Potential methods of recycling brass containing lead

Literature study of lead separation from brass scrap

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Abstract

As regulations regarding the amount of Pb allowed in water systems have gotten stricter Nordic Brass Gusum AB has taken initiative to find a way to process the already existing brass products containing lead that does not meet the new requirements. This report is solely a literature study, whilst observing other preexisting studies as well as studying different types of refining methods to decide the appropriate method Nordic Brass Gusum AB should use to deal with their scrap brass. By reading multiple research papers about processes dealing with similar issues the possibility to focus on certain processes emerged as well as being able to eliminate other processes that already proven not to work. As a result of this literature study it was concluded that compound separation, a method based on adding alloying elements to lift the Pb up to the surface of the material and remove it, was the most suitable method for Nordic Brass Gusum AB to use. However further research would have to be done in order to reach a more concrete decision regarding how to approach the issue of dealing with brass products with Pb that do not reach the safety requirements.

Keywords: Brass scrap recycling, lead removal, compound separation, dilution

Sammanfattning

Eftersom regler om hur mycket Pb som är tillåtet i vattensystem har blivit strängare har Nordic Brass Gusum AB tagit initiativet att hitta ett sätt att bearbeta redan befintliga mässingsprodukter som innehåller bly som inte uppfyller de nya kraven. Denna rapport är enbart en litteraturstudie, samtidigt som man observerar andra tidigare existerande studier, studeras även olika typer av raffineringsmetoder för att bestämma en lämplig metod som Nordic Brass Gusum AB skulle kunna använda för att hantera sitt mässingskort. Genom att läsa flera forskningshandlingar om processer som handlar om liknande problem har man haft möjligheten att fokusera på vissa processer och att kunna eliminera andra processer som redan visat sig inte fungera. Som resultat av denna litteraturstudie drogs slutsatsen att ”Compound separation”, en metod baserad på tillsats av legeringselement för att lyfta upp Pb till ytan av materialet och ta bort det, var den mest lämpliga metoden för Nordic Brass Gusum AB att använda. Ytterligare forskning skulle dock behöva göras för att nå ett mer konkret beslut om hur man behandlar frågan om hantering av mässingsprodukter med Pb som inte når säkerhetskraven.

Nyckelord: Mässingskrotsåtervinning, bly borttagning, compound separation, utspädning
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1 Introduction

1.1 Aim of the project

The aim of this project is to investigate potential methods of separating lead from brass scrap. A literature study will be made to investigate published material on this particular subject. The goal is to present a method that is suitable for Nordic Brass Gusum AB to implement in their production. The ambition is also to do an investment calculation to see if the presented method is profitable.

1.2 Background

1.2.1 Company Description

Nordic Brass Gusum Ab’s has its roots from the 1600th century and is from 2003 a merger of Boliden Gusum and Nordic Brass in Västerås. Nordic Brass Gusum AB have around 130 employees and have a revenue of approximately 1 billion SEK (Tegnér 2017).

1.2.2 Products

Nordic Brass Gusum AB is producing high quality brass in the Nordic region. The amount of brass produced every year is roughly 25000 ton. Nordic Brass Gusum AB make products that afterwards are refined by their customers e.g. bars and rods. Thus, Nordic Brass Gusum AB have a business-to-business strategy. The Brass from Nordic Brass Gusum AB is used to make faucets, electric components, screws etc. The raw material that is used at Nordic Brass Gusum AB is 90 % recycled brass and copper scrap, which is purchased from their own customers as well as from recyclers (Tegnér 2017).

1.2.3 AquaNordic®

Together with Swerea, Nordic Brass Gusum has developed a new lead-free brass-alloy. The new alloy has been named AquaNordic® and it fulfills the health and environmental requirements, as well as high machinability and resistance towards corrosion. Lead has been replaced with ceramic particles in order to keep the machinability. The environmental impact from AquaNordic® is estimated to be at least 30% lower than other lead-free material be recycled with other brass products and must therefore not be specially sorted.

As governments, companys and private persons is more demanding of lead-free products, AquaNordic® is a suitable alloy that meets these requirements (Johansson, 2016). Application where Aqua Nordic is used in is e.g. water faucets and other products that comes in contact with drinking water.

