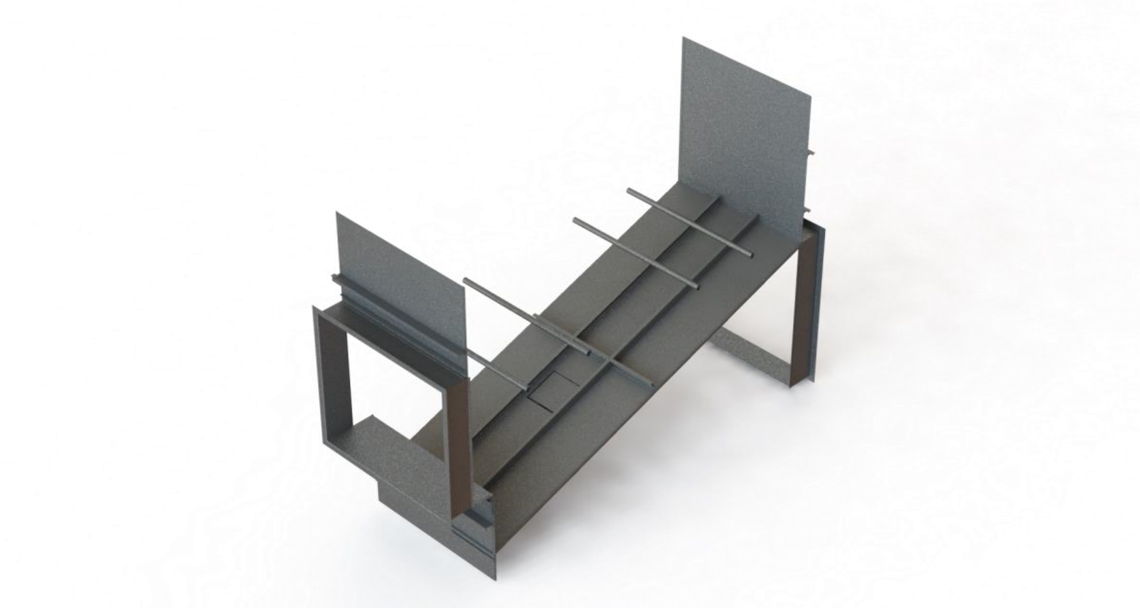
Regarding the issue of stacking the sections inside a container, an option of making the whole module flatter or attaching some of the parts after the transportation was evaluated. By shifting the welding of the hatch edge to the preassembly area, the module would lose 200 mm of its height along most of its length prior to the preassembly, thus making the module flatter, excluding end with the pipes and their support. This would enable placing two sections of the module on their sides next to each other inside a container. The hatch edge is the vertical flange around the top opening covering most of the topside of the module, which can be seen in the picture 6. Consequently, the piping on top of the module would make up the most of the height for the sections, yet overlapping the sections longitudinally will make up enough space to still fit two sections side by side, see picture 7.



PICTURE 7. Illustration of sections of a nozzle house's module inside a 40-foot container, without the hatch edges.

4.2.3 Duct

The parts and subassemblies of the outlet and inlet duct structure between the casing compartments that need to be resized include the flanges for flue gas duct connection on inlet and outlet sides of the BHF, a panel that separates the untreated flue gas side and the clean gas side inside the duct and two panels that form the outside walls of the duct. However, the sizes of these wall panels may vary, and need to be checked BHF-specifically. The modifications of the panels can be completed in a same manner as the ones for casing panels. The panels are steel plates with U-beam stiffeners, so the plates can be separated into pieces that fit inside a container, and are welded together after transportation. The inclined panel in the middle of the duct (between the duct flanges in the picture 8) is to be divided into two parts lengthwise, as the duct is wider than the space inside a container. The plates should be made so as to make it as practical and fluent as possible to join the parts at the pre-assembly site. The flanges of the ducts can also be assembled after transportation instead of at the fabrication shop.



PICTURE 8. Duct subassembly

4.3 Effects on manufacturing

As an insight on modifications required for the implementation of the container concept had been assumed, an evaluation of their effects on fabrication was to be done. From the aspect of the concept the too large subassemblies and their parts were made smaller. Consequently, the bag house filter will be transported to the construction site in smaller pieces, which means there is a shift of welding work from the fabrication facilities to the pre-assembly area at the site for the sake of more fluent transportation. Additionally, the modifications presented previously require changes in some of the work performed at the fabrication facilities as well.

The concept was introduced to the fabrication shop. Comments on the concept received from the shop provided a new aspect and were considered, and eventually led to some re-evaluations on the modified parts.

4.3.1 Casing

Modification of the panels of the casing naturally also affects the fabrication. As the casing panel structure was changed to consist of four vertical two meter panels instead of three panels, extra joints between panels were created. Thus, the modification increases the amount of welding with numerous new welded joints to be done at the pre-assembly site. However, making some of the panels one meter narrower could potentially decrease the amount of welding at the shop. Based on the modified structure, the amount of the welding work was estimated.

As the fourth panel is added on each of the outward sides and the middle walls between the compartments, the combined length of the new weld joints for one two-compartment half of the casing equals to the circumference of the two compartments with the middle panel length added to it, but excluding the panels facing the center of the BHF. To include all four compartments this length is then doubled. Additionally, the four panels facing the duct between the two halves of the casing are divided into two plates, and their combined length is to be added to the total length of the new weld joints as well. However, being as wide as over three meters in the original design, these panels are already made of multiple plates, yet the welding is going to be done at the site instead of the fabrication shop. The casing is a gas-tight construction, and its outer panels are connected with continuous fillet welds from the inside and with an intermittent fillet weld on the outside. A combination of intermittent fillet welds and butt welds is used with the other panels.

With the assessment described above an estimation of the theoretical increase in weld joints was perceived. The fabrication shop was asked to comment the modified panel design, and new factors that affect the implementation of the design were introduced. Based on the comments from the fabrication shop, the increase in the amount of welding work could be higher or the impact on the manufacturing costs would be bigger than expected. Factors affecting the welding and the price are steel sheet widths used by the fabrication facilities and availability of different widths for the shop.

The width of a steel plate affects its price. According to a steel supplier, there are less steel manufacturers, that produce 2000 mm wide steel strips compared to the more common width of 1500 mm. In addition, the leveling procedure might be harder for a wider steel strip. Thus, in Western Europe, the difference in price between these widths could be about 3%. The availability of 1500 mm wide steel strip is better and 1500 mm wide strip, produced in, for example, Russia, can be 5-10% cheaper than 2000 mm wide strip from Western Europe.

The plates used for the fabrication of the panels should be about 2000 mm wide. Thus, to prevent excess welding when creating the panels, instead of joining multiple narrower plates the panels should be formed of 2000 mm wide steel plates. When fabricating the three-meter-high panels of the original design, two steel plates were joined to form the panel. By having to do the same with the panels of the modified design, the advantages of adopting the two-meter-panels would not be as great as possible, only resulting to increase welding costs with the added field welds in addition to the same amount of welding work still performed at the shop.

4.3.2 Nozzle house

Two design options for the nozzle house module were come up with, the panel design and dividing the module into sections. The effects of the changes in the design on manufacturing were assessed. Both designs were assessed separately.

Although the panel design takes up less space during transportation, it has its drawbacks regarding the fabrication. Based on the comments received from the fabrication shop, some problems might arise in the pre-assembly phase. The welding process and the end result’s quality could be an issue if the nozzle house is assembled completely at the pre-assembly area, especially considering the support for filter bags (not visible in the thesis). Managing the deformations related to the welding and supporting the assembly is easier at the shop. Additionally, the amount of welding shifted from the fabrication shop to the preassembly site was considered to be impractically large.

Regarding the sections-design for the nozzle house, the effects on construction are emphasized on the connecting of the two “halves” of the module at the preassembly area. The most critical part is connecting the bag support, divided lengthwise after the two module sections. However, having been constructed from two pieces originally as well, it should be possible to weld the support properly at the pre-assembly area along with the sections. As the module will be transported in multiple sections, that originally would form a rigid box structure, some additional supports to maintain the shape and prevent twisting of the sections during lifting and transportation should be added to the sections. Adding vertical supports between the top and bottom plates of the module, that would be removed after transportation, would decrease the risk of the structure flattening or deforming during its handling.

In general, the connecting of the module sections after transportation increases the amount of welding and more of it happens in the pre-assembly phase and outside of the shop. This may potentially increase costs related to the welding process. These costs may, however, be decreased in the design phase by designing the interfaces of the module sections to be easily located and aligned at the pre-assembly area to minimize the time that preparation work and welding are going to take. The amount of increase in welding can be estimated by acknowledging that the module sections are to be welded around the module, gas tight: along the bottom and the top of the module longitudinally, and vertically across the end facing outwards of the BHF.