1.2.4 Environmental Policy

The process of making brass is very energy consuming and therefore effects the environment in a negative way. Due to the environmental impact and governmental regulations, Nordic brass Gusum AB continuously strives to develop their operations to be more environmental friendly. An important factor is to use as much recycled brass as possible. Nordic Brass
Gusum AB is ISO – certified, which means that they are fulfilling the environmental requirements within the industry (Tegnér 2017).

1.3 Sustainability aspect

When coming to this project the sustainability aspect is regarded throughout the report due to the fact that the problem in question has derived due to how the lead in the brass products is damaging both the environment and human. And is the reason why this project has been put in motion in order to find a solution to deal with the lead. Meaning that due to the lead already being in a large amount of brass products as it has been used to increase properties within the brass products, it is not sustainable for the environment nor the companies to just let those products lay around. By finding a way to refine the brass products containing lead. Waste products that would otherwise lay around will be dealt with and made into materials that will be able to be reused. Therefore by proceeding with this project, in order to help deal with the issue of lead based brass the question of sustainability is not going to be touched at a deeper level because the origin of the project is derived from the unsustainability of not refining the lead based brass scrap.
2 Theory

2.1 Brass

Brass is a combination of the elements zinc and copper. Copper is the main component and the amount of copper varies from 55% to 95%, depending on the type of brass (Encyclopedia, u.å). The European Norm Standard has specified more than 60 different types of brass. Depending on the application, the composition is altered to meet the requirements of the wanted properties (Terence, 2016).

2.1.1 Alpha brass

When there is at least 63% copper, and less than 35% zinc the alloy is called “alpha brass”. This type of brass is characterized by the ductility in room temperature and that it can be deformed by e.g. rolling and pulling. The CuZn30 brass, also called “70/30”, is the most known alpha-brass. The alpha crystal structure, that this alloy has, is formed when the zinc is dissolved into copper. The result of this is a solid solution with a uniform composition (Terence, 2016). The ductility makes this type of brass easy to be worked cold and it has a better corrosion resistance compared to other alloys with higher contents of zinc (Callcut, 2005. 37).

Products where alpha brass is used is e.g. spring contacts in electrical sockets and screws (Terence, 2016).

2.1.2 Duplex brass

Brass that contains between 35% to 45% zinc has a mixture of both alpha-phase and beta-phase. It is called a “Duplex Brass”. The ability to work the material in room temperature with this type of brass is not as good as with alpha brass. However, it is more workable than alpha brass when being heated. Duplex brass can be formed in complex forms such as both solids and hollows. Preferably, a temperature between 750 °C and 650 °C is a suitable hot working temperature. During the mechanical processing, the alpha phase is broken down to small particles. This results in good mechanical properties in the material (Callcut, 2005. 37).

Because copper is more expensive than zinc, Duplex brass is less expensive than Alpha brass due to the higher content of zinc in Duplex brass (Callcut, 2005. 38).

2.2 Alloying elements

In addition to the combination of copper and zinc, other elements are often added to improve different properties of the copper-zinc alloy. Typical reasons for adding other elements is e.g. an increased corrosions resistance and an improvement of the machinability. Lead and silicon are types of elements that are sometimes added to the alloy (Callcut, 2005. 39).

2.2.1 Lead

Adding lead (Pb) to brass increases the machinability. An additional up to 3% is suitable to add to duplex brass. It is not added to alpha brass, because the absence of beta-phase can cause the material to crack during working in hot temperature (Callcut, 2005. 39). However, adding lead tend to decrease the ductility (Callcut, 2005. 40). Although lead gives a good
machinability, it has a toxic effect on people and is not wanted in products that comes in contact with water (Klein, 2016).

2.2.2 Silicon
Additions of silicon to brass increases wear resistance as well as the strength in the material. Silicon can also be added to reduce the oxidation of zinc during gas welding and it increases the corrosion resistance (Callcut, 2005. 40).

2.3 Manufacturing process of brass
Depending on what form and properties is desired, the brass metal is processed in different ways. The process of brass making involves melting of the raw material and then an altering of the solidify material to the desired form (Encyclopedia 2017).