Manufacturer provided its insight on assembling the module. Decreasing the height of the module to fit more sections inside a container is possible by not having the hatch edge of the module welded in its place prior to transport but at the pre-assembly area. To assure the hatch edge and the module sections can be aligned properly and assembled according to requirements, the hatch edge, divided into two sections for transport, could be tack welded in its place on the module sections before connecting the module halves, and adjusted accordingly before final welding.

4.3.3 Duct

As stated previously, the duct and its modifications would need to be evaluated BHF-specifically. However, the inclined panel that divides the duct extends from the inlet to the outlet and is going to be welded together at the site. The assembly of the almost 7-meter-long panel requires additional long site welds.

4.3.4 Welding of the bag house filter

Assembling the modified design for bag house filter introduces an increased amount of site welding as described previously, as some of the welding previously done in the fabrication shop would be performed in the pre-assembly area instead. During discussion with the fabrication shop, multiple matters were pointed out. MIG/MAG is used for fabrication of the bag house filter. The MIG/MAG welding method is more efficient inside the fabrication facilities, but the pre-assembly and erection are done outside and due to the environment and wind, stick electrode welding is used.

The site welding has its drawbacks compared to the welding executed at the shop. Especially, the site welding at the pre-assembly area is slower, and the labour cost including job time is the major factor in welding costs. The stick electrode welding has a smaller arc time and an increased amount of additional time taken up by slag chipping and changing of electrodes. Additionally, the shop has cranes and equipment for handling of the workpieces and parts that don’t exist at the pre-assembly area. Consequently, possibly more time is going to be spent maneuvering the parts during pre-assembly, and in general, more time is required for building platforms for welding, gathering the right pieces for the task at hand, lifting of the parts etc. Yet, comparing the assembly of the original design and the modified one, the main difference will be the new weld joints discussed above, that will be done at the site instead of the shop. An illustration of the new welded joints in the casing and the nozzle house can be seen on appendix 3.

5 RESULTS

The basis for the evaluation of the container concept acquired through research and gathering of background information included the restrictions set by the freight containers. By defining the limits the dimensions of the ISO-containers set, it was possible to establish an approximation of the subassemblies affected and the scope of the modifications required. The about 2 meters wide and from 2 to 2,3 meters high available cross-sectional space inside containers was then used as a basis for the modifications, that were planned to fit the subassemblies inside the defined boundaries. After the dimensions of the subassemblies were checked and the subassemblies that were to be modified (casing, nozzle house and duct) were chosen, the subassemblies were evaluated and a process of finding new solutions for the container-compatible design was started. Solutions for modification of the casing and the nozzle house's largest subassembly were come up with.

Casing of the BHF originally has a simple design. The modification of the casing consisted of turning the panels that were too high into two-meter-high panels and adding an "extra" layer of panels to fill the now lacking height. For the nozzle house, two designs were evaluated: the panel design and the section design. Out of these two, the section design was considered a more probable choice. The panel design would have included a major increase in the amount of welding at the site, but the section design could enable more of the welding to be done at the shop and enable achieving the required quality more easily. Following the idea of the hatch edge's installation after the transportation, the sections could be fitted inside a container which means the nozzle house could be transported in a smaller number of containers.

The fabrication of the modified subassemblies and the change in the amount and location of welding were evaluated, and the result was that the amount of welding is increased along with adoption of the concept and more of it would happen at the pre-assembly area, thus increasing the manufacturing costs.

6 CONCLUSIONS

The container concept was assessed and some conclusions can be made based on the research and development process. First of all, regarding the scope of the thesis, the container concept can be utilized. As expected, modifications were required and they were planned and their effects on manufacturing evaluated, thus forming an idea of the changes compared to the original concept. The assessment can be used as a basis or guidance for possible future actions and evaluations.

Regarding the efforts required, as is previously stated, the adoption of the concept would involve an increase in the amount of welding work at the pre-assembly area. The designs of multiple subassemblies would need to be changed, and more design work is left to be done in addition to the work done so far for the thesis. The manufacturing costs are likely to increase along with the concept, but the concept may provide for lower transport costs.

Should the concept be adopted, future actions would include finalizing detail design work and the modifications. This would include producing new drawings for the modified subassemblies and parts. Additionally, the rest of the BHF would need to be checked, for example the top hatch of the nozzle house module would still need to be modified. An assessment of the transportation costs and a comparison between the container transportation and the original means of transport would be required to determine the possible benefits of the utilization of the concept, despite the possible increase in production costs. For this, the whole BHF should be fitted inside containers to find out how many containers are needed to transport one bag house filter.

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APPENDICES

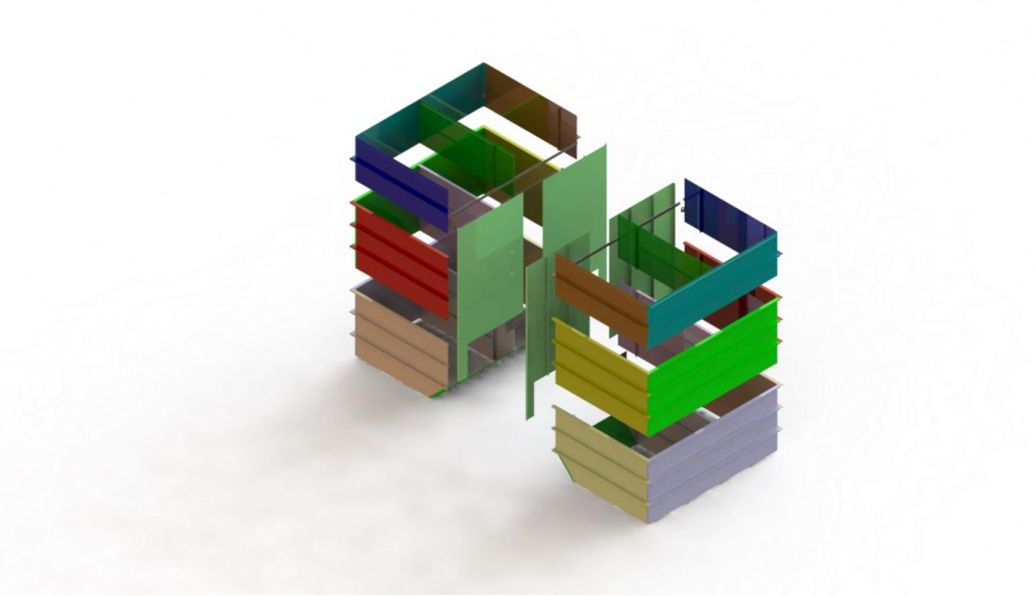
Appendix 1. Table with sizes of subassemblies and their parts.

(Confidential)

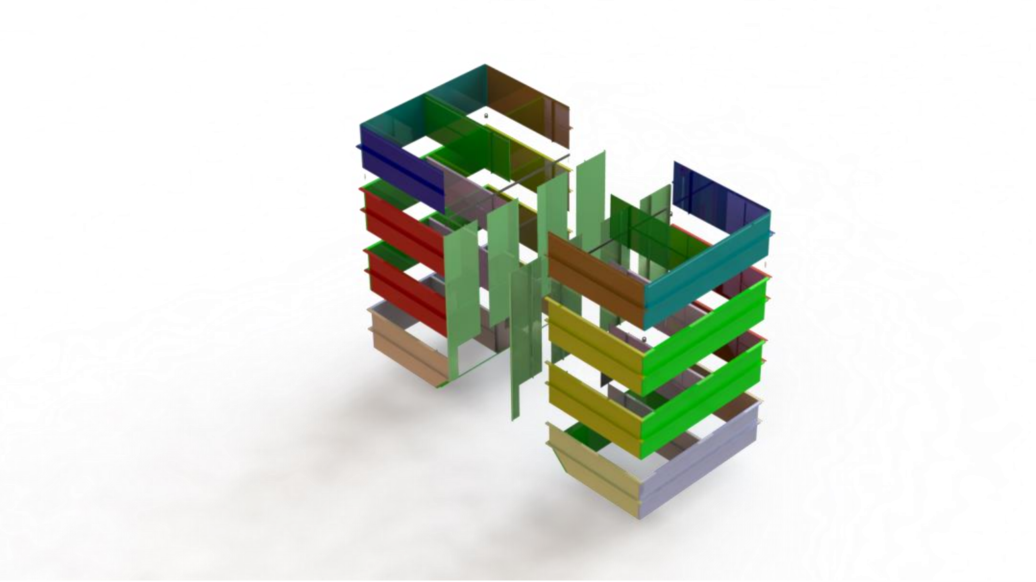
Appendix 2. Modifications of the casing.

4C-8L CASING MODIFICATION ILLUSTRATION

Casing of a four-compartment BHF before suggested modifications:



Casing of a four-compartment BHF after suggested modifications:



Appendix 3. Locations of the new site-welded joints.

ILLUSTRATION OF THE NEW WELDED JOINTS IN MODIFIED DESIGNS

Modified Casing

(Confidential)

Modified Nozzle house module

(Confidential)