2.3.1 Melting
Copper-alloy scrap is melted in an electric furnace at a temperature of 1050 °C. Thereafter, zinc is than added to the copper melt. The amount of zinc is altered depending on the desired properties of the metal. During the melting, zinc vaporizes. Therefore, additional zinc can be added in order to compensate for the vaporized zinc. Other addition elements are also added to the melt. Finally, the melt is then poured into molds where it solidifies in form of slabs. When the temperature of the solidified melt is low enough it is transferred from the molds to a rolling area (Encyclopedia 2017).

2.3.2 Hot rolling
After the melting and solidification, the slabs are moved to the electric furnace and are once again heated. The reheating temperature depends on the desired properties and form of the brass in its final form. Afterwards, the slabs are put through a lot of different rollers which changes the form of the brass. The thickness is reduced and the width of the brass increases. The last step of the hot rolling process is to make the brass through a milling machine. The purpose is to remove oxides from the metals surface that have occurred when it has been exposed to air. The milling machine is used to cut of a layer of the brass surface (Encyclopedia 2017).

2.3.3 Cold rolling and annealing
Hot rolling makes the brass less ductile so that it gets difficult to work with. Thus, before cold rolling, the brass must be annealed. Annealing is a heating operation that is carried out in order to make the metal more ductile and to relieve stress. When heating the brass, a neutral gas is injected in the furnace to avoid a reaction with oxygen. Therefore, the annealed brass is cold rolled. Cold rolling is reducing the thickness and strengthening the material. Depending on the desired properties of the brass, annealing and cold rolling can be repeated (Encyclopedia 2017).

2.4 Problems with lead
Lead as a metal is ductile and it is poor at conducting electricity and it is highly malleable. Adding lead to brass help the material become softer and makes it easier to process. Due to
these characteristics it is a metal that is used for many different applications. However, lead is a poisonous subject for both humans as well as for the environment (Lenntech 2017). Due to stricter rules and regulations the amount of lead that spreads around has decreased. Due to the overall decrease in usage of lead it has shown that the amount of lead in the water also has been lowered since the 90’s. The effect the lead has on animals is that when they consume too much lead the animal’s nervous system is damaged. The lead appears in the environment either naturally or through depositions. The dispersal of lead if hugely done by industries as well as by waste products, for example light bulbs and batteries, furthermore ammunition used for hunting that contains lead that gets left around on the ground after being fired. That is why using lead based ammunition at grounds that have near contact to open water sources is forbidden, so that lead does not diffuse into the water (Linderholm, 2017).

2.4.1 Effect on people
For humans, a small amount of lead is enough to damage the nervous system, especially for fetuses and young children. When entered into the human body the lead damages the red blood cells resulting in a blood deficiency. The biggest exposure of lead for humans is from water and food. Certain food types could contain a higher amount of lead such as oyster, kidney and liver. Drinking water is also a source of lead due to the fact that some faucets leak lead into the water we drink. When the water stands still in the faucet the lead diffuses into the water (Berglund, 2015).

The “European Food Safety Authority EFSA” chose to evaluate what the minimal amount of lead different people could consume with a low risk of consequences. For pregnant women and kids it was 0,5 microgram/kg per day. The risk was low for increased blood pressure at 1,5 microgram/kg per day for all. Also, for chronic kidney disease there was a low risk at consuming 0,63 microgram/kg per day. Because of this evaluation, a limit of maximum of 10 microgram/liter of lead in the drinking water has been suggested, which is based on the ability to drink about 2 liters of water, each day without risking health issues (Boverket 2014).

2.5 New Regulations

2.5.1 Safe water drinking act
To be able to ensure that the drinking water within the United States stayed safe for the population the safe drinking water act was implemented. The safe drinking water act covers all the public water systems in the United States. However this act is not applied for bottled water or private wells. This act makes sure that the Environmental Protection Agency sets a certain standard for the contaminants in the drinking water that might result in health issues, a maximum level of the different contaminants that are allowed to be present in the drinking water. The safe water drinking act had an amendment implemented 1986, which ensures that the amount of lead within the public water system has a limit, in order to define the pipes as “lead free”. To be able to classify the pipes as “lead free” certain requirements have to be reached, which lead to that these regulations got even stricter in 2011. These requirements are that the solders and flux could contain a maximum of 0,2% lead, pipes could contain a maximum of 8% lead (Lead And Copper Rule Revisions White Paper 4-6).
2.5.2 Reach

REACH, which stands for Registration, Evaluation, Authorization and restriction of chemicals, is a legislation implemented in order to secure the environment and the human health from dangerous chemicals. More specifically, the legislation was put in action to make sure that these dangerous chemicals get dealt with in a safe manner.

The products that Nordic Brass sells and exports all fulfill the requirements for REACH, although the products do not have to get registered due to the fact that are made from recycled materials.

When it comes to electronic products a EU directive called “Restriction of Hazardous Substances” forbids specific heavy metals and materials that are flammable to be used in the product. One of these heavy metals that are restricted is lead and according to the directive the maximum amount of lead is 1 % by weight (Lundqvist 1-2).

2.6 Difficulties with lead in Brass

There are different processes that are often used to separate metals. Methods like selective oxidation and liquation. Although when it comes to lead within brass these methods are not suitable for the removal of lead, due to the thermochemical boundaries that this specific system has. (Hilgendorf et al. 1782-1788)
3 Method

In this project, a literature study was performed based on the available material in the open literature. Various research, studies and articles regarding lead separation from brass scrap were searched for. The material that was regarded as relevant to this project was investigated more in depth and the results were compared. The literature that was found was retrieved from search tools such as google scholar and KTHB Primo.

The key words that was used in the search tools were: brass scrap, lead separation, scrap recycling, lead-free brass, lead removal, compound separation. During the research stage of the literature study, 4 articles regarding lead separation from brass was found and was used as a basis for the study.

The articles was: “Removal of lead from brass scrap” written by Yamada et al (2001), “New technology for recycling scrap brass and its application for enviroment friendly-water supply system” written by Taufiqu (2006), “Removal of Lead from Copper Alloy Scraps by Compound-Separation Method” written by Nakano, Taufiqu and Sueyoshi (2005), “Lead Removal From Brass Scrap By Fluorine-Free Compound Separation” written by Hilgendorf et al (2016). During the project, a company visit to Gusum was also made on the 21st of March 2017 with the help from Johan Tegnér, who is the product manager at Nordic Brass Gusum AB, in order to get more information about Nordic Brass Gusum AB’s production and processes.
4 Results

A comparison between the found experiments and projects concerning lead separation from brass scrap was made. Also, the found material in the open literature was studied more in-depth. In the investigated experiments, most of the authors explain the problems with the conventional methods of separating lead from brass scrap. Yamada et al (2001) as well as Taufiqu (2006) describes e.g. oxidation and vaporization methods. Although, separation methods of these sort cannot be applied because of the negative impact these methods have on the environment in form of pollution. The high cost is also a negative factor. Furthermore, Nakano, Taufiqu and Sueyoshi (2005, 2719) states that the long processing time is a problem with these methods. Taufiqu (2006) also describes an attempted method using an addition of Ca to form a compound of Ca-Pb. The addition of Ca was followed by the usage of filtration by using a filter that was pressurized. However, the result regarding the Pb removal was not satisfactory. Specifically, only 29% of the Pb was removed.

4.1 Dilution method

Hilgendorf et al (2016, 1785) describes in their report dilution as a method of Pb removal. They explain that usage of 5 to 10 dilution cycles can lower the Pb content in brass to 0.1 wt%. Using dilution as a Pb removal method, the rod mills can theoretically have lead free production in about 5 years, due to the short return times to the mills. Dilution is a simple method as well as cheap. Although, Hilgendorf et al explain that the market for lead-free brass is not as strong brass with lead content. This is e.g. a problem for the making of small screws. Therefore, Hilgendorf et al means that a more realistic time expectation is between 15 and 25 years, so that the equipment for brass machining of lead free brass can be developed. Their time span is estimated based on the production of brass in Europe. Another problem is the inflow of old brass scrap in the production, which prolongs the dilution time.

4.2 Compound-Separation method

The most commonly used method, conducted in the articles and experiments that was investigated, was the compound-separation method. The idea is to add an compound to the molten brass that will react with Pb to form an aggregate. This means that Pb will grow into larger Pb compounds. The Pb compounds will then float to the surface of the melt due to density differences and can thereby be skimmed off (Taufiqu 2006, 107-108).

Fig (1) shows a schematic process of Pb removal using the compound separation technique (Taufiqu 2006, 107).
4.3 Lead removal factors for compound separation

Important factors regarding how effective the lead removal is using this method were found to be the following:

- Addition of Ca-Si
- Temperature
- Grain size
- Usage of NaF

4.3.1 Addition of Ca-Si

Calcium-Silicon (Ca-Si) is a compound that works as an aggregation agent. Yamada et al (2001, 273-274) describes Ca-Si as a suitable compound to remove Pb from the molten brass due to its high melting point of 980 °C and the ability of Ca-Si to stay in a solid state in the brass melt at a temperature lower than 980 °C. Moreover, the low density of Ca-Si compounds makes it easy to float to the surface of the brass melt. The Ca-Si compound is added to the melt in a nitrogen gas atmosphere. In Yamada et al’s experiment, a brass material with a Pb content of 2.15 mass% was used.

Agitation (brisk stirring) of the melt, after adding Ca-Si, is an important factor. Yamada et al (2001) shows in their experiment that the time of the agitation effects how effective the lead removal will be. In their experiment, 6 minutes of agitation is the optimal time for lead removal. Further agitation tends to decrease the percentage of lead removal. During agitation, Ca-Pb-Si compounds are being formed. In figure (2) the variation of Pb removal during agitation is illustrated. It shows that percentage of Pb removal increases when the melt has been agitated for 6 minutes and thereafter the percentage of Pb removal decreases.

![Graph showing Pb removal percentage vs. agitation time](image)

*Fig (2) shows the ratio between agitation and the percentage of Pb removal (Yamada et al 2001, 276).*

Yamada et al (2001, 276) also shows that the holding time after agitation effects the percentage of Pb removal. A too long holding time will decrease the percentage of Pb removal.
removal, due to a separation of small particles from the larger compound particles. According to their result, a 3.5 minutes holding time is adequate for an optimal Pb removal. It is during the holding of the molten brass the compounds floats to the surface. The curve in figure (3) shows the ratio between percentage of Pb removal and holding time. It shows that the percentage of Pb removal decreases with further holding time after 3.5 minutes.

![Graph showing Pb removal and holding time](image)

*Fig (3) shows the ratio between holding time and the percentage of Pb removal (Yamada et al 2001, 276).*

According to Taufiqu (2006, 109) the optimal amount of added Ca-Si is approximately 4 mass %. Adding more Ca-Si to the melt will decrease the Pb removal. He means that this indicates that when small amounts of Ca-Si are added, the amount of formed Pb compound will also be small. Therefore, the Pb removal will not be successful. A larger amount of added Ca-Si contra wise means that a lot of Pb compounds is formed and hence the percentage of lead removal is high. However, the limitation is 4 mass % of Ca-Si for which the percentage of Pb removal will decrease. Taufiqu used a brass material containing 2.15 mass% Pb, just as Yamada.

Nakano, Taufiqu and Sueyoshi (2005, 2721) also shows in their report that at a 4 mass %, Pb removal tend to decrease. Similar to Yamada et al and Taufiquus experiments, a brass containing 2.15 mass% was used. The name of the brass is JIS CAC203 and the amount of Cu is 58.1 mass% and the amount of Zn is 38.58 mass%. The weight of the brass was 3kg.

Yamada et al (2001, 275) states that the number of adding times of Ca-Si compounds effects the Pb removal. Their study indicates that an increased time for additions of Ca-Si compounds to the melt will result in a lower Pb removal. Therefore, Yamada et al concludes that the formation of Ca-Pb-Si compounds occurs at the first time Ca-Si compound is added and that a further adding of this compound does not contribute to a better removal of Pb. Figure (4) shows the ratio between percentage of Pb removal and adding times of Ca-Si compound. It shows that adding Ca-Si compound 1 time removes more Pb than adding Ca-Si compound 4 times.
Fig (4) shows the ratio between adding times of Ca-Si and the percentage of Pb removal (Yamada et al 2001, 275).

4.3.2 Temperature

The impact of the temperature concerning Pb removal was investigated by Yamada et al (2006, 274). In their study, they show that the Pb removal at a temperature higher than 1006 °C is close to nothing. The optimal temperature of Pb removal is approximately 930 °C. By using scanning electron microscope (SEM) Yamada et al observed that at a compound removal at a temperature of 1006 °C the particles of Ca-Pb compound becomes relatively small in comparison to the compound removal at a temperature of 930°C where several sizes of Ca-Pb compound is observed. The ratio between percentage of Pb removal and temperature during compound removal is shown in figure (5). It shows that the highest percentage of Pb removal occurs at 930 °C.

Fig (5) shows the ratio between percentage of Pb removal and temperature (Yamada et al 2006, 274).
Taufiqu (2006, 108) shows that Pb removal decreases with increasing Pb removal temperature. The optimal temperature according to Taufiqu is 880 °C and the percentage of Pb removal decreases to a temperature up to 1005 °C. Nakano, Taufiqu and Sueyoshi (2005, 2719) also stated in their report that decreasing Pb removal temperature increases Pb removal.

4.3.3 Grain size

Agitation and holding time as well as the temperature effects the size of the formed compound. Nakano, Taufiqu and Sueyoshi (2005, 2719) shows in their study that the grain size of the compound has an important impact whether the Pb removal will be successful or not. Their experiment shows that the larger grain size of the compound floats easier to the surface in comparison to smaller particles. Therefore, Pb removal increases with increased grain size. Yamada et al (2001, 274-275) is also showing in their report that smaller particles do not tend to float so easily to the surface of the melt. Also, Taufiqu (2006, 109) describes the importance of the size of the particles. Larger compounds react easier with Pb and can thereby make it float to the surface so it can be skimmed off. Figure (6) shows the ratio between percentage of Pb removal and grain size. It shows that particles larger than 1,4 mm is generating the highest percentage of Pb removal.

![Grain size/mm](image)

*Fig. (6) shows the ratio between grain size of Ca-Si compound and percentage of Pb removal (Yamada et al 2001, 275).*

4.3.4 Usage of NaF

A problem with only using a Ca-Si compound to remove Pb from the brass melt is that it do not remove all of the Pb. Taufiqu (2006, 109) shows in his experiment that the Pb removal after using a Ca-Si compound removes up to 53 % Pb. In order to remove more Pb from the brass melt, a NaF compound can be added. In the same experiment, Taufiqu shows that by using a NaF compound the Pb removal can be increased up to 95 %. The NaF compound also removes the dissolved Ca-Si compound in the melt. Nakano, Taufiqu and Sueyoshi (2005,
2723) also describes the aggregating effect of small Pb compounds using NaF. Their study indicates that Pb removal can reach a maximum of 83%.

4.4 Investment Calculation

4.4.1 Compound separation method:

As Nordic brass produces 25k ton of brass products every year this investment calculation will consider a 25k ton brass products containing lead. Nordic Brass Gusum AB already has an induction oven at their facility and therefore a purchase of a new induction oven is unnecessary.

If focusing on the compound separation method, the investment calculation for implementing it into Nordic Brass’s establishment would roughly mostly include the purchase of the alloying elements for the procedure. This is due to that the induction oven and running is already an expense that Nordic Brass Gusum AB already has. As stated previously in the report, when using the compound separation method, the amount of Ca-Si will be 4wt% of the amount of brass products. Meaning for 25k ton of brass products an estimate of about 1000 ton of Ca-Si would be needed. However, none of the research papers that were studied had a suggested amount of NaF that should have been used. Therefore, makes it difficult to make an investment calculation without the amount of one of the vital materials. However, due to the company already having and running a induction oven all the time as long as the profit of selling the newly refined brass is higher than the cost of buying in the materials to refine it the method would be worth trying.

4.4.2 Dilution method:

When it comes to making an investment calculation for the dilution method no expenses would be present except for running the induction oven, which is always running at Nordic Brass Gusum AB. The dilution method uses brass scrap to melt and dilute the brass. As Nordic Brass Gusum AB already buys back brass scrap from their customers no new expenses would occur from this aspect as well. Therefore, if Nordic Brass Gusum AB decided to implement the dilute method as their official refining method for Brass containing lead there would be no new expenses as all the material and machines needed for the dilute method are already present at Nordic Brass Gusum AB.

4.4.3 Efficiency:

When looking on what would be more efficient and save more money, whether to refine the brass containing lead or just making new lead free brass and throwing away the existing lead based brass. In the case of producing new lead free brass, the already existing lead based brass would have to be dealt with so a landfill expense, which for brass is around 1.94-2.68 USD/kg, would be added to those expenses. Factors such as induction oven and the cost of running it would be the same for both cases. Therefore, they can be overlooked without giving it too much thought. Whilst the materials used for the respective methods would be the key expenses behind the investment calculations. However, as stated earlier in the report, when using the compound separation method the duration of the process is short. Therefore, the cost of running the induction oven for the process of compound separation method would be cheaper compared to when using it during the dilution method. Based on the hypothesis that the compound separation method takes an estimate of 2-3 hours compared to the dilution method, which hypothetically is estimated to take about 15-25 years.
At this moment in time companies are already trying to turn to lead free brass. Therefore, in the near future all lead based brass will most likely have to be replaced with lead free brass or trying actively to do so. As Nordic Brass Gusum AB already has the alloy AquaNordic® that they sell. This fulfills these requirements, they will earn 5,5 kr/kg more for this product compared to the brass products containing lead which means that it is just a matter of time before their refining methods start paying back the money they invested into refining it. Even though it would cost a bit they would still be able to sell the new lead free brass for a higher price meaning that sooner or later a sufficient profit would be made in order to account it as a success.
5 Discussion

As the results of this report show, potential methods of separating brass scrap containing Pb is dilution and compound separation. According to the results, the conventional methods as Yamada et al (2001) mentioned e.g. oxidation and vaporization cannot be implemented due to negative environmental impact such as pollution.

5.1 Dilution

As stated in the results, dilution is an easy way of separating Pb. It is beneficial due to its low costs and simple way of executing. Hilgendorf et al (2016) writes that it is possible to receive Pb free brass within 5 years. However, they conclude that due to companies inadequate ability to adapt the Pb free brass to their production, 15 to 25 years is more of a realistic estimation.

Nevertheless, Hilgendorf et al do not present how they estimated their time span. Their calculation is based on the brass production in Europe, but whether this time span can be adapted to Nordic Brass Gusums AB’s production is rather unclear. The inflowing of old brass scrap containing Pb is a problem for Nordic Brass Gusum AB as well. The duration of the dilution will therefore take a long time. Due to Pb in brass being a highly concerning problem receiving Pb free brass in 25 years, as Hilgendorf et al estimated, can be considered too long to be reasonable. Moreover, dilution is beneficial for Nordic brass Gusum AB’s production since they already have all the inventory required to execute this Pb separation method.

5.2 Compound separation

As the results show, using compound separation to remove Pb from brass scrap is highly effective. Ca-Si compound was added to the melt to form large Ca-Pb-Si compounds that are floating to the surface of the melt and is then skimmed off. The best results were presented by Taufiqu (2006) who managed to remove 95 % of the lead content in the melt. The high Pb removal was achieved by adding the aggregating agent NaF compound. Adding NaF also removes remaining Ca and Si in the melt. Compound separation is a potential method for Nordic Brass Gusum AB to implement in their production.

In the investigated studies, no one executed their experiment on a big scale. Nakano, Taufiqu and Sueyoshi (2005, 2719) e.g. only melted 3kg of brass in their experiments. In Nordic Brass Gusum AB’s production thousands of tons of brass is produced every year and whether the Pb removal using compound separation will be effective at these large quantities is not sure. However, if Pb removal at large quantities of brass scrap is shown to equally efficient as in smaller scale, compound separation would be a suitable method for Nordic Brass Gusum AB to implement in their production. In comparison to dilution, compound separation can produce Pb free brass in less than 15-25 years.

As stated in the results, several factors during the process of compound separation effects how successful the Pb removal will be.
5.2.1 Addition of Ca-Si

As stated in the results, Ca-Si compound is a suitable compound due to high melting point, easy to float etc. Although, because only Ca-Si compounds is used in the investigated studies, it is not possible to conclude that it is that optimal aggregating compound to use in compound separation. However, the high percentage of Pb removal showed in the results, indicates that Ca-Si compound is highly effective.

The agitation of the brass melt effects Pb removal. As shown in the experiment conducted by Yamada et al (2001,275), 6 minutes of agitation is the optimal time for Pb removal. In their study, the speed of the agitation is not presented. An increasing or decreasing speed of the rod agitating the melt might therefore effect the percentage of Pb removal.

The holding time after agitation effects Pb removal as well and according to the result is 3,5 minutes of holding time that gives the highest percentage of Pb removal. Although, this result conducted by Yamada et al (2001, 276) is executed on an unknown amount of melted brass. The holding time of a large respectively small amount of melted brass regarding the optimal time of Pb removal, might not be the same.

According to the results, the optimal amount of Ca-Si compound added to the molten brass is 4 mass%. However, in the experiments conducted in the results, the percentage of Pb in the melted brass was 2,15 %. The amount of Ca-Si compound might be different if the percentage of Pb in the brass is higher or lower. The weight of the melt might also effect the percentage of Ca-Si compound added.

5.2.2 Temperature

Yamada et al shows that temperature during compound separation highly effects the results of Pb removal. In their study, they show that 930 °C is the optimal temperature that generates the highest percentage of Pb removal. At the same time, Taufiqu’s (2006, 109) experiment shows that 880 °C is the optimal temperature for Pb removal. However, since Taufiqu (2006, 111) managed to remove 95% Pb, the Pb removal at 880 °C has proven to generate the best results. The lower temperature will also be less energy consuming and will therefore be more friendly to Nordic Brass Gusum AB’s operating costs.

5.2.3 Grain size

As stated in the results, particles larger than 1,4 mm floats easy to the surface. This was shown by Yamada et al. However, 1,4 mm is not a reasonable value. This is probably a type error made by the authors of the experiment. More realistic value is 1,4 μm (Jönsson 2017). Furthermore, the size of the particles effects how high the percentage of Pb removal will be. Therefore, if Nordic Brass Gusum AB will implement compound separation in their production it is important to attempt to achieve as large particles as possible, which thereafter can be skimmed off the surface of the melt. As mentioned in the results, agitation and holding time effects the size of the formed compound.
5.2.4 Usage of NaF

The results show that NaF compound is a necessary aggregating agent to achieve high percentage of Pb removal. However, Taufiqu managed to achieve 95 % Pb removal while Nakano, Taufiqu and Sueyoshi (2005) managed to remove 83 % Pb in the brass melt. The amount of added NaF compound to the melt is not stated in their experiment. Therefore, a possible reason why the results of Pb removal differ is because they did not use equal amount of NaF compound in their experiment.
6 Conclusion and recommendations

This report treated two methods regarding Pb removal: dilution and compound separation. Dilution is the easiest way of removing Pb. However, the estimated time of achieving a Pb free brass in the production is too long. Furthermore, this approximation is not certain and it could take longer time than this. Therefore, Nordic Brass Gusum AB should not attempt to implement this Pb removal method in their production. However, the compound separation method has shown to achieve higher percentage of Pb removal with a shorter process time. Therefore the conclusion of this report is that compound separation is the procedure to go with, if it is successful at an industrial scale, because of it procedure time and its high Pb removal rate. Making it possible to deal with the massive amount of brass containing Pb in a reasonable time period as well as obtaining brass that reach the requirements of the new regulation and can therefore be reused in production to make new products.

Even though the issue with brass containing Pb has just recently surfaced within the industry, the issue will become a more discussed point in the future of brass development. Therefore, when looking at this literature study from an overall perspective some vital information is missing such as the amount NaF needed for the separation method to be effective. Therefore, for further studies it would be recommended to have the possibility to try out the procedure both in a laboratory scale but also on a scale that would give a clearer picture of the success rate if the compound separation method would to be implemented at Nordic Brass Gusum AB.
7 Acknowledgements

Gratitude to the projects supervisors Pär Jönsson, who is a professor at the material science institution at KTH, and Johan Tegnér from Nordic Brass Gusum AB for the support.
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